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Organisational and Financial Innovation for Collective Self-Consumption: The Role of ESCOs in Renewable Energy Communities

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SUMMARY

ABSTRACT

The transition to decentralised and renewable energy systems marks a critical shift in global energy governance, driven by climate imperatives, regulatory evolution and the need for socio-economic resilience. Renewable Energy Communities represent an innovative framework that allows collective self-consumption, promoting local energy autonomy, sustainability and financial sustainability. However, their large-scale implementation is often hampered by financial constraints, governance complexities and regulatory fragmentation. This thesis examines how energy service companies act as strategic enablers to overcome these challenges, providing technical expertise, financial structuring and operational management.

The study adopts a blended approach, integrating qualitative and quantitative methodologies to analyse the intersection between governance, financial mechanisms and stakeholder engagement within RECs. By assessing the European regulatory landscape, in particular the RED II Directive and the Italian legislative frameworks (D. Lgs. 199/2021), this research highlights the critical role of ESCOs in ensuring the sustainability of RECs. Through the case study of REC Caserta, the thesis empirically evaluates self-consumption models, investment structures and incentive schemes, demonstrating how RECs supported by ESCOs optimise financial performance while promoting decentralised energy solutions.

The results contribute to the academic discourse on the democratization of energy, providing policy recommendations and strategic insights to improve the scalability of RECs and the attractiveness of investments. This research underlines the need for an integrated governance and finance approach, positioning RECs as pivotal tools in Europe's energy transition. By aligning with ESG principles, the European Green Deal, and global decarbonization goals, RECs have the potential to transform energy markets, making decentralised, community-driven energy models viable and scalable.

INTRODUCTION

The European Union has set an ambitious renewable energy target of at least 42.5% by 2030, with an aspirational target of 45%, as outlined in EU Directive 2023/2413. This directive is part of a broader strategy to decarbonise the energy sector, improve energy security and promote decentralised renewable energy models. However, achieving these goals requires not only technological advances, but also robust financial and organisational frameworks to ensure both economic viability and social acceptance of renewable energy projects.

Among the most promising solutions to advance this transition are Renewable Energy Communities (RECs). RECs enable local actors, including citizens, businesses and municipalities, to collectively produce, share and consume renewable energy. By promoting energy autonomy and self-consumption, RECs have the potential to reduce energy dependency, democratize access to clean energy, and promote local sustainability. Despite regulatory incentives and growing interest, large-scale implementation remains constrained by financial instability, governance complexity, and bureaucratic hurdles. Strategic partnerships are essential to close these gaps and unlock the full potential of RECs.

A crucial, but often overlooked, factor for RECs is the Energy Service Company (ESCO). Traditionally focused on energy efficiency, ESCOs have developed into key enablers of renewable energy adoption, offering technical expertise, financial structuring and operational support. Their involvement mitigates economic and regulatory risks while improving the long-term sustainability and scalability of decentralised energy projects. This thesis examines the role of ESCOs in optimising the financial and organisational sustainability of RECs, with a specific focus on the European and Italian regulatory landscape.

While previous studies have thoroughly analysed the technical feasibility and regulatory framework of RECs, relatively little attention has been paid to their financial sustainability and governance models, particularly in relation to the role of ESCOs. The intersection of organisational design, financial innovation, and decentralised energy systems remains an underexplored area in the literature. This research addresses this gap by studying how ESCOs can facilitate investments, mitigate risks, and improve governance structures within RECs. In addition, it provides empirical insights through a case study of the REC Caserta, assessing its financial performance, operational framework and stakeholder dynamics.

A distinctive aspect of this thesis is its interdisciplinary approach, which integrates organisational and financial perspectives to offer a holistic understanding of the sustainability of RECs. Unlike most studies that focus predominantly on technological efficiency, this research emphasizes the effectiveness of governance, examining how financial, operational, and participatory dimensions interact to shape the success of RECs. Using both qualitative and quantitative methodologies, the study provides a comprehensive analysis that is both academically rigorous and practically relevant.

The study aims to assess the transition from centralised to decentralised energy models, highlighting the evolution of self-consumption and the financial mechanisms supporting RECs. The key objectives of the research concern the evaluation of the regulatory and policy landscape governing RECs in Europe and Italy, highlighting the associated opportunities and challenges and exploring the role of ESCOs as financial and management enablers, examining their ability to attract investment and optimise governance structures. In addition, the study assesses the financial sustainability of RECs through economic modelling and quantitative simulations.

It also investigates stakeholder motivations and decision-making processes using qualitative methods, in particular structured interviews with the laddering method. In addition, the REC Caserta case study results in empirical insights, which examine in depth its financial performance, operational governance and stakeholder engagement strategies.

To achieve these goals, the research takes a blended approach that integrates policy analysis, stakeholder interviews, and quantitative financial modelling. The REC Caserta serves as a practical case to assess real-world feasibility, providing valuable insights into financial and organisational performance. In addition, qualitative interviews applying the laddering method offer an in-depth understanding of participants' motivations, contributing with a nuanced perspective on REC dynamics.

To clearly contextualize the findings within the overall analysis, the following synthesis highlights the main outcomes derived from the policy review and empirical investigation.

The comprehensive analysis of European and Italian policies conducted in this research has revealed substantial progress in regulatory frameworks aimed at supporting the establishment and growth of RECs. Nevertheless, critical challenges persist, primarily due to bureaucratic intricacies, fragmented regulatory approaches, and inadequately designed financial incentives, often leading to delays and hindering efficient project execution and scale-up. The empirical findings from the REC Caserta case study further emphasized that financial sustainability and robust organisational governance structures are essential preconditions for the success of REC initiatives. Specifically, it was observed that clearly defined governance processes, transparent decision-making frameworks, and strong stakeholder engagement strategies significantly enhance operational effectiveness and community acceptance.

The case study underscored the transformative role of ESCOs in addressing these critical issues. ESCOs proved indispensable by leveraging innovative financial instruments such as green bonds and tailored power-purchase agreements (PPAs), thus attracting essential capital and enhancing financial viability. Moreover, ESCOs provided technical expertise to streamline operational management, simplify complex bureaucratic procedures, and ensure regulatory compliance, effectively reducing risks and barriers for stakeholders. Additionally, the involvement of ESCOs significantly improved participatory governance by fostering a collaborative environment that enhanced trust and commitment among community members and investors.

Consequently, this thesis demonstrates that integrating ESCOs within REC frameworks is a pivotal strategic approach to overcoming the identified barriers and maximizing the financial and organisational sustainability of decentralised energy initiatives. By effectively bridging the gap between regulatory aspirations and practical implementation, ESCOs not only support the scalability of RECs but also ensure their long-term economic resilience and adaptability in the evolving renewable energy landscape.

The transition to decentralised, community-led energy systems is not just a technological change, but a structural transformation that requires robust financial models, adaptive governance structures, and effective policy support. While RECs represent a promising model for energy decentralisation, their long-term viability depends on overcoming regulatory barriers, ensuring financial sustainability, and fostering strong local ownership. In this context, ESCOs emerge as crucial enablers, providing the financial, operational and management skills needed to effectively scale RECs.

By integrating ESCOs into the REC framework, communities can improve economic sustainability, simplify administrative complexities, and accelerate scalability. Their role is crucial in bridging the gap between policy ambition and real-world implementation, transforming RECs from isolated pilot projects into vital, large-scale contributions to Europe's renewable energy transition.

This research highlights the strategic potential of ESCO-led RECs, offering insights into how financial innovation and governance optimisation can reshape decentralised energy systems. By fostering stronger collaboration between policymakers, energy operators and local communities, RECs can become a cornerstone of Europe's energy transition, ensuring both economic resilience and environmental sustainability.

CHAPTER I – GENERAL INTRODUCTION AND RESEARCH OBJECTIVES

1.1. Energy and Environmental Transition: A Global Perspective

1.1.1. Climate Change and the Energy Transition: Addressing Global Challenges

Climate change is one of the current and global challenges of the 21st century and the effect of climate change is not limited to environmental changes, but also generates socio-economic and geo-political complexities, ethical issues and paradigm shift reactions. Many scientific findings show that there is a causal link between human greenhouse gas (GHG) emissions and the increase in global temperature, and these result in serious damage to ecology, human health and global security (Carbon Brief, 2024).

The current energy system, based mainly on fossil energy, is the main driver of climate change. Carbon, oil, and natural gas emissions account for 75-80% of global GHG emissions, along with carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Carbon Brief, 2024). These emissions have led to an unprecedented increase in CO_2 concentrations in the atmosphere. Due to this phenomenal wave, a number of climate changes have occurred, including global warming, the melting of marginal polar ice caps, and more frequent and intense events (e.g., droughts, heat waves, and storms) (Doumon, 2024).

The effects of climate change affect a highly complex network of interconnected systems. Global warming due to ecologically negative impacts on the natural system leads to the loss of biodiversity, the extinction of habitats and the consequent modification of the hydrological regime (Nuccitelli, 2024). For example, the Arctic is melting at a rate about four times faster than the global average, leading to the drastic reduction of sea ice and permafrost, which release methane into the atmosphere (Box et al., 2022).

From an economic point of view, the costs of climate inaction are staggering. As reported by the World Economic Forum (2023), by 2050 climate-related damage could amount to 10-20% of global GDP, assuming the current trend. This includes, inter alia, damage resulting from severe weather events (e.g. hurricanes, floods, droughts) that disproportionately burden the most disadvantaged people and widen existing social inequalities. Significantly, for example, Pakistan's 2022 floods led to the displacement of hundreds of thousands of people, with economic costs of more than $15 billion, revealing the magnitude of the human and economic cost of a warming world (European Commission, n.d.).

Climate change also exacerbates social inequality and new vulnerabilities. Less able to withstand the impact of it, marginalized groups are often forced to endure most of it. Women, children and indigenous peoples are the most affected when climate-related events occur (Habtezion, 2016).

Action is needed to shift energy production, transmission and consumption to respond to climate change. The transformation driven by the energy transition, defined as the shift from fossil carbon-derived energy resources to a zero-emission energy system based on REs (solar, wind, hydroelectric and geothermal), is not only a technological issue, but also a public issue and requires multidisciplinary work in policy, finance and behavioural design (Adelekan et al., 2024).

In this framework, the generation of renewable energy devices is the basis for reducing GHG emissions, as well as for meeting the growing demand for energy in the world. Solar power has experienced explosive growth with combined global capacity growth of around 30% (European Commission, 2024). This technology continues to grow steadily in terms of competitive cost, to such an extent that solar PV systems currently have a levelized cost of electricity (LCOE) of $0.04/kWh, which is competitive or even lower than that of fossil fuels (GSE, 2022).

In addition to ecological merits, REs, therefore, provide energy security, i.e. they contribute to energy security by diversifying the supply of energy and making it less vulnerable to unpredictable and rapid fluctuations in the prices and supply of fossil fuels. For example, the EU's REPowerEU action plan seeks to accelerate the pace of renewable energy integration to mitigate dependence on Russian gas, providing an example of how the energy transition is also an area of geopolitics (European Commission, 2022).

Energy efficiency is another key feature of the energy transition. Interventions ranging from home insulation to progressive energy efficiency of homes and appliances through efficient industrial processes and end users, can lead to substantial reductions in energy consumption. According to the IEA (2021), energy efficiency accounts for more than 40% of the emissions abatement needed by 2040 (with total emission reductions of 90%).

Another topic is that of technical, financial and political constraints that often hinder progress, especially in low- and middle-income countries (LMICs). There are often jurisdictions where the equipment and resources to sell renewable energy on a large scale are not available and, as a result, create global inequalities. More specifically, the changes must be adjusted in such a way that the result is proportionate and fair (ANCI, 2024). Workers working financed by the fossil fuel industry, such as coal mining, are particularly at risk of unemployment and will need to put in place sound policies to reskill and diversify economic policies. Therefore, the idea of a just transition and therefore of a fair social process is at the heart of the global energy transition agenda (ILO, 2016).

Effective policies and governance are also a key component of the energy transition. Market-based indices (e.g., carbon taxes or cap-and-trade systems) have been proposed as efficient tools to internalize the environmental damage associated with fossil fuel consumption. For example, Swedish politics has already shown that it is capable, against a \$130 benchmark for the CO_2 carbon tax of \$130/t, to deliver emission reductions, economic growth and, in doing so, serve as a benchmark for other nations (World Bank, 2024).

International cooperation is equally crucial. Each of these also aims to create synergies and channel funds and resources to the poorest and most vulnerable. However, this rate of evolution is still fluctuating, as countries do not meet the same commitments they have made (Banks, n.d.).

As an additional consideration, technical innovation and business model innovation are at the forefront of the list of challenges to overcome obstacles to the energy transition. Improvements in energy storage, including lithium-ion batteries and emerging batteries such as the solid-state battery, mitigate the unpredictability of renewables and enable them to provide grid-scale power. Analogous to digital technologies (smart grids and blockchain-based energy trading platforms), digital innovation improves performance and enables end-users (Aggeli et al., 2022).

These twin problems of climate and the energy crisis underscore the urgent need for international support for the energy revolution. While problems and challenges still exist, transformation is most, if not all, in favour of designing and implementing a sustainable, inclusive, and resilient energy system. Victory will require cross-sectoral and multifaceted collaboration between government and industry and a commitment to science-based intergenerational equity (Fernandez, 2021).

1.1.2. Decentralised Energy Systems and Self-Consumption: Strategic Pillars of the Energy Transition

The energy transition is among the main challenges and opportunities of modern times. It has been defined as the response to increasing environmental stressors, fluctuations in green energy, and the decoupling of economic growth and GHG emissions (European Commission, n.d.). To sum up, the energy transition is an evolution in the structure of energy production, distribution and consumption towards cleaner, renewable and decentralised systems. There is a need to implement systemic changes that are not only critical to addressing the risks associated with climate change, but also to address social inequity and build economic resilience (Adelekan et al., 2024).

An international consensus has been reached that there is a great urgency for the transition to a low-carbon energy world, as determined by international agreements, such as the Paris Agreement, which sets targets in terms of limiting the global temperature increase to below 1.5 degrees Celsius above the pre-industrial level (Parlamento europeo, 2017). However, this vision also requires unprecedented systemic changes, starting with the energy sector, which already bears all GHG emissions (Connors et al., 2021).

One phase of this energy transition is the shift from a centralised energy system powered by high-power power generation from conventional fossil fuels to a decentralised energy system based on renewable energy. All of this has been achieved thanks to advances in photovoltaics (PV) and wind technologies, energy storage systems, and digital platforms, which have lowered the cost and accessibility of renewable energy.

Decentralised energy ecosystems, especially self-consumption, call into question the typical way energy is used. Decentralised systems instead of conventional centralised systems, through which energy flows unidirectionally from producer to consumer, support bidirectional energy flows (D'Herbemont et al., 2020). This can separate people, organisations, and communities from each other and the grid in generating, consuming, and even supplying excess energy to their own, another, or even the grid. In this way, the model discourages traditional producer-consumer separation and promotes a more integrated, networked and resilient energy ecosystem (IEA, 2020).

The idea of REC is always an expression of the total decentralisation of production and the extension of self-consumption. Primarily considered as cooperatives or partnerships, these organisations allow members to jointly hold and manage their renewable energy projects. RECs promote equitable access to renewable generation, localised economic development, and localised energy independence through resource pooling and benefit-sharing among members (Local Energy Communities, n.d.).

RECs have the potential to play an important role in the energy transition, facilitating a seamless link between technological frontiers and societal acceptance. Although competition from renewable energy generation technologies has increased, large-scale penetration requires the development of organisational and financial models (Barr et al., 2005). RECs provide a mechanism through which individuals and institutions can collectively invest in renewable energy resource projects, share those benefits equitably, and similarly build collective resilience against climate and economic uncertainty.

In this framework, self-consumption is that consumption of energy at or very close to the point of generation and is one of the pillars of REC and the energy transition in general. It is in line with the principle of energy saving and ecological transition because it minimises losses in long-distance transmission and reduces dependence on fossil fuel-based energy (Just Energy, 2023). In addition, self-consumption also offers a motivation for the installation of renewable energy systems (e.g., solar panels on roofs) which are also very interesting for the transition of buildings to net-zero energy buildings.

From an economic perspective, self-consumption is a pretty good idea, as it helps individuals and groups pocket their energy bills, mitigate their exposure to energy market volatility, and generate local jobs (Cavallaro et al., 2023). The more self-consumption is concentrated in RECs, the more extensive these gains become, incorporating benefits of scale, energy efficiency of a portfolio of entities, along with other social innovations.

The main building blocks of self-consumption are solar PV and energy storage devices. This includes technology that allows individuals and communities to produce renewable energy on-site, to store the excess for later use and independently of the grid. Smart grid technologies make it possible to monitor and control energy supply in real time, thus achieving efficient use of energy (May et al., 2024). The data provided by devices in smart meters and energy management systems (EMS) is useful information for end-users for their energy consumption so that it can be improved effectively.

Digital platforms are peer-to-peer energy trading tools in REC that allow members to buy and sell excess electricity directly. This is an improvement in economic feasibility not only in terms of self-consumption, but also in terms of a sense of community and solidarity.

As far as Artificial Intelligence (AI) is concerned, predictive energy management, through tools assisted by AI, can be achieved by detecting consumption trends, weather forecasts and market developments. These devices allow us to implement the use of renewable energy, reduce costs and increase the reliability of self-consumption systems (Anaya et al., 2019).

Self-consumption in the energy transition is therefore a requirement for the implementation of appropriate regulatory and policy measures. The Renewable Energy Directive II (RED II) and the Electricity Market Directive, both within the EU framework, set out a coherent package to encourage self-consumption and RECs in EU law. In these guidelines, Member States have been granted the rights to develop and use renewable energy sources (RES) and to organise their transfer off the grid, while they have an obligation to remove barriers to self-consumption as prescribed by law (Ahmed et al., 2024).

In addition, the role of the REC has been continuously supported by legislative measures, for example Legislative Decree (D. Lgs.) 199/2021 in Italy with its Annex VII, which provides financial incentives, in the form of incentive tariffs and tax credits, to encourage the development of renewable energy projects. They also explicitly define criteria for the design and operation of RECs that ensure that these activities are participatory, transparent and fair (European Commission, 2023).

However, challenges persist. Bureaucratic complexity, regulatory (in)coherence, and public ignorance are all barriers to the spread of self-consumption and RECs. To overcome these barriers, joint efforts will be needed between policymakers, industry and civil society to create an ecosystem for decentralised energy systems.

The introduction of self-consumption and RECs has profound social and economic impacts. These models, through the decentralisation of energy production and distribution, support energy democracy, i.e. the fate of energy control by citizens and communities. This democratization of energy is a force of social bonding, builds community resilience, and reduces dependence on external energy suppliers.

From an economic point of view, self-consumption drives local economic growth through the creation of jobs in the field of installation, maintenance and management of renewable energy (Bartels, 2023). It is also an innovative energy source in the field of energy, at the same time a catalyst in the process of innovative technologies, new business models and new ways of financing. In addition, community-owned self-consumption minimises energy cost savings, potentially reinvested in other community-funded initiatives (Candelise & Ruggieri, 2020).

Equally important are the environmental benefits. Self-consumption, through a reduction in dependence on fossil fuels and energy dissipation, contributes directly to the reduction of GHG emissions. It is compatible with the integration of variable RES into the energy system, leading to a more sustainable and reliable energy system (Banks, n.d.).

With reference to ESCOs, they play a key role in self-consumption and in the production of RECs. They offer technical expertise, financial support, and project management services, thereby enabling individuals and communities to overcome the barriers associated with renewable energy projects. Their involvement reduces the risks of self-consumption and, for its part, helps to establish the long-term economic viability of projects, so it is consistently a determining factor for success (FIRE, 2024).

ESCOs also act as connectors for multiple actors (e.g., policymakers, energy generators, energy consumers). Their involvement in driving cooperation and trust between stakeholders is of paramount importance for the implementation of RECs and, more generally, for the energy transition (Bertoldi & Boza-Kiss, 2017).

The high potential of self-consumption to play a role in the energy revolution is therefore evident. Technological advancement and cost reduction make self-consumption a promising solution for the good of the person and the community. However, long-term integrated thinking is needed, covering all aspects, including technical, organisational and financial innovation, to reach its full potential.

Regulatory, financial and social acceptability difficulties are some of the most critical issues that should be addressed in future research actions and policies for the management of self-consumption (4-Energy, 2023). A key problem is trying to explore new models to increase self-consumption loads in an environmentally friendly way. The transition to renewable energy is not, and should not be, a matter of technical necessity, but rather a profound social change that requires a new way of thinking, organising and functioning. In this way, the use of self-consumption helps to empower individuals and communities by making them experts in their energy destinies, to provide resilience, equity and to ensure environmental sustainability (Ahmed & Măgurean, 2024).

Self-consumption will be of fundamental value for the energy transition. Achieving a low-carbon future through attracting the adoption of renewable energy, energy efficiency and social innovation is one of the key pathways.

1.1.3. The Role of Self-Consumption in Sustainable Energy and Economic Resilience

Sustainability and self-consumption have long been two of the most discussed concepts for solving environmental pollution and economic instability in this era. The global push for sustainable development, as exemplified by the consensus, such as the UN Sustainable Development Goals (SDGs) framework, emphasizes the need to balance environmental protection, economic growth, and social equity (Ma et al., 2023). More precisely, self-consumption –the ability to transform energy consumers into energy producers in the context of collective renewables– presents a fundamentally different path through which environmental and economic resilience can be built. And this paradigm shift not only reduces the negative effects of climate change, but also gives the community and people the chance to become more autonomous and confident in exploiting the energy potential (Aggeli et al., 2022).

Sustainability, in general terms, means that the current needs of the present can be met without compromising the future generations' ability to meet their own needs (Alvarez-Alvarado et al., 2020). For the energy sector, it consists of reducing carbon monoxide emissions, maintaining the state of resources and using energy sources to the exclusion of old fuels. Sustainability concepts are often in support of the abandonment of linear and extractive behaviours and towards circular and regenerative models (Cisma et al., 2024). Self-consumption of energy is also fully in line with these principles, as it favours energy production at the local level, with collective rather than centralised electricity grids, and minimises energy transmission losses.

As far as energy sustainability is concerned, it is linked to environmental resilience. Reducing dependence on fossil fuels means that self-consumption systems will emit fewer GHGs, and this is part of climate regulation (CarbonBudget, 2024). In particular, the inherent decentralisation of self-consumption brings robustness to the system by reducing the risk of an outage caused by a grid failure, as well as the upstream risk, e.g. geopolitical instability, natural disasters.

Self-consumption refers to the complete generation of end-user energy for personal use, typically using PVs or other renewable sources. Self-generation – the ability of individuals, businesses, and communities to generate their own electricity – fosters a more direct involvement in electricity development and a reliance on non-fossil grids (Gaio, 2024).

Self-consumption has solid consequences for the environment, decreasing the carbon footprint of energy consumption. The application of solar PVs cells, wind energy converters, and other renewable energy technologies in combination provides clean energy generation from point sources, which in turn replaces energy generation from fossil fuels (D'Adamo et al., 2022). This change is very relevant to the achievement of global climate goals, such as those of the Paris Agreement, in which the overall goals are to limit the increase in the global average temperature to below 2 degrees Celsius compared to pre-industrial levels.

The economic benefits of self-consumption are equally convincing. You can make significant savings in the form of electricity bills and benefit from hedging against price variability through local energy production. This is a major issue in regions where energy prices are linked to geopolitical developments or market fluctuations. For example, in

2022, households and businesses in energy crisis with self-consumption schemes were less affected by the sharp increases in the cost of fossil fuels, thanks to this benefit obtained by the model in achieving economic stability (Febranzah & Krisprimandoyo, n.d.).

In addition, a surplus of energy, for example when it is equipped with self-consumption systems, is always available to be fed back into the grid or reshared among the members of the energy community, obtaining additional income. These economic consequences give households and small businesses greater financial resilience on which they can use reinvestments in other sustainable practices or in the local economy (Bartels, 2023).

The idea of energy communities is an obvious development as a result of self-consumption, in which a group of people or entities mutually commit to producing, sharing and using renewable energy (Caboni et al., 2023). These communities are the result of exploiting collective action with the aim of setting higher environmental and economic returns at the expense of their use for self-consumption. By using shared resources and infrastructure, energy communities can prevent economies of scale, reduce costs, and increase system efficiency (Joshi et al., 2016).

Energy communities also foster social cohesion and collective resilience. Local stakeholders involved in decision-making facilitate democratic governance and fair benefit-sharing by communities. They also offer a platform for education and innovation, promoting awareness of sustainability and inspiring the use of innovative technologies.

On an environmental level, they play a key role in promoting the installation of renewable energy plants, which will be maintained to achieve regional decarbonization aspirations (Giordano, 2024). In Europe, RED II has already stimulated the creation of energy communities, through the establishment of a supporting legal framework, leading to the generation and use of renewable energy (Girardi, 2023).

Even though the wide applications of self-consumption have several advantages, it is limited by so many factors. These include high upfront capital expenditures, regulatory constraints, and technical limitations (e.g., intermittency in renewable energy generation) (Di Silvestre et al., 2021). Achieving any of these challenges is an agenda that requires creative policies, financial instruments, and technology.

The high upfront cost of renewable energy systems is one of the main disadvantages of self-consumption. Innovative financing instruments, such as green loans, rebates and tax credits, can overcome these barriers and drive the penetration rate.

In addition, feed-in tariffs and on-site trading laws are particularly important to improve the economic sustainability of consumption at the second level, balancing the cost of the user's workload to supply excess energy to the grid (Carel Diehl et al., n.d.). But such policies should be designed with maximum care so that the policies are sustainable in the long run and are not creating market distortions.

In addition, technical developments are needed to set in motion several self-consumption systems. Energy storage devices, including lithium-ion batteries and next-generation energy storage devices, reduce the intermittency of renewables by providing energy storage for use during periods of low generation (Badrudeen et al., 2024). Technology based on smart grids and demand management systems, among others, allow for better management of energy distribution and use, and thus the efficiency of the entire system.

Favourable regulatory frameworks are also essential to scale up self-consumption. Policymakers, for example, should offer a basic infrastructure that allows for the integration of self-consumption systems into the existing energy market. Examples of these are the ease of processing applicant requests, standardization of interconnection requirements, and elimination of bureaucracy (Trevisan et al., 2023). Regulation should also encourage network operators to share decentralised energy systems, fair access and fair cost-sharing.

In this context, given the combined increase in the severity of climate change impacts and resource depletion, sustainability and self-sufficiency in this regard will become an even more important aspect of resilient community development. Recent advancements, such as the growing number of blockchain-enabled energy trading platforms and the integration of AI for energy management, are intended to fundamentally change the framework of the self-consumption ecosystem, facilitating proximity and effectiveness (Cebekhulu et al., 2024).

On the other hand, international cooperation and the dissemination of knowledge will play a key role in resolving the systemic obstacle and providing a sustainable and balanced distribution of benefits on the way to self-consumption (World Bank, 2024).

What emerges is that sustainability and self-consumption are strong resources for environmental and economic resilience in the face of an unprecedented stressor. In terms of emissions mitigation, energy security, and community engagement, these models offer a pathway to a more sustainable and just tomorrow. However, these have yet to reach their full potential and to achieve this they must be achieved holistically, including technological innovation, enabling legislation and participatory governance. Therefore, further development of sustainability and self-consumption will not only help reduce the effects of climate change, but also allow us to create a strong, resilient and thriving social world.

1.2. The Energy Transition: Key Concepts

1.2.1. Global Sustainability Goals and the Role of Renewable Energy

In a 21st-century society with limited resources and inequality, a major shift in basic assumptions is needed. The challenge of finding solutions to these problems is based on a set of principles of balancing environmental, economic and social outcomes proposed by the United Nations, and programmes have been established to reconcile environmental, economic and social needs (United Nations, n.d.-b). In this perspective, clean energy is the winner in creating a sustainable future not only because of the powerful effect of mitigating climate change emissions (e.g., reducing the rate of anthropogenic GHG emissions), but also because of the resulting strength of the energy system and the positive effect on the economy. More precisely, in this work, the complex relationship between the general objectives related to sustainability and the specific importance of renewable energy is declined in the framework of the transition to clean energy (Hargroves et al., 2023).

The United Nations SDGs are a set of globally harmonized goals for global challenges. Historically, of the seventeen goals, SDG7 (ensure access to affordable, sustainable, reliable and modern energy for sustainable development) has remained at the heart of the development of international energy policy (Badrudeen et al., 2024). This, mediated by the possibility that regenerative energy can provide the basis from which to decarbonize energy systems, energy security and resilient economies, is at the heart of this vision. SDG 7 clashes with the others, showing the systematic importance of energy for sustainable development. Specificity is also a demand of SDG 13, which calls for even bolder and more immediate policy action to address climate change, which in turn should unleash the potential of deep renewable technologies to free economies from dependence on non-renewable energy technologies (REN21, 2025). In addition, Goal 9 is aimed at the development of sustainable infrastructure, i.e. related enabling technologies, which are also of fundamental importance for the application of RES (e.g. use of smart grid systems and storage devices).

The international goals of climate action are supported and partly achieved by REs and can therefore be reconciled with the 2015 Paris Agreement. According to the agreement, global warming should not exceed two degrees Celsius and the transition from fossil fuels to clean energy will take place in a short time. Clean energy technologies are at the heart of the nationally determined contributions of signatory countries and offer viable options for climate mitigation (United Nations, n.d.).

The decarbonization of energy systems is one of the pillars of global sustainability efforts. The potential of large-scale renewable energy production could be undermined by fossil fuels, as renewable energy production relies on the availability of renewable natural capital. Compared to conventional energy supply, REs produce little or no CO2 during the operational phase and can therefore help to reduce the load of CO2 (and consequently GHG) in the atmosphere (World Bank, 2024).

The use of renewable technologies has grown at a rapid pace in recent years thanks to efficiency improvements linked to cost reductions made possible by technical advances (Fernandez, 2021). The LCOE of solar PV panels continues to decline exponentially, and in some cases, PV is a possible competitive and even less expensive replacement for traditional fossil fuel generation. These savings have led to greater affordability of renewable energy, for example in countries with deep energy poverty.

In addition to the environmental benefits, this boom in renewable energy is also beneficial for socioeconomic development. The renewable energy industry is a generator of jobs, and there is work at every point of the entire value chain, from research and development, to production, installation and after-sales maintenance (Cozzani, 2024). According to the International Renewable Energy Agency (IRENA), the global renewable energy economy employed around 12.7 million people in 2022, with solar PV being the largest sector (Alia Energia, 2025). Renewable energy projects can also target local economic development. Renewables integrated and managed by RECs not only lead to cost-efficient electricity production locally, but also provide and address socio-economic value by sharing a portion of their earnings with one or more members of the local community (Girardi, 2023).

A topic of heated discussion is environmental health concerns related to the spread of renewable energy. At the same time, with the depletion of fossil fuels, renewable energy is a valuable resource for reducing air pollution, which is a major cause of respiratory and cardiovascular morbidity and mortality (IEA, 2021). For this reason, the process of transformation towards clean energy solutions in accordance with SDG 3, healthy, productive, equitable and inclusive societies for all, is not only a trend, but is natural for everyone.

At the same time as the acceleration of research and development of renewable energy devices, a significant number of policy measures have been taken to encourage and reduce costs in support of research and development. They are specifically defined by a unit cost of energy per unit of energy produced by a renewable energy producer with a constant price, which varies over time of use (Trevisan et al., 2023). Renewable portfolio standards (RPS) therefore lead to the development of a clean energy market by requiring that a certain percentage of the total energy supply be generated using clean technologies.

Grants, tax credits and subsidies thus reduce the cost of renewable energy and thus the number of investors, i.e. its attractiveness. In rare cases, carbon pricing policies have been implemented through a carbon tax or cap-and-trade system to internalise the environmental damage caused by the use of fossil fuels and to promote competition in the sustainable development of renewable energy (World Economic Forum, n.d.).

Capacity building and information exchange opportunities - organised by the International Solar Alliance (ISA) in collaboration with the Clean Energy Ministerial (CEM) at the international level - are the spaces where information can be shared, knowledge can be gained, and skills can be created. By participating in activities such as these, they can help provide best practice, support change in the way things are done, and accelerate the global deployment of clean energy technologies.

In this context, the most difficult challenge remains the stochastic nature of solar and wind energy (e.g. due to climatic and seasonal variations). The high initial capital outlay in locations with limited capital resources is another constraint. Although the LCOE from renewables is falling, the capital costs borne by infrastructure operators are still unsustainable and very high (Kamali Saraji & Streimikiene, 2023).

One of the main challenges facing project developers is the lack of a strong policy base, which creates the temptation to attribute problems to administrative barriers, political obstacles and obstruction by powerful and entrenched vested interests. Such problems require partnerships between government, industry and civil society to create a culture of development, implementation and support for renewable energy production.

Advances in technology are a by-product of the growth of renewable energy resources. The concurrent decline in the price of renewable energy technologies is the result of recent developments in PV cells and energy storage. In addition, the use of digital and integration technologies, such as the Internet of Things (IoT) and AI, has been used to improve the management of energy systems for dynamic monitoring and real-time optimisation (Di Silvestre et al., 2021).

Innovation is not limited to the transformation of the business environment (e.g. clean renewable energy production in the technology industry). Blockchains are presented as being able to transfer peer-to-peer energy exchange capacity in large systems. However, the transparency and fair partnerships with which blockchain can be used will enable prosumers to transform themselves into RECs as agents in the energy market.

Traditionally, the constructive interaction between renewables and other green technologies (e.g. electric/hybrid vehicles (EVs) and green H_2) plays a central role in the synergy, further increasing the net impact. For deep decarbonisation, e.g. at sector level, such integrated techniques are needed (Ameriekhtiar Abadi, 2023).

In developing countries, there is a need for training to develop the capacity to market renewable energy domestically. Financial support for projects in LMICs is also clearly established, e.g. through the Green Climate Fund (GCF) or the Global Environment Facility (GEF), which aim to remove barriers to entry and promote equity in the energy transition, respectively.

More specifically, public-private partnerships (PPPs) can also be used as an incentive (Bertoni, 2023). With financial and technical support from governments and the private sector, PPPs lend themselves to ongoing investment and accelerated project delivery (OECD, 2023). Finally, multi-level commitments (such as the European Green Deal) illustrate the importance of renewables in addressing local sustainability and as a proxy for local action to achieve local sustainability goals.

What emerges is that the SDGs, renewables and so on are related social policy instruments that can be used to address social, environmental and economic issues. In addition to its ability to efficiently decarbonise the economy, renewable energy production promotes a country's economic well-being, energy security and social equity. Although challenges remain, such as intermittency, capital costs and regulatory difficulties, technological advances, policies and international cooperation are the cornerstones of an energy efficient world. The possibility of coordinating renewable energy initiatives and the regulatory framework for sustainability can lead to a paradigm shift, not only for present but also for future generations. The energy transition made possible by renewable energy goes hand in hand with environmental regulation and the attempt to build a fairer, safer and more equitable global population.

1.2.2. Definition of Collective Self-Consumption

The energy transition, which has led to a fundamental shift from centralised to collective energy systems, has promoted the concept of collective self-consumption as an area of great interest (Hargroves et al., 2023). Collective self-consumption refers to renewable energy produced, consumed and shared locally by a specific network, usually composed of resident producers and consumers or members of associations, e.g. RECs. This new paradigm follows the emergence of the energy distribution model, as traditionally envisaged by the actors' practice, and distributes it to end-users and prosumer-type actors in energy markets. The self-consumption of energy, made possible by renewable energy production (PV systems and energy storage), promotes greater sustainability, energy independence and economic resilience (Minucci, 2022).

In its simplest form, collective self-consumption is the generation of electricity at or along the point of use, always from RE. Solar PV remains the de facto technology for this type of system due to its scalability and low cost (Angelucci et al., 2020). In addition, other technologies, such as small wind turbines and micro-hydro systems, add to the diversity of collective generation.

Self-consumption is the scenario in which the energy produced by these systems is consumed by the generating unit itself, to maximise the amount of electricity produced and supplied to the grid. The aim is to minimise the amount of electricity not used for production during the day. In addition, the extra unused energy can be stored in batteries or other energy storage devices for later use (Caboni et al., 2023). Where possible, excess electricity will be fed back into the grid or exchanged within the neighbourhood energy network, further increasing the energy efficiency and sustainability of the system.

The performance characteristics of collective self-consumption will be defined by technological developments in energy storage, grid deployment and digital technologies (Boccardo, 2020). Energy storage devices (e.g. lithium-ion batteries) allow the end user to respond to fluctuations in production and increase self-sufficiency. Real-time monitoring and optimisation of the self-consumption system is enabled by smart meters and energy management platforms, which provide the best economic and environmental benefits for a self-consumption system.

This concept of collective self-consumption is based on an inherently dynamic regulatory ecosystem that nevertheless ensures the viability of decentralised energy solutions. From an EU perspective, RED II is a binding legal basis for self-consumption, as it provides a legal justification for individuals and organisations that produce, consume and transmit renewable energy. This technical guidance aims to encourage Member States to ensure that the conditions for collective self-consumption are met, to remove legal barriers and to ensure a level playing field for access to the energy market (K. E. H. Jenkins & Martiskainen, 2018).

These are further supported by national legislation, which includes specific articles to support self-consumption. In the case of Italy, D. Lgs. 199/2021 (transposition of RED II) has introduced support schemes for renewable energy installations and streamlined the rules on self-consumption. In other countries, existing legislation in the form of feed-in tariffs and net metering has led to the spread of collective energy technologies (Candelise & Ruggieri, 2020).

Obviously, the legal context differs a priori between autonomy and collectivism of self-consumption. Both the single-entity self-consumption model (i.e. production and consumption by a single actor) and the multi-entity collective model (i.e. subjects living in a spatially limited context, e.g. apartment blocks or communities, all of whom produce and/or generate/consume energy) are considered. The latter is rapidly gaining considerable popularity, mainly due to its ability to promote social inclusion and improve the use of certain resources through the creation of shared infrastructures (Ahmed & Măgurean, 2024).

The development of collective self-consumption systems is of great socio-economic importance. At an individual level, self-consumption is an example of reducing costs by minimising energy consumption from the grid. Consumers can also benefit from financial incentives, including tax deductions and subsidies, which reduce the cost of installing renewable energy systems (Cavallaro et al., 2023). These reserves gradually accumulate to create a larger disposable income and an economic buffer against shocks.

Community self-sufficiency promotes both the expansion of the community and the equitable distribution of benefits among participants through cooperative means. RECs, for example, provide a way for people to share in and benefit from a community-based energy effort and to learn the nature of mutuality and shared responsibility (Angelucci et al., 2020). At a fundamental level, these communities also generate financial returns for local community programmes, education, health and infrastructure, increasing their social impact.

The economic benefits extend to the wider energy sector, where self-consumption of the energy generated is driving new demand for renewable energy technologies and related services. This pressure has also created a huge number of opportunities (jobs and industrial development related to manufacturing, installation and maintenance industries) (Nisi, 2024). Moreover, by reducing short-term demand on the grid, self-consumption facilities relieve the construction burden and reduce operating costs for utilities.

Collective self-consumption is in line with global sustainability efforts to reduce GHG emissions and the environmental impact of co-produced energy. The use of RES, such as solar PV and wind power, therefore, significantly reduces the carbon footprint of fossil fuel-based plants. This change is a platform for achieving the climate change reductions envisaged by the Paris Agreement and other international treaties (REScoop, 2022).

In addition to reducing carbon dioxide emissions, self-consumption also conserves resources by reducing energy losses during transmission over long distances. Centralised energy systems are also subject to significant losses in long distribution lines, whereas shared generation provides extremely low energy consumption close to the loads. Energy efficiency reduces the total energy required for power generation, conserving resources and minimising environmental damage.

In addition, energy storage and the integration of smart grid technologies increase the resilience of collective energy systems (Aggeli et al., 2022). Such arrangements allow communities to prepare for and respond to climate-related changes (e.g. extreme events), ensuring a steady supply of reliable energy and resilience to external shocks.

Despite the benefits of collective self-consumption, there are many difficulties in promoting its widespread adoption. The excessive cost of renewable energy and energy storage technologies remains a major barrier, particularly for low-income individuals and communities. Although some of these costs have been offset by financial incentives, more needs to be done to ensure access and affordability (Kamali Saraji & Streimikiene, 2023).

Technical challenges remain, including the intermittency of renewable energy and the complexity of integrating collective systems into the existing grid infrastructure. System reliability can be threatened by the intermittency of solar generation, so accurate energy storage and demand response are needed to avoid compromising system reliability. Furthermore, grid operators need to address the challenges of bidirectional energy flow, voltage stability and cyber security to adequately respond to the distributed energy framework (IEA, 2024).

Regulatory uncertainty is another major problem, as non-standardised rules and administrative restrictions favour captive projects. Simplified licensing, clear rules and ongoing political commitment are essential to build investor confidence and facilitate implementation.

Biological and behavioural variables can also affect the effectiveness of collective self-consumption programmes. Public awareness and competence regarding the cost/benefit and technical advantages of household energy self-consumption are sometimes still limited and may require education and promotional activities. Resistance to change, i.e. the involvement of stakeholders and traditional energy industries, may further hinder research, highlighting the need to consider the importance of inclusive dialogue practices and stakeholder engagement (Cotana et al., 2024).

Collective self-consumption has developed under the impetus of technological advances, thanks to a favourable policy environment and policies based on collaborative models between a wide range of actors. Advances in energy storage, including next-generation batteries and hydrogen-based technologies, could be applied to fill key knowledge gaps and improve the scalability of self-consumption. The use of digital technologies, such as blockchain and AI, is seen as an essential next step to improve energy management and promote peer-to-peer energy exchange in decentralised networks (Aggeli et al., 2022).

Policy change is one of the most important factors in the development of collective self-consumption. Policymakers, especially governments and regulators, should pay attention to policy harmonisation, stimulate innovation and create mechanisms for knowledge dissemination. International cooperation, such as IRENA, will play a key role in disseminating best practices and in the global shift towards sustainable energy supply.

The growth of self-consumption will be driven by co-generation, through RECs and PPPs. Such models, generated through the participation of citizens, businesses and communities, have the potential to shape economic, social and environmental objectives and can thus serve as a model for sustainable development (World Bank, 2024).

Collective self-consumption represents a paradigm shift in generation, consumption and management. Based on renewable energy technologies and driven by digital and regulatory innovations, this model offers a solution for sustainable energy systems with a strong focus on efficiency, resilience, and inclusiveness. Although the scenario is far from perfect, the continuous evolution of technology, law, and social phenomena in principle offers room to maximize the potential of collective self-consumption.

In addition to the potential for people and communities to become active players in the energy market, collective self-consumption not only contributes to the overall vision of sustainability goals but also represents a change in the interaction between energy and society. It is not only a substitute for traditional energy sources, but also the basis for a more equitable and ecological future.

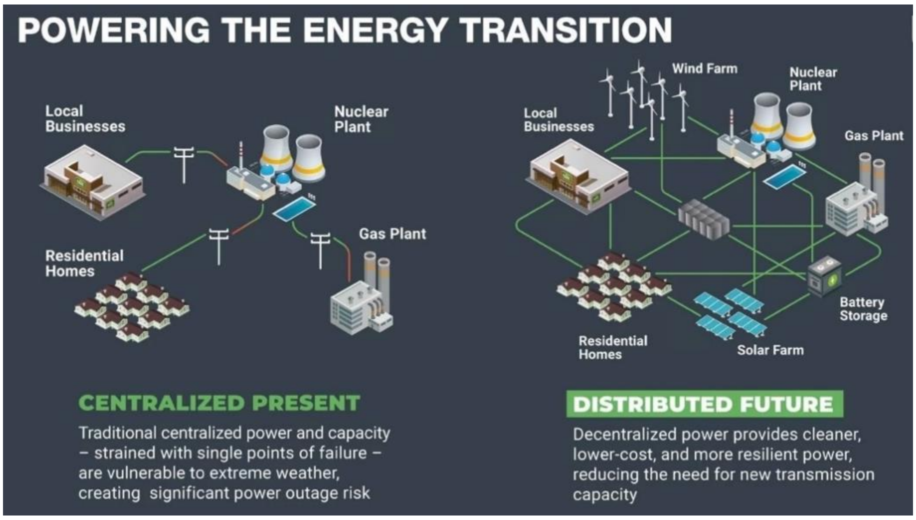
1.3. From Centralised to Decentralised Energy Models

1.3.1. Traditional Models vs Collective Models

The evolution of energy systems from centralised to decentralised layouts is one of the most profound paradigm's shifts in the history of energy infrastructure. Classic centralised energy systems, in which energy is generated on a large scale and collectively over large distances from consumers, are a historical feature of the global energy landscape (Ceschin et al., 2018). However, these models are increasingly challenged by considerations related to the environment, aging infrastructure, and the desire for greater energy resilience.

In contrast, decentralised energy modelling was created as a disruptive counterpoint based on local generation, smart technologies, and consumer engagement. These systems are consistent with global sustainability programs, providing a more robust, flexible, and equitable way of producing and using energy (Devine-Wright & Walker, 2024). This subsection makes a contrastive comparison between the two traditional and collective energy models and explores the nature, advantages, disadvantages and implications of the energy transformation from the traditional model to the collective model (see Fig. 1.1).

FIG. 1.1



SOURCE: BLOOM ENERGY

Traditional energy systems are modelled as vertically integrated, where generation, transmission, and distribution are stacked in a chain. Power plants, usually based on coal, natural gas or nuclear fuels, make up the main production units. The energy produced by these plants is supplied using the public high-voltage grid to substations, where the energy is declassified and supplied to customers (Hargroves et al., 2023).

Key features of centralised systems

Scale and efficiency

Centralised systems have the advantage of economies of scale and can produce energy at low unit cost using large power plants. But, at the same time, this power has always supported economic development and industrialization, an ongoing, stable and continuous source of energy (Ceschin et al., 2018).

Standardized infrastructure

The standardization of centralised networks enables planning, operation, and maintenance. Utilities operate in stable regulatory frameworks that ensure homogeneity and reliability across very large service scales.

Centralised control

These systems are controlled by a control structure (top-down) in which utilities are created, transmitted and collective to allow no interaction with the end consumer. Obtaining this consolidated supervision ensures stability, but also introduces inefficiencies and vulnerabilities (GSE, 2022). Centralised control can lead to slower response times in critical situations, reduced adaptability to fluctuations in local demand, and potential points of failure that can disrupt the entire system.

Challenges of centralised systems

Environmental impact

Traditional energy infrastructure relies primarily on fossil fuels, thus producing GHGs and environmental pollution. This centralisation also requires large infrastructures, which in turn cause habitat disruption and hunting pressure on resources.

Transmission losses

Long-distance transmission of electrical power has the unintended consequence of energy loss, which results in low overall system efficiency (GSE, 2022). For example, in cases where these power losses can be significant enough, they can contribute to a significant fraction of the total energy generated, in turn worsening the problem of energy inefficiency.

Vulnerability to disruptions

Centralised networks are prone to widespread disruptions caused by natural disasters, cyberattacks, or technical failures. Single points of failure can cause cascading failures over large geographic areas.

Inflexibility

The rigid architecture of centralised systems limits their flexibility to evolving energy supply needs or coupling with intermittent RES (Ceschin et al., 2018). This inflexibility contrasts with the transition to a low-carbon energy economy.

Collective energy systems are defined as an inherently decentralised approach to generating, storing, and using energy with greater proximity to the customer. These systems integrate different renewable energy technologies, such as PV solar panels, wind turbines, and energy storage solutions, promoting localised energy autonomy (Hargroves et al., 2023).

Key features of collective systems

Localised generation

Energy is generated at the point of use to minimise the distance it must travel, and the losses associated with the process. This localised generation improves efficiency and minimises environmental impact.

Consumer empowerment

Networked models replace the customer as a "prosumer" with the ability to produce, consume and control energy. This participatory approach promotes energy awareness that inspires the implementation of ecological behaviours.

Flexibility and resilience

Gradually, from the point of view of local implementation and adaptation, modularization is a natural feature of decentralised systems (Abbas et al., 2023). This resilience is strengthened by providing the ability to be flexible in this vulnerability, so that communities can survive disruptions and maintain energy supply in times of crisis.

Technological integration

Using cutting-edge technologies such as smart grids, IoT devices, and blockchain, collective architectures can create a framework to effectively perform energy management, enable peer-to-peer exchanges, and improve system performance (Abbas et al., 2023).

Opportunities of collective systems

Decarbonization

Therefore, the introduction of renewable energy resources into local grids significantly reduces carbon emissions, which in turn contributes to global climate goals. These models are used for this purpose, with a focus on clean energy technologies.

Energy equity

Decentralised systems open access to energy to otherwise excluded communities to contribute to and profit from a renewable energy enterprise. Generation and consumption are in the process of decoupling, so economic growth is achieved through employment and local interaction.

Innovation and investment

Collective systems stimulate innovations not only in energy production, but also in business models. This dynamism attracts capital, which in turn promotes the expansion of the green sector and the implementation of renewable technologies (Glicker & Vitali, 2020).

Comparative analysis

Efficiency and sustainability

While centralised architectures are scalable, homogeneous, and therefore successful, collective architectures are more efficient and feasible due to their minimal transmission losses and better integration of renewables (Ahmed et al., 2024). Due to the local nature of collective systems, the environmental footprint therefore remains extremely small and tends to follow the principles of the circular economy.

Resilience and reliability

Networks are susceptible to global failures, while collective systems compensate for such failures by increasing resilience through redundancy and modularity. Local-scale production and energy storage allow communities to maintain energy autonomy during outages by providing constant access to energy.

Economic implications

Centralised design has the advantage of existing infrastructure and economies of scale but can lead to high operating and maintenance costs. On the other hand, collective models have associated the advantage of energy efficiency and low transmission losses with the cost of a high initial investment cost (Gaio, 2024).

Social and behavioural dynamics

Centralised systems have an implicit user base, while collective systems have an explicit active user base such as consumers or prosumers. This transition promotes energy literacy, social solidarity and collective responsibility and, as a result, is driving a change in terms of sustainable energy practices (PRI, n.d.).

Despite their advantages, collective energy systems face significant challenges. Due to the large initial outlay required to acquire renewable energy and storage infrastructure, they serve as a roof for the disadvantaged population. Spaces for policy and regulatory experimentation are often slow to respond to technological progress and lead to uncertainty and hesitation for widespread adoption.

Technological challenges, such as fluctuations in renewable energy (RE) production and grid performance, require sophisticated solutions, like next-generation energy storage and customer responsiveness characteristics (Gaio, 2024). Also, social acceptance and behavioural adjustment are of critical importance for practical success of collective systems and thus education and dissemination are in demand.

The shift from centralisation to decentralisation is governed by a favourable political environment and new market effects. There is a strong and pressing need for government action to promote the deployment of renewable energy, to remove barriers to licensing and to bear the financial burden of distributed energy projects (G. Jenkins, 2023). The regulatory mechanisms are intended to enable the grid modernisation process that allows for the smooth coupling of renewable resources and to induce cooperation between the distribution system operator (DSO) and the transmission system operator (TSO) (Anaya et al., 2019).

Market mechanisms such as feed-in tariffs, on-site trading, peer-to-peer trading platforms, etc., can make the economic sustainability of collective systems possible. Scale-up of PPPs and community-led programs with an expansion in scale and coverage of decentralised energy concepts.

In conclusion, the shift from legacy centralised to collective energy paradigms is a fundamental shift in the energy landscape on a global scale. Although centralised systems have long been the drivers of industrial and economic development and progress, such inefficiencies, lack of robustness, and environmental footprint induce a shift towards decentralised approaches.

Collective energy systems, which incorporate collective generation, active and renewable end-uses of energy, offer a pathway to a fairer, more just and resilient energy world. By removing technical, economic and regulatory barriers, these models can now be leveraged to realise their full potential to drive the energy transition and help achieve global sustainability goals.

This comparative work underlines the need for a coherent and combined approach that can exploit the benefits of both centralised and decentralised approaches. The ability to innovate, to collaborate and to be inclusive will guide the energy industry through this change and to build a sustainable future for today's generation and for future generations.

1.3.2. The role of Renewable Energy Communities in the energy transition

The global view of energy is shifting away from traditional centralised energy systems towards collective energy systems where sustainability, inclusion, and resilience are becoming increasingly central considerations (ILO, 2016). Central is the role of RECs, a networked, integrated and collaborative learning framework, in which professionals, communities and elected officials will be able to develop, implement and control renewable energy resources. RECs are a potential deep bottleneck communication channel and can be used to achieve decentralisation of energy generation and consumption, independence from fossil fuels, and local economic and environmental benefits (United Nations, n.d.).

RECs are symbiotically organised units of energy consumers and producers that come together to produce, supply, control, and distribute REs. These groups rely to a significant extent on cooperation, group decision-making, and being a member of the group (Giordano, 2024). In almost all states, RECs enjoy full legal personality (legal persons) and cannot be prohibited from operating within regulatory structures that favour the development and implementation of decentralised energy technologies (Minucci, 2022). The European Union's RED II has done much to cement the notion of RECs; formally recognizing RECs as people whose economic model prioritises environmental, social, and economic benefits over monetary gain, above profit. The operation of a REC is commonly represented at a range of scales by a variety of actors, namely households, industry, government, and ESCOs. Common goals include, for example, reducing carbon emissions, achieving partial energy independence and saving energy. As a collaborative organisation, RECs induce a sense of belonging and responsibility, which, by inertia, induces a decision-making process according to the perception of the common good of the community (Lozza, 2023).

Key functions and benefits of RECs

Decentralised energy production

RECs allow to predict the operating time of PV panels, wind farms, and so on. By leveraging available resources, RECs reduce transmission energy loss, improve grid stability, and reduce the environmental impact of centralised generation (Hendricks, 2022). However, decentralised production also has the advantage of increasing energy security, especially in regions threatened by natural disasters or geopolitical instability.

Energy sharing and self-consumption

RECs have been confirmed to confer the ability to provide an energy link to members. Highly advanced technologies such as smart grids and blockchain platforms allow for transparent and much cheaper energy trading, thus motivating domestic energy consumption as consumers and utilities depend on external energy suppliers (Devine-Wright & Walker, 2024). By extending energy supply and demand to the community, RECs would also have the potential to further optimise waste and resource costs.

Economic empowerment

RECs have an impact on local GDP due to employment in the installation, maintenance and management of renewable energy technologies. Members save money on energy outright and, in the process, save other community funds out of their own pockets. In terms of revenue sharing from the use of moderate-power electronics, they are not only valid to ensure that each party has equally rewarding economic returns (economic gains), but also energy poverty and social cohesion.

Environmental impact

Due to the emphasis placed on renewable energy resources, RECs can have a significant impact in reducing GHGs and climate change. Not only that, and not infrequently, community-level initiatives will depend on whether the energy generation context is supported by the development of eco-itinerant initiatives, including waste management, conservation of parks and greenways, or eco-friendly transport (Connors et al., 2021).

Social innovation and participation

RECs will also be seen as a function that fosters the civic dimension of energy governance and thus contributes to the formation of a community and a common responsibility. In this component of social innovation, the importance of energy literacy is crucial not only to make energy more accessible to disadvantaged groups, but also to give these disadvantaged actors a voice in energy-related decision-making processes (Laera et al., 2023).

The strategic role of RECs in the energy transition

Advancing renewable energy adoption

RECs play a key role in clean energy technological developments and their transfer to energy applications. By improving the resilience and flexibility of the grid, it becomes more secure and stable, including with regard to fluctuations in energy supply and demand, and, through the sharing of resources (information) and knowledge, RECs circumvent (or overcome) barriers that would otherwise prevent consumers and small businesses from nesting renewable technologies, And so on.

Aligning with policy objectives

RECs are consistent with deep sustainability goals, for example, the UN SDGs. They produce goals 7 (Affordable and clean energy), 11 (Sustainable cities and communities) and 13 (Climate action). Regarding the ability of RECs to achieve these goals, policymakers have enabled the use of RECs through policy approval and other (United Nations, n.d.).

Promoting energy justice

Energy justice is a necessary wheel of change and, therefore, a driver of equity in sharing some of the gains from change with the wider community. RECs perform all these functions within the framework of inclusiveness and clean energy supply, ensuring that the benefits of decentralised energy production are not only accessible to a privileged few, but are instead distributed equally among all participants. By promoting local engagement and prioritising social and environmental well-being, RECs act as a catalyst for a fairer and more sustainable energy transition.

Challenges facing RECs

Regulatory and bureaucratic barriers

Changes in regional legislative frameworks and increasingly complex administrative requirements can hamper the operational effectiveness and engagement of RECs (European Commission, 2023). To address these challenges, policies should minimise regulatory burdens to encourage participation or establish clear and well-defined thresholds to ensure consistency and feasibility.

Financial constraints

Investment costs for renewable energy plants with low revenue streams remain a significant barrier to widespread adoption. These financial burdens can dissuade smaller stakeholders from participating in the energy transition and slow down the implementation of decentralised energy projects (OECD, n.d.). To close the funding gap and make these initiatives more financially sustainable, the introduction of innovative financing mechanisms, such as crowdfunding, green bonds and impact investment funds, is essential. These tools can attract a wider range of investors, increase community engagement, and provide the capital needed to accelerate the growth of RECs and other decentralised energy models.

Technological integration

The effectiveness and functionality of RECs depend heavily on the seamless integration of cutting-edge technologies, such as smart meters, EMS, and blockchain-based solutions for secure and transparent energy transactions. These advanced tools enable real-time monitoring, energy distribution optimisation, and increased consumer participation, ultimately driving efficiency and sustainability (IEA, n.d.). However, ensuring the accessibility and affordability of these technologies remains a key challenge. Without wide availability and cost-effective implementation strategies, their benefits can be limited to larger or more financially sound communities, potentially widening gaps between different regions and socio-economic groups. Therefore, targeted policies and financial incentives are needed to facilitate the uptake of these technologies across all models of RECs, promoting a more inclusive and effective transition to decentralised energy systems (Joshi et al., 2016).

Stakeholder engagement

Networking and promotion, particularly through confidence-building initiatives and sponsorship agreements, can present significant challenges for stakeholders involved in RECs. Establishing credibility and fostering collaboration between different actors, ranging from local authorities and businesses to individual consumers, requires a structured approach to engagement. The assumption that community resolution emerges naturally through open information sharing and active participation is valid to some extent, but in practice it often requires deliberate facilitation (Granovetter, 1973). Transparent communication channels, regular stakeholder meetings and inclusive decision-making frameworks are essential to ensure that concerns are addressed effectively. In addition, targeted outreach efforts and educational programmes can play a crucial role in promoting REC initiatives and encouraging wider participation, ultimately strengthening the network and improving the sustainability of projects.

The energy transition from fossil fuels to green energy will facilitate the identification of the location of RECs. Future developments could include integration with digital platforms, where emerging and current information and communication technologies, such as AI and IoT, play a critical role in optimising the efficiency and scalability of RECs' digital infrastructures, including applications such as energy trading algorithms and predictive maintenance systems (Yasar, 2024). In parallel, more policy support is expected, as governments and private or public organisations are likely to contribute more funding through grants, subsidies and capacity-building projects, with harmonised regulations further facilitating the way for cross-border collaborations. In addition, the concept of replication and global scalability of RECs appears increasingly viable, as their application can be extrapolated to a multitude of contexts around the world and then expanded, potentially evolving into a paradigm that advances both global access to energy and the achievement of climate goals (European Commission, 2022).

RECs represent a conceptual paradigm in the energy transition in the social and ecological spheres with technical innovation at the centre. Thanks to the support of local representatives and the expansion of networks, RECs address the most serious problems in energy generation, distribution and consumption. These opportunities to fuel a transformation of renewable energy policies, grid security and energy justice are of fundamental strategic value and represent the only way to achieve a sustainable and equitable energy future. Despite the reservations still expressed, the rapidly growing number of RECs in terms of policy and technological advances will ensure that RECs remain the basis for the energy transition around the world.

CHAPTER II – ORGANISATION AND MANAGEMENT OF RECS: THE ROLE OF ESCOS

2.1. The Italian and European Regulatory Framework

2.1.1. The RED II Directive and Italian Legislation (D. Lgs. 199/2021)

The European Union's RED II Directive (Directive EU 2018/2001) is a key component of the EU's energy and environmental policy. It provides a legal framework for the implementation of RES in all Member States and sets ambitious targets for sustainability and energy transition (Energia Clima 2030, 2018). As an EU Member State of high interest, Italy has transposed the principles of the Directive into national law under D. Lgs. No. 199 of 2021 (D. Lgs. 199/2021) (European Commission, 2023). Within this legal framework, one of the main tasks is entrusted to the integration of the RECs and the use of collective self-consumption equipment that reinterprets national legislation within the EU framework (European Commission, 2018).

The EU RED II derives from the Renewable Energy Directive (2009/28/EC) and should be seen as the European undertaking of a harmless energy system. It sets a binding ambition on EU Member States to reach at least 32% of final energy consumption from renewable energy targets by 2030. The revision of the RED II Directive (EU/2023/2413) raises the EU's binding renewable energy target for 2030 to a minimum of 42.5%, compared to the previous target of 32%, with the aim of reaching 45% (Infobuildenergia, 2023). The directive is characterised by the introduction of a number of new provisions to promote the energy transition and democratisation, with a focus on the development of RECs and the empowerment of citizens (Gangemi, 2022).

RED II emphasizes the importance of prosumers, individuals and entities that produce and consume renewable energy. It grants them the freedom to produce, store, and trade excess energy and the power to access them, on par with any market. This vision is part of the broader European strategy to strengthen local energy autonomy and reduce dependence on fossil fuel imports (Laudisa, 2023).

A key innovation introduced by RED II is the concept of RECs, defined as cooperative structures that allow citizens, businesses and municipalities to cross paths to work together on renewable energy projects (European Commission, 2023). RECs promote local communities, fuel self-consumption, improve energy independence, and drive the economic prosperity of communities.

The RED II Directive requires Member States to continue to optimise permitting and administrative procedures for renewable energy installations and, in the case of installations, also on a marginal scale. This includes digitizing processes and reducing bureaucratic barriers (Cavallaro et al., 2023).

Member countries are invited to develop support measures for renewable energy and to include it in a competitive energy market. Among the proposals to be implemented (e.g. auctions, feed-in tariffs, premium schemes and other measures), the development of RES is encouraged (Stylianou, 2022).

RED II defines one of its main objectives as providing a platform for Member States from which they can achieve and monitor the results of the energy transition tailored by considering the context and constraints of the Member State.

D. Lgs. 199/2021 is a measure that transposes the requirements of RED II into national legislation. The decree sets national renewable energy targets and provides for financial and regulatory mechanisms to incentivise the uptake of renewable energy within RECs, in the context of EU regulations and national targets (MASE, 2024).

For example, Italy, after a recent revision, aims to achieve a final gross annual net renewable energy consumption of 40% by 2030 with activity sub-targets for the electricity, heating and transport sectors (Seneca ESG, 2023).

The regulation of the development and operation of the RECs is dictated by a series of exceptionally refined rules contained in the decree. This regulation codifies RECs as legal entities, i.e. human actors, small and medium-sized enterprises (SMEs) and local authorities, which produce, consume and redistribute renewable energy as a group (Glicker & Vitali, 2020). The key features of this regulation include:

- Simplified registration processes: streamlined procedures for RECs registration and governance.
- Incentives for self-consumption: financial support and tax incentives for self-consumed energy.
- Grid access and management: both the reconnection experience itself and its by-products have proven to be the most relevant gateway to the grid, allowing them to exchange energy like any other High-Voltage Direct Current (HVDC) system.
- Collective self-consumption models:
    - Simplification of authorization procedures: reduction of administrative obstacles to the implementation of PV and other RES technologies.
    - Introduction of innovative tariff structures: to model the reduced load on the core networks thanks to collective generation and local consumption.

The financial incentives provided for by D. Lgs. 199/2021, managed by ARERA and GSE, are structured to support self-consumption and the sharing of renewable energy through REC (KPMG, 2023). These include:

- Assessment of self-consumed energy: self-consumed energy within the REC is assessed based on the regulatory tariffs established by ARERA (Resolution 727/2022). Members receive compensation for shared energy consumption, reducing electricity costs.
- Incentive for shared energy: the REC model is incentivized through a premium tariff for shared energy within the community. Incentive rates vary based on system size and geographic location:
  - ≤200 kW: fixed base tariff of 80 €/MWh plus a geographic adjustment (+10 €/MWh in Northern Italy, +4 €/MWh in Central Italy).
  - 200-600 kW: Fixed base tariff of 70 €/MWh with the same geographic adjustments.
  - >600 kW: fixed base tariff of 60 €/MWh with a cap of 100 €/MWh.

The incentive is dynamic and inversely proportional to the wholesale price of electricity, ensuring market stability (GSE, 2024).

- Contribution for energy exported to the grid: if requested, the GSE can purchase the excess energy exported to the grid, providing additional income streams for the REC.
- Capital grants under the PNRR: RECs of municipalities with less than 5,000 inhabitants can benefit from capital grants covering up to 40% of investment costs, supporting the deployment of renewable energy and storage systems (GSE, 2024).

The implementation of Regulation (EU) No 1289/2013 transposed into Italian law is a very significant factor for the Italian energy industry. The decentralisation of energy systems, citizen participation and the adoption of renewables through D. Lgs. 199/2021 advance Italy's transition to sustainability (Bizzarri et al., 2024).

Collective self-consumption and on-site generation increase energy security by reducing dependence on fossil fuels. This issue has been addressed by the Italian plan, aimed at incentivizing Italian national producers of renewable energy with financial aid. The plan implies the achievement of multiple benefits.

Economic and social benefits

The economic and social benefits extend to the design of RECs and small-scale renewable energy, including, but not limited to, job creation, reducing energy insecurity and facilitating local economic development (Laera et al., 2023).

Alignment with EU sustainability goals

The compliance with the requirements of RED II recently found in Italy is reflected on a European scale in the achievement of sustainability goals. Access to EU funding and support for the commercialisation of renewable energy resources, as provided for in this agreement, is granted (Trevisan et al., 2023).

Despite its progressive framework, the implementation of D. Lgs. 199/2021 is facing several challenges that require strategic intervention.

Administrative and bureaucratic barriers

The simplification of administrative and authorisation procedures, however, remains ongoing. Nevertheless, continuous adaptation is needed to be more digitised and for better intergovernmental/intragovernmental collaboration to take these next steps.

Public awareness and engagement

There is a significant need to increase public awareness of RECs and collective self-consumption systems. Educational groups and stakeholder engagement activities can improve enrolment and participation (Blazejewski et al., 2017).

Grid modernization and investment

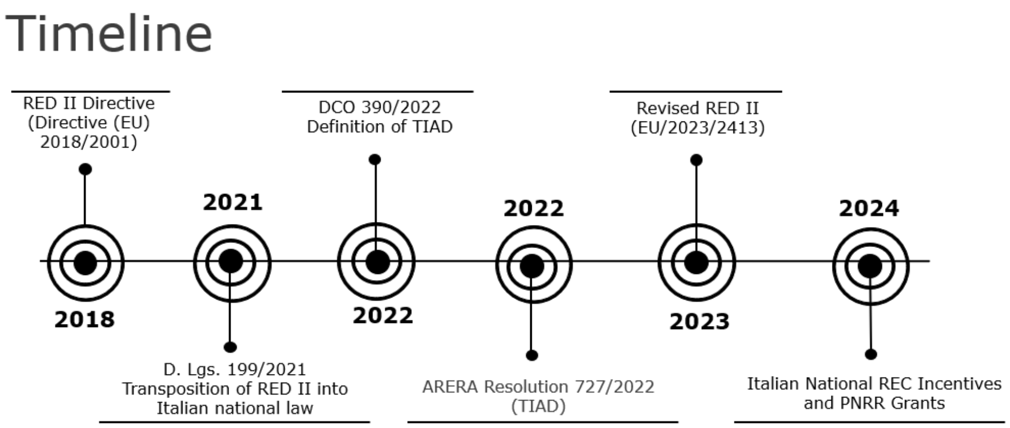
The implementation of a decentralised energy system involves a significant financial commitment to the modernization of the grid. Sufficient funding and promoting private sector involvement are also crucial.

Policy coherence and stability

Consistent and consistent policymaking is key to building investor confidence and achieving sustainable success. Frequent policy changes could undermine progress and discourage investment (Carel Diehl et al., n.d.).

In conclusion, the RED II Directive and its applications in D. Lgs. 199/2021 represent fundamental milestones in Europe's energy transition path (see Fig. 2.1). Through cooperation to achieve a compliant, decentralised renewable energy policy based on the empowerment of citizens, this type of law lays the foundations from which a just and sustainable energy world can be achieved. Italy is also reaching great results in achieving global sustainability and European sustainability goals (Seneca ESG, 2023). However, realising the potential of these reference programmes will require overcoming current technical challenges and maintaining the expectation of participation of all stakeholders.

FIG. 2.1



SOURCE: OUR ELABORATION

2.1.2. Support Mechanisms and Incentives for RECs

The emergence of RECs is not just a technological or organisational phenomenon, but a real paradigm shift in the generation, sharing and consumption of energy. To support this paradigm shift, governments and organisations provide a variety of enabling programs and benefits linked to financial, technical, and social constraints (Cavallaro et al., 2023). These instruments, starting from grants and tax credits to technical assistance schemes, are organised to enable communities to envision renewable energy projects, to encourage and lead energy democracy, and to accelerate the transition to the sustainable energy order.

Grants, loans and subsidies have been provided, at national and local level, to promote the adoption of RECs. The financial attractiveness of having a lower initial capital cost for renewable electricity generation is one of the main incentives that has led to the development and expansion of these projects by communities.

In the EU, the Clean Energy Package for All of Europe (supported by RED II, as a facilitator) requires Member States to establish all the necessary legal conditions for RECs (Kamali Saraji & Streimikiene, 2023). This includes financial support mechanisms adapted to community-led initiatives. In general, feed-in tariffs and premiums provide a stable income stream to renewable energy producers, linking the producer to a one-off fixed cost or price advantage over the market price of electricity sold to the electricity grid.

Italy has introduced several measures to incentivize RECs. For example, the decree mandates the disbursement of grants and some low-interest loans for community-owned renewable energy projects. In addition, individual and corporate donors to RECs receive tax incentives to exceed the economic threshold, in order to promote commercialization (Causone et al., 2023).

One of the main obstacles to the development of RECs is the updating of the structure of the administrative and regulatory system. In many cases, permitting and grid connection regulations are a disincentive that can be a problem for community-based projects. In response to these challenges, virtually all jurisdictions have adopted simplified permitting and formed agencies to help RECs with regulation.

Also in Italy, D. Lgs. 199/2021 attaches great importance to the presentation of a simplified grid connection process adapted to RECs. Regional authorities should also be increasingly motivated to act for individual regions when prioritising renewable energy installations (Trevisan et al., 2023). In addition to paving the way for procedural hurdles, these steps also help reduce the cost and time required for project development, thereby increasing the viability of renewable energy projects for communities. In addition, the Italian legal framework allows for the combination of RECs and the consequent direct integration of RECs into local planning plans.

Based on the requirement that municipalities are required to consider the possibility of a REC when planning their energy strategy, the policy ensures that community energy projects are feasible in the context of global sustainability aspirations (Adelekan et al., 2024). By working cooperatively, there are benefits that local authorities and communities can leverage together to work in synergy, with the aim of developing a beneficial and supportive environment for the prosperity of the REC.

Energy sharing is at the heart of the REC model and therefore provides optimal use of local renewable energy produced by members' assets, for example to promote shared energy self-consumption, authorities have presented differentiated incentive packages aimed at motivating communities to self-supply and self-consumption of local energy production-consumption.

Italian legislation provides for economic rewards for energy shared within RECs. Producers' energy consumption by members who draw on energy provided by the community's renewable generation (electricity) facilities, is at lower energy prices and offers additional cost savings for energy use to help reduce demand on the national grid during peak demand hours. On the contrary, it could not only be an energy saver for communities, but it is also able to stabilize and strengthen electricity grids (De Vincenzo, 2022).

Moreover, in Italy, legal measures have been taken to promote the penetration of smart metering and energy management devices in RECs. This type of technology allows for the sending of energy flow monitoring optimisation messages online so that as many potential consumer benefits as possible can be realised.

However, it is not just a matter of financial compensation, but a matter of knowledge, skills, experience and technical ability. Realising this, governments and agencies are offering a capacity-building and technical support program and a self-sufficiency program to support communities in the architecture and implementation of renewable energy projects (Ma et al., 2023).

Across the EU, developments in this area are providing substantial funding for REC themes for training, research and technical assistance. These efforts provide communities with the skills and knowledge to understand the challenges related to these project development complexities in terms of feasibility, financing, installation and operation, and so on.

The Italian national and regional calendars have also been formulated along the lines of the programs. For example, the Ministry for Ecological Transition has set up a dedicated office to support the REC to provide advice on legal issues, financial aspects and technical solutions (IEA, 2023). There have been pilot projects undertaken by local authorities with the aim of illustrating the feasibility of REC models, which will provide fundamental insights and guidance on how these models could progress.

Despite the strong relationship between finance and regulation, the ultimate success of RECs will depend on public engagement and social integration. Through the following actions, the government has stepped in, taking steps to encourage participation and create a community-owned place.

In Italy, regional work often consists of community communication plans to support educational/demonstration programs for the benefit of RECs (Moretti & Stamponi, 2023). Activities such as workshops, town halls and trainings are all organised to educate citizens about the possibilities of renewable energy and what they can do to overcome the transition. This type of tool, or similar, in addition to promoting civic spirit, ensures that REC projects are representative of the neighbourhood and the needs of the local population (Aggeli et al., 2022).

In addition, social incentives such as community grants and shared ownership models allow residents to take an active role in the governance of RECs. Through the inclusion of citizens in political decision-making, these interventions promote transparency, accountability, trust, and collaborative relationships within the community.

Despite significant investments made in the design and development of support and incentive mechanisms for RECs, some challenges remain. Financial constraints, particularly in socioeconomically disadvantaged populations, can limit financial access and stability. Regulatory hurdles, including complex permitting and grid interconnection regulations, remain an obstacle to many projects. In addition, due to the fact that technical expertise and capacity are available locally, the scale of project development and implementation is likely to be limited (OECD, n.d.).

But these are also opportunities for innovation and collaboration. Since with the advent of new forms of financing, e.g. crowdfunding or cooperative financing, there are a multitude of possibilities to organise the mobilization of resources, advances in digital technologies have the potential to improve administrative work and its applicability to EMS (Hendricks, 2022). Developments in this area hold promise to enable governments and other agencies to capitalize on its full capabilities and achieve the goal of providing a collective renewable energy generation system.

In conclusion, the incentive and support mechanism is a crucial success factor in promoting the development and achievement of RECs. By offering financial aid, simplifying regulation and supporting community engagement, these measures have the following potential to enable citizens to take an active role in the energy transition. While the road ahead is still littered with challenges, the continued and growing adoption of innovative policies and programmes can help achieve the goal of deploying a fair and inclusive energy system. Although Italy and other European countries are only now launching RED II and related actions, REC's vision for fuelling the energy transition is becoming clearer than ever. In the next section, the most important challenges and opportunities facing RECs will be detailed.

2.2. Challenges and Opportunities for the Organisational and Financial Management of RECs

2.2.1. Regulatory and Bureaucratic Obstacles

Now that RECs are at the top of the energy transition, this comes at the price of having to deal with many regulatory and bureaucratic constraints. These issues generate a list of questions that require a good degree of attention when trying to achieve healthy development and functioning of the RECs (Kamali Saraji & Streimikiene, 2023). These obstacles need to be analysed in detail to create pathways for their development and to progress in a direction that aligns with higher-level sustainability goals.

The heterogeneity of the regulatory landscape across jurisdictions is one of the biggest issues in REC design. At the European level, RED II established a legal mandate for energy communities. However, there have been considerable variations in the implementation of the Directive at national level. In Italy, D. Lgs. 199/2021 aimed to implement the logic underlying RED II but its articulation and rooting in the regions has led to a lack of homogeneity in administrative operational behaviour and access to support services (Donati, 2024).

This unravelling comes at the price that, in the context of the further evolution of RECs it cannot be predicted, e.g., due to a rising complexity of long-range planning and finances difficult to foresee. For example, while in some Italian municipalities, measures have been taken step by step by introducing reduced barriers to permit access, other municipalities have a high level of bureaucratic complexity that increases cost and duration of projects (Lozza, 2023). This is further confounded by the heterogeneity in regulation of grid access and energy exchange, which creates a gap between local and national authority.

Installation permitting of renewable energies (REs) in RECs is one of the most challenging bureaucratic schemes. In some cases, it is required to obtain the appropriate approvals which pass through multiple stages of administrative control (e.g., city hall, regional and national agencies). Constraints on environmental impact assessments, grid connection and land use permits can vary across different entities to fulfil unique needs (Corradetti, 2023). These piecemeal approvals give rise to significant delays, with projects stalled for years by gaps in documentation or procedural aspects.

Furthermore, the existing grid codes are imprecise regarding the way energy systems are integrated from a decentralisation perspective. This regulatory uncertainty pushes RECs' stakeholders to spend decades arguing with utility companies and grid managers, delaying commissioning. Adding to this difficulty, there is no single digital submission point of entry for document submission and receipt, and applicants are left without a consistent set of guidelines of who they need to contact (De Vincenzo, 2022).

Regulatory uncertainty significantly impacts the financial viability of RECs. It is hesitant of investors and financial institutions to make funds available to activities operating within ambiguous legal environments. Specifically, the absence of clear energy-sharing criteria and the taxation of internal power in certain jurisdictions has been responsible for concern about the long-term viability of RECs (IEA, 2023). When consistent revenue streams cannot be relied upon, REC is also particularly difficult to secure loans or attract private equity capital.

Additionally, regulatory compliance is typically high cost to implement for the initial phase. These include costs for environmental permit fees, grid interconnection studies, and legal advice to rescind complex legislation (KPMG, 2023). Nonetheless, for the smaller RECs, in general with tight budgets, the cost of this might be prohibitive and thus exclude small RECs, being thus effectively excluded from the energy transition process.

However, to be considered, amongst other regulatory issues, there is still another problem with the incompatibility between, on the one hand, the traditional grid systems and, on the other hand, the decentralised concepts of energy (Gärttner et al., 2018). Grid infrastructures were designed previously only assuming unidirectional energy flow from power plants to consumers and centralised energy generation. Nevertheless, the integration of RECs (i.e., bidirectional energy dissipation) leads to the need of many modifications to current grid codes and hardware.

In Italy, as in other European countries, the grid operation regulatory framework has never kept pace with the technical need (IEA, n.d.). This latency restricts the utility which the RECs have for full realisation of exploitation of the potential benefits in energy sharing and demand-side management. In addition, the absence of standard procedures for incorporating renewable energy into distribution networks puts additional burdens on the owners of RECs, who are frequently required to invest in tailor-made solutions to meet archaic grid rules.

Recurrent small-scale RECs are limited because of an unacceptable administrative workload that is not justified by the size of their operations. Regulatory frameworks do not make sufficient allowance to the needs and capabilities of community-based projects (Adu-Kankam & Camarinha-Matos, 2023). For instance, the same permitting and reporting requirements that are extended to big-scale renewable energy projects are often extended to small-scale RECs, placing an unnecessary load on its limited resources.

This gap is most noticeable when reporting the two sides of energy production and consumption. Because of a lack of technical ability and financial status, many RECs are not in the capacity to satisfy complex reporting requirements and can suffer from financial sanctions and delays in getting access to support services.

Although incentive programs for RECs do exist, designing them often does not fit with the operational context of community energy projects. For example, in Italy, support offered by public funds to the size of installed renewable energy technologies is often associated with specific technology or project type, whereas thousands of technologies are not included in the financial support scheme (ANCI, 2024). In a similar vein, for instance, it is not unusual to control feed-in-tariff and tax exemption schemes such that those systems are more advantageous for single producers rather than for systems that have collective energy sharing.

It is also important to mention the absence of the tailored incentive to use REC-specific implementations (e.g., energy exchange, under-responsiveness-to-demand) to achieve greater economic utility, making the implementations less feasible (Bertoni, 2023). Policy makers also must patch those gaps by designing targeted benefits that address the unique tasks of RECs for grid stability, energy economy, and equity.

Local administrations serve as a driver and a blocker of RECs. Municipal governments are typically the first point of contact between the RECs' stakeholders and land access, grid connection, and regional incentives. Nevertheless, the power of local authorities in providing such support for RECs is such that there is enormous gradient. In some jurisdictions, local governments have chosen to take a precautionary approach by delivering technical assistance and grants in the direction of community energy initiatives. In the rest of the cases, awareness or resource gap leads to RECs initiatives engaged to an extent of only partial or no involvement (European Commission, 2016).

As a reflection of the demand for locally tailored programs, this non-uniform support reflects the need for programs that equip authorities with the information, skills, and the resources to achieve and sustain high-quality support for RECs. Creating dedicated RECs support offices at the citywide level may facilitate communication between community partners and regulatory agencies, thereby mitigating bureaucratic obstacles and encouraging a more connectionist relationship.

Governance mechanisms of RECs frequently experience legal vagueness, especially concerning the mix of RECs as energy producers, distributors, and consumers. However, the current laws are, in most jurisdictions, not explicitly written out to cover the rights and obligations of RECs with respect to the traditional energy market participants. This ambiguity can give rise to competitive applications for grid access, price, and cost of infrastructure improvements.

For example, a persistent issue regarding legal attribution of surplus electrical power produced by RECs is a topic that is frequently a point of argument (Andoni et al., 2022). It is not clear whether this energy is equivalent to a proprietary good, or to a public good, on which one could intervene in market terms. Overcoming these challenges depends on the creation of comprehensive legal architectures that consider the specific properties of RECs and correspond with more general goals of the energy market.

There are therefore many obstacles, but there are also equal opportunities for regulatory changes that could make the full potential of RECs a reality. Currently, one of the biggest challenges is to streamline permitting, standardize the grid integration process, and formulate transparent rules for energy sharing. Furthermore, use of specific funding instruments for the small-scale RECs can avoid funding issues and foster wider involvement in the energy transition (Celata, 2020).

Digital platforms that combine administrative activities (e.g., permit applications and compliance reporting) hold the potential for even more streamlining of the regulatory experience. Technology can be applied to policy to counteract the administrative inflexibility that affects the REC stakeholders, with a view to their achievement of sustainability objectives.

The regulatory/bureaucratic constraints factors of RECs necessitate an interdisciplinary policy solution that can integrate and respond to technical, economic, and social demands. Policy makers should know that RECs are not only energy plants, but also community oriented social businesses promoting community empowerment and environmental sustainability (United Nations, n.d.). Government should, through an overarching plan, provide a policy context to build up and expand the capacity of RECs.

In conclusion, while regulatory and bureaucratic obstacles present significant challenges for the development of RECs, they are not insurmountable. Policy makers can, using targeted policy, capacity building and deployment of novel technologies, create a regulatory framework in place to ensure the success of RECs. By doing so, they not only accelerate the energy conversion process, but they will also grant us a more accessible and sustainable energy future.

2.2.2. RECs as Opportunities for Social and Technological Innovation

RECs are not only an example of organisational communities intended to foster the production and the use of energy in their community zone, but they are also opportunities for social and multidisciplinary innovation. Their ability not just to remodel energy metabolisms, but also promote community resilience, make them one of the transformative actors in a wider societal energy transition landscape (Andoni et al., 2022). The challenge presented by RECs pushes to create opportunities for collaboration, integration, and innovation.

Highly efficient RECs are also capable of profoundly restoring the social ties of communities. Classic forms of energy systems typically insulate agents from the source of the generated energy and, consequently, create transactional dependencies of the agent and its distant utility. In this context, RECs support a participatory perspective in which people are co-producers and participants.

RECs inherently promote energy democracy by decentralizing decision-making processes. Community members, households, companies, or public bodies discuss energy generation, supply, and reinvestment policy. This democratisation does not stop with the energy systems, their potential to respond to, education, community governance or SDGs, is evident. When supplying RECs, there will be no excluded population (e.g., low family income, marginalized groups) in the transition to energy (Campagnoli, n.d.). The personalized models of finance and support schemes (e.g., low energy bills, community investment activities) can be employed to directly tackle the energy poverty issue, showing the social dimension of RECs.

In addition, RECs are also vehicles of innovation, and innovations may assume completely new forms as collaborative interaction between the community and industry (IRENA, 2019). These partnerships have the capacity to generate solutions that go beyond energy, such as programs involving shared mobility, or local food production initiatives. Discussion between opposed perspectives leads to a multidimensional perspective on sustainability, involving simultaneous consideration of the economic, environmental, and social dimensions.

Despite the significant social implications of RECs, the potential technological innovation that RECs represent should not be trivialized. Due to the collective design of the RECs, it is necessary to use the high-end technology to manage the movement and leverage of energy flow, optimise the reception and integration of the renewable sources (IRENA, 2019).

At the heart of RECs' technical efforts are smart grids. These, overlaid on current global energy networks, provide real-time control and monitoring of the energy generated and used. With the use of advanced metering infrastructure (AMI) community users learn to monitor their own energy patterns, making them more empowered to make intelligent decisions for both economic benefit and environmental considerations (Febranzah & Krisprimandoyo, n.d.). Smart grids enable also the flow of energy in both directions, surplus energy from PV or WTs can be shared among the community members or injected into the grid.

EMS are capable of the most efficient use of RECs based on energy allocation optimisation. Such systems are a set of tools that optimally distributes energy flows between connected collective energy resources. They are based on AI and machine learning algorithms that can forecast energy demand, estimate the energy generation from non-renewable sources, and appropriately adjust predicted energy demand. This enables more informed and effective decision-making to enhance efficiency, increase sustainability and optimise performance across an entire site (GridX, 2024). By integrating data streams from different sources, EMS ensures the highest possible efficiency and sustainability of RECs (Esposito et al., 2024).

The IoT is among the most important devices for achieving the rewirable connectivity of REC components. Smart devices (e.g., thermostat, appliance, and EV charger) fully control and interact with each other, as well as with the central management system, to optimise the energy use. Using IoT devices and sensors, ESCOs can obtain granular information on energy consumption, generation, storage, etc. The type of data used has a crucial effect on the optimisation of energy transfer and the overall efficiency of collective energy systems (Abbas et al., 2023).

Digital platforms are one of the structural pillars of technological innovation in RECs. These web sites can serve as platforms of communication between community stakeholders and platforms of energy production, use, and revenue tracking (Di Silvestre et al., 2018). Specifically, blockchain technologies have made peer-to-peer energy trading possible in RECs and have sparked interest as an enabler of transparency and security of RECs themselves. The use of energy transaction record keeping on a ledger via blockchain creates trust on the part of individual members of the community and facilitates more efficient administration. ESCOs also use these platforms to provide open, decentralised markets where energy packages are exchanged directly between community members.

Technical advances are also to be observed in the introduction of renewable power generation and energy storage systems. PV panels, wind turbines, and biogas plants are common in RECs to provide onsite clean energy. However, from a reliability and prediction standpoint, the uncontrollability of renewables is a problem (Nisi, 2024). With the above in mind, energy storage systems (e.g., lithium-ion batteries or next generation flow batteries) are increasingly used in RECs. These technologies store energy for the high generation time and produce energy for the high demand later, and thus the energy system energy is stable.

In contrast, a range of renewable power systems (hybrid energy systems) have been increasingly used for RECs. For instance, a community may end up coupling solar PV and wind energy production to compensate for the fluctuating production of energy resulting from the varying weather conditions. Furthermore, new points of view, such as the use of the hydrogen electrolysis and fuel cells are also forwarded as a next generation storage solution and to increase the robustness and sustainability of RECs (Brandtzaeg et al., 2022).

The transforming potential of RECs extends from immediate application areas to a much more fundamental and widespread applications. RECs not only serve an important task in questioning the long-established utility-embedded systems but also motivate policy changes. At the same time governments and regulators are now actively redefining the position of the future of RECs towards the attainment of renewable energy targets and thus implementing supportive legislation and incentives (MASE, 2024).

Moreover, RECs act as incubators for emerging technologies, as startups and research laboratories often collaborate with these communities for the development, testing and operational of novel energy related options.

RECs therefore represent a frontier of social and technological innovation in the reconfiguration of the energy generation, consumption and control chain and, through community mediation or next-generation technologies, they constitute the path to a more just, sustainable and robust energy future.

Despite being highly desirable, the potential for RECs to lead to social and technological innovation is by no means assured. Regulatory barriers (i.e., complex permitting or limited grid access rules) may impede the penetration and growth of RECs. Financial factors, such as the upfront costs of renewable energy and storage technologies, can also be significant barriers (Williams, 2024).

However, these challenges present opportunities for further innovation. For instance, it can be done by using new types of financial instruments (e.g., community crowdfunding or green bonds) to finance the construction of RECs. Action at government, financial, and private levels also can help overcome regulatory and financial barriers as well (Ahmed et al., 2024).

The desired training and construction capacity is also high in this context. Having a mobilized community with the knowledge and capacity to manage RECs efficiently, allows stakeholders to guarantee the sustainability and expansion of these efforts, in the long run. Educational courses and workshops could also facilitate an innovation culture within the local community, encouraging residents to produce new thoughts and inventions.

2.3. ESCOs: Definition and Key Features

The evolution and expansion of ESCOs represent a central phase in the international narrative of the energy transition. Once considered technological energy conservation tools, ESCOs have transformed sufficiently to cope with changing paradigms in energy generation, supply and consumption. This section describes the evolution of ESCOs, the growing scope of tasks they can perform, and their critical role in providing the mechanism for sustainable energy technologies.

2.3.1. The Evolution of ESCOs: from Energy Efficiency Providers to Partners for Collective Self-Consumption

The advent of ESCOs can be explained by the energy crisis of the 1970s, which highlighted the weaknesses of energy systems based on centrally produced fossil fuel-powered infrastructure. Governments and industries have recognised the crucial importance of tools to help optimise and reduce energy consumption; these tools have been defined as ESCOs in the form of self-contained boxes that provide end-to-end energy efficiency solutions, including energy audits and best practices, as well as performance-based contracts (Celikyilmaz et al., n.d.).

Initially the main interest was aimed at the industrial and commercial sectors, because in these sectors substantial energy savings are possible thanks to the optimisation of the process, machinery and construction systems (Cebekhulu et al., 2024). These early ESCOs operated under a shared savings business model, where their revenues were tied to the measurable reduction in energy costs achieved for their customers. The strategy leveraged the willingness of stakeholders to undertake energy efficiency, even at the cost of delaying financial risks for customers (Bertoldi & Boza-Kiss, 2017).

Along with the change in the energy landscape caused by engineering and directional environmental influences, the size of ESCO operations has also changed in scale. Several ESCOs included the development of renewable energy projects in their business portfolio in the late 1990s and early 2000s. This shift marked the shift from a focus on energy conservation to a broader emphasis on sustainable energy solutions (Celikyilmaz et al., n.d.).

Furthermore, regulatory policies in various countries have begun to encourage the use of renewable energy and energy saving activities. Shields aimed at encouraging solar energy, such as feed-in tariffs, tax incentives and green certification programs, have opened the door for ESCOs to venture into the project financing and development market (FIRE, 2024). By developing access to these incentives, ESCOs have become major drivers of the clean energy boom.

The change that has occurred in the world, regarding the decentralisation of energy systems, is paradigmatic in the sense that it is a change of course in energy systems. The paradigm revolution was based on collective self-consumption, i.e. production, consumption and exchange on a localised scale covered by individuals, entrepreneurs or communities of renewable energy (FIRE, 2024). Here, in this environment, ESCOs have transformed into brokers, aggregators and managers of energy resources.

This evolution was driven by several factors. On the one hand, recent developments in digital technologies, including the spread of smart meters, EMS and blockchain-enabled energy markets, may enable the emergence of complex, spatially separated, coupled energy networks. Secondly, the integration of climate change awareness and the desire for energy autonomy has led us to use these self-consumption schemes, thus reducing dependence on primary energy producers (Girardi, 2023). ESCOs, while they may be of interest to the energy efficiency and project management sector, are best placed to profit from such innovations.

While ESCOs are effective, there are many challenges that have prevented them from evolving from collective consumption agents to the limits of their capabilities. Regulatory uncertainty, the costs of developing technologies related to renewable energy and the necessary involvement of all interested parties still represent important obstacles (Minucci, 2022). Furthermore, the evolutionary path of energy markets suggests that business models and skills must be constantly updated.

The evolution of ESCOs could also extend to a broader context with the emergence of both technologies and their concomitant political structures (FIRE, n.d.). The combination of AI, machine learning and decentralised finance in EMS promises to unlock new levels of awareness and effectiveness.

2.3.2. Strategic Role in the Implementation of RECs

ESCOs continue to be a crucial element in the growth and maintenance of RECs as key players in the collective energy system. Using their deep knowledge of energy efficiency, financial structuring and project management, ESCOs provide the basis to establish and maintain RECs. Their role involves planning from early stages through to long-term operation and maintenance and are a key part of the partnership to achieve energy transition goals.

RECs are a case study of collective self-consumption that results from architecture, involving a collective experience of community-wide energy production and consumption for residents of the local community. As an example, the Clean Energy

Package, particularly the RED II, regulated the supply of RECs and demonstrated the ability of RECs to support the achievement of climate and energy objectives (Febranzah & Krisprimandoyo, n.d.). ESCOs have now also emerged as focal actors with their role in the development and formation of communities and their governance, this is mainly due to:

- Technical expertise: ESCOs are responsible for the planning, design, construction and maintenance of renewable energy systems, which will be operated and operated at full capacity.
- Financial structuring: since renewable energy projects involve high upfront costs, ESCOs play an important role in terms of acquiring financing.
- Regulatory navigation: the legal framework for RECs is opaque and difficult to understand. ESCOs help provide advice on how to comply to achieve the creation of energy communities.
- Energy management and optimisation: using advanced EMS, ESCOs permeate the daytime consumption pattern with the intention of extracting maximum self-distribution (i.e., end-user self-consumption), while reducing dependence on a third-party based energy supplier (FIRE, 2024).

Furthermore, the emergence of ESCOs from efficiency-focused consumers to collective, self-oriented consumers have also been, at least in part, attributable to technological progress. Smart grids, the IoT and digital platforms are the brains of these systems, enabling continuous monitoring, predictive energy analytics and dynamic control of energy dispatch (Di Silvestre et al., 2018).

In addition to technology and finance, social and environmental transformation are the main drivers of ESCOs. Building RECs to enable communities to realise control of their local energy supply is a broader notion of democracy and energy inclusiveness (Llanso, 2024). This direction of decentralisation of energy supply translates into a decrease in dependence on these fossil fuels and, therefore, in a notable decrease in GHG emissions.

Moreover, the existence of ESCOs in RECs is traditionally associated with local job creation in the installation, monitoring and management of renewable energy. These beneficial socioeconomic outcomes are further deepened within the community through improved resilience and sustainability leading to a positive feedback loop of development and innovation.

The multidisciplinary team, technological innovation, stakeholder involvement and regulatory orchestration are all necessary elements for the successful launch of RECs. ESCOs are particularly good at bringing these elements together, serving as an intermediary between technological innovations and community goals. Thanks to their vast experience in renewable energy systems (parks, PV cells, wind generators, batteries, etc.), ESCOs design and implement specific actions so that the maximum amount of energy is available for the community and the highest possible rate of self-consumption.

Moreover, ESCOs have driven technological innovations by applying advanced technologies such as smart grids and IoT module-based control systems which subsequently improve the efficiency and stability of REC operation (Ameriekhtiar Abadi, 2023). This development, however, enables real-time control, fault conditioning, dynamic load control and thus achieving a cost-saving energy path compromise in networks on both sides. These innovations will enable ESCOs to operate not only as service providers, but also to function as strategic allies in the technological development of RECs.

The initial investment capital required to create a REC from scratch is one of the most important limitations in implementing RECs. ESCOs address this challenge through new financial instruments, energy performance contracts (EPCs) and joint savings contracts. These families of configurations allow communities to implement projects for free, in the same way that being an ESCO is a way to finance, build and maintain energy infrastructure.

ESCOs also offer a tool for risk reduction. Feasibility studies, including sophisticated feasibility studies that analyse all potential risks involved in project design, regulatory changes and market volatility (Heading & Zahidi, 2023). Proactively mitigating these risks through ESCOs ensures the financial stability and operational resilience of RECs. By fulfilling their deep quest in navigating difficult economic times, they can be the special, model partner when a community strives for energy independence and economic security.

ESCOs could act as a mediator in the process, through the integration of a diverse and broad range of actors (e.g. communities, companies and territorial authorities). And precisely because they can deconstruct the technical jargon, stakeholders are able to grasp and start the process of energy change.

In addition, ESCOs also have the capacity building function which can help in providing educational and training materials as a service function. These interventions provide community members with the data and capacity to competently manage energy systems and address governance, for example (Hendricks, 2022).

Despite the complexity of RECs, the regulatory framework is the cornerstone of REC development. ESCOs have much to offer, for example, in terms of extensive experience in managing programs associated with national and international regulatory frameworks, because of the European Union's RED II directive and national regulatory legality. This means that their expertise can streamline the development process and, as a result, delays and related administrative expenses can be avoided.

In addition to regulating compliance, ESCOs have also acted by establishing policies to promote the development of RECs. They are directly involved in the design and implementation of a policy framework to support the decentralisation of energy production and consumption, collaborating with policy makers and industrial partners (Trevisan et al., 2023). The dynamic function of the implementer/supporter maintains the strategic one in defining the governance of energy policy.

There is growing recognition of the need to give social equity work a central role in REC work. ESCOs are an architectural concept on benefit sharing between local communities based on solar energy (Latini, 2025). Through specific outreach and equitable project design, they, together, provide solutions to the challenges of both low-income and rural populations.

ESCOs generate financial instruments appropriate for a variety of socioeconomic environments, allowing RECs to be seen on a broader scale. In addition, they are increasingly fascinated by the design and use of energy technologies that offer efficiency in energy use in terms of energy supply and availability of energy supply, unavailability of energy at a lower cost and energy poverty that promotes social inclusion (United Nations, n.d.). Such ESCOs, by incorporating equity considerations into their approach, contribute to a pathway through which they can play a role in facilitating the development of energy systems adequate to support the energy needs of the communities in which they are located.

The effectiveness of RECs, for example, is based on continuous, long-term, continuous and/or chronic and sustainable control and improvement. ESCOs provide ongoing services in the sense of maintenance, performance monitoring and system tuning. Their ability to adapt to fluctuations in energy demand and technical advances are virtues that have enabled the resilience of RECs today and their imperviousness to the future.

Furthermore, ESCOs encourage the hybridization of new technologies, for example hydrogen storage and Vehicle-to-Grid combined with REC infrastructures (Di Silvestre et al., 2018). Through a relentless drive for innovation, they create the opportunity for communities to take advantage of the new possibilities that will emerge and ensure that momentum will come with the full force of the energy transition.

Due to the heterogeneous ownership of RECs, there is a transdisciplinary, multidisciplinary, open and interdisciplinary approach, which removes barriers in the conventional sense, i.e. ESCOs are also central to design and integration plans to enable community, industry and research to come together. By acting through the lens of knowledge dissemination and encouraging collaborative innovation and development, they drive the diffusion of effective/scalable solutions.

For example, ESCOs also often participate in planning multi-stakeholder workshops, conferences and pilot studies that seek to find solutions to common problems and how to leverage them for new and creative solutions. Together with the performance improvements of the autonomous REC, these activities also drive the entire evolution of the energy sector (Ahmed & Măgurean, 2024).

ESCOs are ideally positioned to shape policies and market forces to achieve maximum benefit from RECs. Their ongoing commitment to interacting with regulators, industry organisations and the global community gives them the ability to continue to deliver effective policies aimed at advancing decentralised energy systems.

Moreover, ESCOs alter the market environment by showing not only economic but also environmental advantages of RECs (US EPA, 2015). The success stories emerging from case studies and communications have helped build confidence in the eyes of investors, policy makers and the public.

The role of ESCOs in building RECs is multifaceted and irreplaceable. Through expertise, financial planning, stakeholder relationships and long-term support, they address the meta-level challenges of the decentralised energy system. RECs' ability to combine technological progress with socioeconomic justice and regulatory integrity will enable RECs to be sustainable, equitable and resilient businesses.

As the trajectory of the energy transition accelerates, traditional ESCO jurisdiction will still be responsible for building the infrastructure for a collective, long-term and sustainably scalable energy future. By using community approaches carefully tailored to their capabilities, companies can achieve the greatest potential energy independence benefits of RECs alongside achieving other broader environmental and social goals.

2.3.3. Relationships Between ESCOs, Businesses, Citizens, And Local Stakeholders

ESCOs have established a fundamental position in the energy transition process and act as a communication point between the economy, resident and territorial stakeholders. The power of this contribution goes beyond technical solutions and the ability to mediate on behalf of clients but can ensure that integrators respectively are able to speak fairly and equitably on behalf of competing stakeholder interests and deliver on the promise of making sustainability goals a reality (WWF, 2024). This paragraph investigates the complex interactions between ESCOs and their key collaborators by examining the interactions between trust, information flow, and common goals that drive ESCO collaborations. Therefore, ESCOs demonstrate that can also bring community energy democratization and econometric innovation.

ESCOs stand at the crossroads of technical innovation and local enrolment, as bridge builders across the expectations gap. Cost-effectiveness, statutory regulations, safety and purification of the city plan and ideas for citizens' health, improvement of quality of life and local governance are the key issues for companies, as are cost-effectiveness, urban plan and improvement of ideas.

Their ability to respond to stakeholder requests at a specific level has been of immense interest when reflecting on renewable energy applications in general. In the Italian energy landscape, ESCOs have coexisted and played a key role in reaching consensus between regional authorities and private individuals to install community-scale PV and wind power plants (FIRE, n.d.). These collaborations demonstrate the use of ESCOs as endogenous agents, to produce cooperative interactions so that, over time, they promote socially optimal individual performance for all agents.

Relationship building is the foundation on which ESCOs cultivate trust and relationships with local people. However, the public is burdened by a deep suspicion of large energy projects, based on fears of disruption or shock, “backdoor” capital, and information poverty. To respond to these problems, ESCO is also carried out in an embodied way, i.e. the citizen participates in the design process from the beginning (EPConsult Energies, n.d.). It is also implemented through consultations, seminars and public information sessions to disseminate information and to facilitate the acquisition of benefits and the development of renewable generation projects in a complex energy system.

Business organisations are the workhorse of ESCOs and remain the indispensable ones to carry out most if not all the work that industry and commerce are engaged in. ESCOs offer a tailored response to ensure the most effective use of energy, the lowest possible operating costs and the achievement of sustainability objectives (Campagnoli, n.d.). For example, energy audits, renovation and/or commissioning of renewable energy production, are of enormous value.

However, due to the ESCO/corporate experience framework, development has shifted from transactional to strategic in more recent years. These long-term cooperative partners and not occasional novelty providers are today seen as a hallmark of the new business world. These partnerships describe the mechanisms through which ESCOs can confer financial and reputational benefits not only to the companies that operate them, but also to those with whom they do business.

There may be a specific subsidiary or additional role for ESCOs beyond their ability to act as trainers, providing energy services. As for the idea of creating a decentralised/collective generation platform of energy supply systems of ESCOs, it is possible to realise local control, using local energy resources controlled by the local group, and reduce the dependence of the energy supply system on other traditional energy suppliers (OECD, 2020). This feature is of considerable interest in remote or underserved areas, where energy cost is irrelevant, and energy reliability is not a priority.

Additionally, ESCOs are leading the way in this transition by licensing projects to the grid. In Spain, for example, a solar microgrid designed by an ESCO has been put into operation in a village, where both the generation and supply of energy to the villagers can be managed. The intervention not only made it possible to obtain energy but went further by focusing on the property and community of the community.

The local authority, which represents one of the main actors within the energy transition, has its own role which must be considered not only in the sense of technical, political and regulatory role of implementing policies and regulations, but also, and much less often, at a national or international level (Hendricks, 2022). Given that ESCOs are a valuable tool for jurisdictions that go beyond simply owning and owning technology, also having the ability to define and implement energy projects, it is reasonable to consider this as the scope of the project. In this paradigm, energy efficiency and climate policies were achieved through cooperation between ESCOs and local governments (Box et al., 2022).

In this context ESCOs must consider the need for customised solutions, effective communication (is essential to create an underlying infrastructure of trust and expectation) and innovative financing models that can be truly effective.

As the pace of energy transformation is accelerating day by day, the dynamic changes of ESCOs and their involved stakeholders will be increasingly important. Developments, for example digitalisation, electrification, prosumerism and so on, will change the dynamics between the two actors. However, the difficulty of innovation is now also present in the application of new technologies (such as blockchain for electricity dispatching and AI for the management of the electricity system) to remain at the forefront and generate value for the rest of the group of artists.

Moreover, policy frameworks must evolve to support these collaborations. Policy actions are needed to support collaboration between ESCOs and stakeholders, both by offering incentives (e.g., preferential tax treatment) and administrative aid (IRENA, 2019). For example, in this process, ESCOs can subsequently gain importance and be transformed into a topic of interest for related energy and technology purposes.

Is clear that the implementation of ESCOs from energy-saving devices to devices that provide energy for collective self-consumption introduces a potentially disruptive change in the operational and tactical parameters of ESCOs. ESCOs, leveraging their expertise in energy efficiency, project financing and stakeholder management, have become increasingly important in ensuring the success of RECs and the energy revolution in general. Their ability to move along the axes around the synovium of decentralised energy systems and their focus on social and ecological goals place them at the forefront of the shift towards sustainable energy. And as the energy framework evolves, the expertise and creativity of ESCOs will play a central role in achieving both national and global climate and energy goals.

To conclude, ESCOs, citizens, local politicians and companies are at the centre of the energy transition. By being supporters, organisers and inspirers of social and political coalitions, ESCOs play a fundamental role in this transformative action which will be leveraged to push the transformation process towards achieving the desired sustainability outcomes. While still a problem, the good news is that internationally it is still possible to contribute to this change, with this opportunity to be used for innovation, economic growth and building social connections. However, in the coming years, the role of ESCOs in building solid connections between all the actors involved will be one of the key aspects in the journey towards the sustainable and equitable energy era of tomorrow.

CHAPTER III – ORGANISATION AND MANAGEMENT OF RECS: THE ROLE OF ESCOS

3.1. Organisational Design and Change Management in RECs

3.1.1. Organisational Structure of RECs: Mechanisms and Procedural Framework

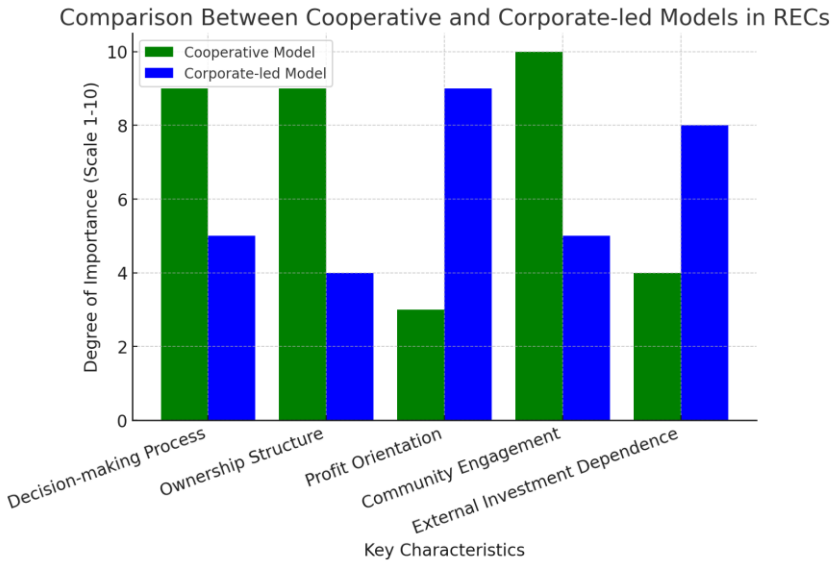
The establishment of a REC represents a structured and multi-layered process, guided by legal frameworks, governance structures, and economic sustainability models. The REC is conceptualised as a legally recognised entity that enables collective self-consumption of renewable energy while fostering socio-economic and environmental benefits for its members and the broader community (World Economic Forum, n.d.). The cooperative structure has emerged as one of the most successful frameworks regarding energy equity, active stakeholder participation and long-term sustainability. This subsection discusses the collaborative structures in place at RECs, the functions performed by REC members and some best practices for improving governance and decision-making.

From an inter-organisational perspective, RECs can be understood as complex collaborative networks that rely on the strategic coordination of multiple actors. Theories of network governance suggest that the success of such structures is highly dependent on their ability to manage interdependencies effectively (Jarillo, 1988). In particular, the concept of strategic networks highlights how RECs must cultivate stable yet flexible alliances to sustain long-term energy production and self-consumption. This theoretical approach is essential in explaining how RECs maintain operational coherence while navigating regulatory constraints and market conditions (Soda, 1999).

The cooperative model is considered the ideal form of governance for RECs because it focuses on shared ownership, democratic management by members and the fair distribution of benefits to members. Unlike traditional investor-controlled energy companies, energy cooperatives prioritise environmental and social considerations over economic outcomes, thus keeping in harmony with the ideas of sustainability and community building.

In cooperative RECs, all members, whether families, businesses, municipalities or other stakeholders, have equal voting rights regardless of their financial contributions (Bout et al., 2018). It is therefore a guarantee that decisions are not made by a few powerful investors, favouring inclusive governance of the community in the balance between the needs and concerns of all stakeholders in choosing the community's energy strategy.

GRAPH 3.1



SOURCE: OUR ELABORATION

As shown in Graph 3.1, cooperative RECs are highly democratic, with decisions made collectively by members, whereas corporate-led models have a more centralised structure. Ownership in cooperative ones is shared among the community, while corporate-led RECs are primarily investor-driven. Profit isn't a priority for cooperative RECs, which focus on community benefits, whereas corporate-led models are profit-oriented. Community engagement is much stronger in cooperative models, while corporate RECs involve the stakeholders but retain corporate control. Finally, cooperative ones rely more on self-funding, while corporate-led RECs depend heavily on external investments.

Briefly, cooperative RECs prioritise community and sustainability, while corporate-led ones focus on profit and efficiency.

The first step in the creation of a REC involves the formal constitution of an association, which, in this case, follows the provisions of Articles 36 et seq. of the Italian Civil Code (Ciana & Vacca, 2024). The REC is established as a non-profit association with a mutualistic purpose, ensuring that its primary objectives remain environmental, social, and economic rather than commercial. The statute and the internal regulation document set the legal and procedural framework under which the REC will operate, guaranteeing compliance with national and European legislation governing energy communities.

The REC is configured around a primary electricity substation, ensuring that all production and consumption points fall within the area serviced by the same infrastructure. This territorial constraint is necessary to qualify for economic incentives and tariff benefits, as specified by the TIAD and other regulatory provisions (Simari, 2024). If the REC does not own the production plants, it must enter into formal agreements with third-party energy producers, clearly establishing that the latter operate their plants in accordance with the objectives and operational guidelines defined by the REC.

RECs only work properly if there is an orderly framework where roles and responsibilities are clearly structured. While governance models may vary across RECs, certain fundamental elements ensure efficient operations and governance (ILO, 2016). Together, these roles enable RECs to function effectively, promoting sustainable energy solutions and community participation. Most RECs are governed by a multi-tiered governance structure, typically composed of a General Assembly, a Board of Directors, a President, a Secretary-Treasurer. In some cases, additional supervisory or auditing bodies may be required, depending on regulatory frameworks and internal governance needs (Ameriekhtiar Abadi, 2023).

General Assembly

The General Assembly functions as the highest decision-making body of a REC, composed of all members of the community. It serves as the primary platform for deliberation on strategic initiatives, financial planning, and policy modifications. The democratic character of the General Assembly ensures that all entities, regardless of their financial participation, have equal influence in the governance of the REC (Calado et al., 2025).

The main responsibilities of the General Assembly include:

- Approve the mission, objectives and strategic direction of the REC.
- Election of members of the board and supervisory committees.
- Review and approval of financial statements and operational reports (ensuring transparency).
- Vote on the feasibility of expanding or modifying REC energy projects.

Board of Directors

The Board of Directors manages the operational aspects and strategic decisions of the REC. Chosen by the General Assembly, the board serves as the chair, leadership team, and sets policy and agenda for community energy projects, maintains regulatory compliance, and provides financial oversight (Calado et al., 2025).

The main responsibilities of the Board of Directors include:

- Define the REC's long-term strategic vision.
- Oversee project implementation.
- Managing relationships with regulators, investors and technology providers.
- Ensure compliance with legal and environmental regulations.

The President represents the REC in legal and institutional matters, while the Secretary-Treasurer manages financial transactions and maintains organisational records.

Membership in the REC is open to a wide range of entities, including individuals, SMEs, local authorities, research institutions, religious organisations, and third-sector entities. These entities must have their electricity consumption or production points within the same territorial area covered by the REC's primary substation. Each member is required to apply for membership, which is evaluated by the Board of Directors and approved by the General Assembly (MASE, 2024). The membership status is indefinite unless terminated by withdrawal, exclusion, or non-compliance with the statutory provisions.

The role of ESCOs has become increasingly relevant in providing technical, financial, and managerial expertise. ESCOs act as facilitators, assisting with site selection, pre-dimensioning of plants, and energy production estimates through advanced software tools. Their involvement reduces risk and enhances financial feasibility for participating entities.

From an inter-organisational theory perspective, RECs can be analysed as dynamic networks where success depends on the ability to coordinate interactions between multiple stakeholders. The concept of "organisational action sets" (Aldrich & Whetten, 1981) helps explain how RECs function as temporary alliances formed to achieve shared goals. These action sets allow RECs to remain adaptable to evolving regulatory conditions while maintaining participatory decision-making structures.

To ensure the best possible effectiveness and inclusiveness, RECs must adopt sound organisational and governance principles. Some of the most effective strategies include the implementation of transparent digital platforms for real-time measurement of energy use, financial reporting and decision-making processes, as well as close collaboration with ESCOs and local public authorities to ensure technical expertise and financial assistance to implement energy projects (Trevisan et al., 2023). Evolving adaptability of the governance structure in RECs is needed to meet changing market and energy policy conditions.

The long-term sustainability of a REC depends on the implementation of a sound economic model that ensures financial sustainability while maximizing shared benefits (Buchner & Naran, 2024).

The REC must adopt a reference economic model that considers the technical parameters of renewable energy plants, including installed capacity and expected production. It should also account for investment and operational costs, covering infrastructure maintenance and administrative expenses. Additionally, expected self-consumption levels should be estimated based on members' historical consumption patterns, while incorporating tariff incentives and other economic benefits provided by the State.

This model ensures that the REC remains economically sustainable throughout the entire 20-year operational period, thanks also to cost-sharing and incentive-sharing mechanisms. Any excess revenue generated by the incentive system is reinvested in further environmental projects or social initiatives (Simari, 2024).

What emerges is that the organisational model of RECs especially those based on cooperative model has a very crucial role to play in the effectiveness of RECs. Emphasizing democratic governance, equitable benefit-sharing, and strategic leadership responsibilities, RECs establish a basis for sustainability and community empowerment over time. Good governance not only helps to improve operational efficiency but also ensures that the good effects of the renewable energy transition are shared equitably with members.

Moving forward, RECs remain in the process of perfecting their governance framework, further incorporating digital capabilities to promote transparency, foster engagement with stakeholders, and actively engage with ESCOs and municipal governments to extend their coverage.

3.1.2. Dynamics of Organisational Change: Managing Resistance and Stakeholder Engagement

The transformation towards RECs represents a fundamental shift in the traditional energy landscape. Unlike centralised energy systems, RECs operate under a decentralised model that emphasizes local energy production, shared ownership, and democratic decision-making. However, like any major organisational change, the transition to RECs faces resistance from various stakeholders, including politicians, businesses and local communities (Ma et al., 2023). Effectively managing this resistance and promoting active stakeholder engagement is critical to ensuring the successful adoption and long-term sustainability of RECs.

This section explores the barriers to organisational change in RECs, the underlying causes of resistance, and the strategic approaches needed to overcome these challenges. Furthermore, it highlights the need for structured stakeholder engagement to align different interests and facilitate a smooth transition towards community-led energy models.

Implementing RECs requires significant structural, behavioural, and regulatory adjustments, which can create resistance at multiple levels. Understanding these barriers is essential to developing targeted strategies to mitigate opposition and facilitate smoother adoption (Blazejewski et al., 2017).

Drawing on theories of organisational change, the resistance observed in the transition towards RECs can be linked to uncertainty, power dynamics, and the inertia of established institutions (Greenwood & Hinings, 1996). Network theories also emphasize the role of weak and strong ties (Granovetter, 1973) in facilitating organisational adaptation.

While strong ties within a REC help ensure stability and cohesion, weak ties, such as partnerships with municipalities or technology providers, serve as crucial conduits for innovation and regulatory adaptation. In this context, there are some obstacles that need to be overcome.

Regulatory and policy constraints

Existing energy regulations are primarily designed for centralised utilities, creating obstacles for decentralised energy models such as RECs. Lack of clear legal frameworks, slow regulatory approvals and complex permitting processes can delay project implementation (Alvarez-Alvarado et al., 2020). In some cases, traditional utilities may lobby against policies that promote energy democratization, viewing RECs as a competitive threat.

Financial and economic barriers

The financial sustainability of RECs depends on securing sufficient funding for infrastructure investments, operational costs and maintenance. Many communities have difficulty accessing adequate financing mechanisms, such as green bonds, cooperative financing models or public grants. Furthermore, uncertainty about return on investment (ROI) can discourage individuals and companies from participating in REC initiatives.

Technological challenges

Integrating advanced energy technologies, such as smart grids, IoT-based EMS, and energy storage solutions, requires technical expertise that may not be readily available within local communities. Cybersecurity and data privacy concerns further contribute to the hesitancy in adopting digitized REC systems (Adelekan et al., 2024).

Drawing from organisational change theory, resistance can be mitigated by increasing transparency, fostering early stakeholder engagement, and implementing gradual adaptation strategies. Granovetter's (1985) theory of "relational embeddedness" underscores the importance of building strong ties between stakeholders, including municipalities, energy providers, and consumers. The strength of these ties directly influences trust, collaboration, and long-term commitment to the REC model.

Additionally, the role of ESCOs as aggregators is crucial. If a community has yet to be fully established, ESCOs can facilitate its formation by identifying potential participants and aligning their energy needs. In cases where a single company hosts a PV installation but lacks sufficient energy consumption, ESCOs can establish partnerships with other enterprises to optimise shared energy distribution. This aggregation function enhances the scalability and economic viability of RECs.

Cultural and psychological resistance

Moving from passive energy consumption to active participation in an energy community requires a cultural shift. Many stakeholders may be reluctant to take on new responsibilities, preferring to remain consumers rather than co-managers of energy resources. Scepticism about the reliability, cost-effectiveness and equity of the REC model can further hinder participation (Hendricks, 2022).

Addressing these barriers requires a strategic approach that recognises the root causes of resistance, while implementing mechanisms to facilitate acceptance and adoption.

Resistance to change often stems from uncertainty, misinformation or perceived risks associated with the transition to a new energy model. To overcome this resistance, it is necessary to effectively communicate the urgency and benefits of RECs, while addressing stakeholder concerns.

Clear communication of benefits

Stakeholders are more likely to support change when they understand the direct benefits it brings (Campagnoli, n.d.). REC advocates should highlight tangible benefits such as reducing energy costs through shared resources and decentralised energy generation. They should emphasize greater energy security and independence from volatile fossil fuel markets, as well as the environmental benefits of lower carbon emissions and increased sustainability. Additionally, RECs create economic opportunities, including job creation in renewable energy infrastructure and local development.

Financial incentives and policy support

Providing financial incentives, such as subsidies, tax breaks or reduced fees for early adopters, can encourage greater stakeholder engagement. Governments and policymakers should establish regulatory frameworks that simplify legal and administrative processes for RECs, reducing bureaucratic burdens.

Community-driven transition strategies

People are more likely to embrace change when they feel they have an active role in the decision-making process. Encouraging local leadership in REC projects ensures that change is perceived as a bottom-up initiative rather than an externally imposed transformation. Conducting participatory workshops, town hall meetings and educational campaigns allows stakeholders to express concerns, gain clarity and build trust in the REC model (Laera et al., 2023).

Therefore, unlike conventional energy systems, where consumers play a passive role, RECs require active collaboration between multiple stakeholders, including municipalities, businesses, individual citizens, and providers of technology and expertise (Hendricks, 2022). Developing an inclusive engagement strategy ensures that all stakeholders feel valued and motivated to contribute to the energy transition.

Engagement strategies need to be tailored to the specific interests and concerns of different stakeholder groups. In the case of RECs, local governments and municipalities play a vital role by providing regulatory support, making key infrastructure investments, and offering policy incentives that help streamline administrative processes while also facilitating community involvement (Hendricks, 2022). At the same time, businesses and industry leaders act as technology providers, financial investors, and large-scale energy consumers, collaborating closely to integrate REC energy solutions into their broader corporate sustainability strategies.

Equally important are community members and citizen groups, who not only contribute investments and participate in the co-governance of the REC but also take the lead in outreach efforts to promote community-based renewable energy initiatives. Moreover, ESCOs and technology providers bring essential expertise in energy efficiency, smart grid integration, and maintenance services, supporting REC members with training, technology implementation, and optimisation strategies (Aggeli et al., 2022).

Methods for effective stakeholder engagement

Participatory governance models and education initiatives

Creating cooperative governance structures where all REC members have direct voting rights promotes inclusiveness and strengthens stakeholder engagement. Democratic decision-making then increases trust and reduces resistance. Additionally, providing training sessions, online courses, and information campaigns helps build trust in REC operations among non-expert participants. Stakeholders who understand the REC framework are more likely to engage actively.

Incentive-based participation

Rewarding early adopters through lower energy tariffs, attractive dividends on their investments, or other meaningful financial incentives, increases stakeholder motivation and long-term commitment. Stakeholders who clearly see direct economic benefits from their participation are significantly more likely to actively support and accelerate the energy transition (GSE, 2024).

Utilizing digital platforms for engagement

Online forums, community decision-making apps and blockchain-enabled energy trading platforms help maintain transparency and encourage active participation (Di Silvestre et al., 2018). Digital tools provide real-time access to REC governance processes, financial performance and energy distribution insights.

Trust, long-term commitment and transparency

Building and maintaining trust is essential to the long-term success of RECs. Ensuring transparency, fairness and accountability in governance and operations strengthens stakeholder trust. Publishing regular financial reports, holding open meetings and maintaining an accessible information sharing system ensure that all REC members are informed about project developments, financial performance and operational strategies.

Equity, inclusivity in benefit distribution and engagement

Ensuring that all community members, regardless of financial contribution, receive equitable benefits from the REC improves social cohesion and encourages sustained participation (Campagnoli, n.d.).

Stakeholder involvement should not be limited to the initial stages of REC formation. Ongoing dialogue, periodic assessments, and adaptive governance structures allow RECs to evolve based on changing community needs and external market conditions.

What is clear is that the transition to RECs represents a fundamental change in the way energy is generated, collective and consumed. However, such organisational change faces resistance due to regulatory, financial, technological and social barriers. Effectively managing this resistance requires a combination of clear communication, financial incentives and inclusive stakeholder engagement strategies.

By promoting collaboration between key actors – municipalities, businesses, citizens and energy service providers – RECs can build resilient, transparent and community-led energy models. Going forward, the success of RECs will depend on their ability to integrate innovative engagement strategies, ensuring that all stakeholders are aligned in achieving a decentralised and sustainable energy future.

3.2. Governance and Collaborative Management Models

3.2.1. Designing Decision-Making Processes: Participation and Transparency

The governance of RECs is rooted in participatory decision-making processes that ensure inclusiveness, transparency and accountability. Unlike in traditional energy governance, which is often centralised and hierarchical, RECs operate according to the principles of collective ownership and democratic engagement (Carel Diehl et al., n.d.). The structure of decision-making within these communities must therefore balance efficiency with fair representation, ensuring that all stakeholders, from individual members to municipal authorities and energy service providers, have a significant role in shaping policy and strategic directions.

In network-based governance models, decision-making structures must strike a balance between flexibility and control. The notion of “organisational action sets” (Aldrich & Whetten, 1981) as tools enabling individuals to learn from their own experiences and those of their peers, is useful in understanding how RECs function as evolving alliances that require continuous negotiation and realignment. This is particularly relevant in the context of energy governance, where regulatory shifts and market fluctuations demand high levels of adaptability. The design of governance structures must therefore incorporate feedback loops, real-time performance tracking, and mechanisms for iterative policy adjustments to ensure resilience and long-term sustainability (Soda, 1999).

In this context, the effectiveness of decision-making in RECs depends on three key dimensions: the institutional framework that defines governance structures, the mechanisms that facilitate participation and transparency, and the tools that support accountability (Corradetti, 2023). A well-designed decision-making process strengthens community trust, mitigates conflict and ensures that governance decisions are aligned with both regulatory requirements and the community’s energy needs.

RECs adopt different governance models depending on their legal structure, community size and energy objectives. The most common approach is the cooperative model, in which decision-making is collective among members who participate directly or through elected representatives. This model is widely considered to be the most effective in maintaining alignment between community interests and operational strategies (Trevisan et al., 2023).

At the centre of this framework is the General Assembly, which is made up of all community members who meet regularly to discuss and vote on strategic decisions, financial planning and project development. The Board of Directors or a similar governing body, is responsible for executing decisions, managing day-to-day operations and ensuring regulatory compliance. In larger RECs, specialized committees or working groups may be formed to oversee specific areas such as financial management, technology implementation or stakeholder engagement (Adu-Kankam & Camarinha-Matos, 2023).

For decision-making to be effective, it must be supported by mechanisms that facilitate active participation among REC’s members. Participation extends beyond formal voting processes; includes deliberation, consultation and ongoing engagement in governance activities (Hendricks, 2022). Different methodologies can improve participation, each tailored to the specific dynamics of a REC.

One of the most effective participation strategies is deliberative democracy, in which structured discussions and debates precede important decisions. This approach ensures that members are well informed before voting on complex issues such as energy tariffs, investment strategies or infrastructure projects.

Incentivized participation is another approach that can improve engagement, particularly in communities where participation rates are low (De Vidovich et al., 2023). RECs can implement reward-based mechanisms, such as discounted energy tariffs or priority access to new projects, to encourage members to take an active role in governance. While financial incentives should not replace intrinsic motivation, they can serve as effective tools to enhance participation.

The concept of "organisational sets" (Scott, 1985) offers a theoretical lens through which to view REC governance. Here, each participant plays a distinct yet interconnected role, requiring structured communication channels to facilitate effective collaboration. Blockchain-enabled governance mechanisms, for example, can enhance transparency by securely recording and verifying voting outcomes, energy transactions, and financial distributions.

Moreover, participatory governance aligns with Ostrom’s (1990) principles for managing common-pool resources. These principles emphasize collective rulemaking, conflict resolution mechanisms, and graduated sanctions for non-compliance, all of which can strengthen REC governance structures. By adopting such models, RECs can ensure fair and efficient resource management while minimising the risk of internal disputes.

Transparency is an essential principle in REC's decision-making process, as it fosters trust among members and ensures accountability in financial and operational management. Transparency can be achieved through a combination of procedural clarity, open data policies and regular reporting.

One of the key aspects in this framework is financial reporting (Trevisan et al., 2023). Because RECs are based on collective investments and shared revenue models, it is essential that financial statements –including income, expenses and reinvestments– are accessible to all members. Many RECs implement open budget practices, where financial decisions are collectively reviewed before approval (Laudisa, 2023).

Furthermore, the adoption of digital governance platforms has improved transparency by providing real-time access to decision documents. Online platforms allow members to track project developments, review governance decisions and participate in virtual voting. Blockchain technology is increasingly being explored as a means of ensuring clear and tamper-proof voting mechanisms within RECs (Blazejewski et al., 2017).

Periodic governance checks further strengthen transparency by ensuring compliance with both internal policies and external regulatory frameworks. Independent committees or external auditors can evaluate whether decision-making processes adhere to ethical and financial integrity standards. These audits, combined with member-led oversight mechanisms, reduce risks related to mismanagement and conflicts of interest (Heading & Zahidi, 2023).

Despite the benefits of participatory governance, RECs face challenges in ensuring effective decision-making processes. One of the main obstacles is balancing inclusiveness and efficiency. While in-depth discussions and open forums encourage participation, they can also slow down decision-making, leading to delays in project implementation.

Another challenge is managing stakeholder diversity (D'Herbemont et al., 2020). RECs often include a mix of residential users, businesses and local authorities, each with different priorities and risk tolerance. To address these differences, governance structures should incorporate mechanisms that ensure that conflicting interests are resolved through dialogue rather than unilateral decision-making.

To overcome these challenges, best practices for effective decision making include:

- Structured governance training for RECs' members, providing them with knowledge of energy policies, financial management and cooperative governance (Alvarez-Alvarado et al., 2020).
- Annual governance reviews to evaluate the effectiveness of decision-making structures and implement improvements.
- Feedback loops that allow members to express concerns and suggest policy revisions in a structured way.

In conclusion, the success of RECs depends not only on their technical and financial sustainability, but also on the strength of their governance structures. Well-designed decision-making processes ensure that participation remains meaningful, transparency is maintained, and accountability is maintained. By adopting inclusive governance frameworks, implementing clear participation mechanisms and leveraging technology for transparency, RECs can create democratic and efficient decision-making models.

As the transition to renewable energy continues to evolve, RECs must remain adaptable, refining their governance practices in response to changing regulatory landscapes and community needs. By placing participation and transparency at the heart of their decision-making processes, RECs can build resilient and empowered energy communities capable of driving sustainable transformation at both local and systemic levels.

3.2.2. Governance Models for RECs Supported by ESCOs

Governance is a key part of RECs, defining their structure, decision-making processes and long-term sustainability. The involvement of ESCOs in RECs introduces new opportunities for financial stability, technical efficiency and regulatory compliance.

However, their participation also requires a governance model that ensures community control while benefiting from ESCO expertise (Coenen et al., 2012). Developing the right governance framework is essential to balance democratic participation, operational effectiveness and financial sustainability.

In analysing inter-firm relationships within RECs, it is useful to consider the concept of 'brokerage and closure' (Burt, 2005), which explains how intermediary actors—such as ESCOs—can facilitate coordination between otherwise disconnected entities. By assuming the role of knowledge and resource integrators, ESCOs bridge gaps in expertise and regulatory compliance, thereby enhancing the strategic effectiveness of REC governance. However, to prevent conflicts of interest, it is crucial to establish clear contractual frameworks that delineate the scope of ESCO involvement, ensuring that decision-making authority remains distributed among REC members (Soda, 1999).

In traditional centralised energy systems, decision making is largely hierarchical, with utility companies or government bodies dictating policies and pricing structures. In contrast, RECs operate according to principles of decentralised governance, emphasizing inclusiveness, collective ownership and shared benefits (Boccardo, 2020). However, as RECs grow and complexity, they require professionalized management, financial expertise and technical capabilities, which ESCOs can provide.

ESCOs support RECs in multiple roles, contributing to infrastructure development, including planning, designing, constructing, and installing renewable energy systems. Additionally, they manage maintenance tasks, ensuring the ongoing reliability, safety, and performance of energy infrastructure through regular inspections, preventive maintenance, and timely upgrades.

In terms of energy optimisation, ESCOs use their specialized knowledge to maximize the efficiency of energy generation, storage, distribution, and consumption. They implement innovative solutions, such as demand-response programs, smart grids, advanced monitoring tools, and data-driven analytics, helping communities achieve both economic savings and environmental sustainability. Their involvement can take different forms depending on the governance model chosen. The main challenge is to ensure that

ESCO participation improves efficiency without compromising the democratic essence of RECs (FIRE, n.d.).

Governance structures must be designed to preserve the autonomy of the REC, maintaining democratic decision-making processes and integrating ESCOs in a way that maximizes their contribution. The governance model adopted by a REC determines how decisions are made, how responsibilities are collective, and how financial benefits are shared among stakeholders (Febranzah & Krisprimandoyo, n.d.).

Different governance models exist to integrate ESCOs into RECs while preserving the cooperative and participatory nature of the community. Each model has benefits and challenges, depending on the REC's financial structure, regulatory environment, and levels of community involvement.

Within the cooperative governance model ESCOs act exclusively as external service providers, offering technical and financial solutions while remaining contractually bound to community-driven decision-making (Celikyilmaz et al., n.d.). This ensures that key strategic decisions remain in the hands of REC members, preserving democratic legitimacy and preventing conflicts of interest.

A variant of this is the joint governance model, where ESCOs play an advisory role within the REC's board of directors or executive committees. This model allows RECs to leverage ESCOs' expertise in financial and operational management, while maintaining the fundamental principles of collective governance (Febranzah & Krisprimandoyo, n.d.). The presence of ESCOs in strategic planning discussions ensures that energy projects are optimised for efficiency and long-term sustainability.

In some cases, where a community does not have the technical expertise or financial resources to manage a REC independently, an ESCO-led governance model can be used. In this framework, the ESCO takes on a more central management role, making key operational decisions while the REC maintains oversight through a supervisory board or community representation mechanism (De Vidovich et al., 2023). This model is particularly relevant for newly established RECs that need professional support in their initial stages. However, it is critical to establish clear transition plans that ultimately return full governance to the community once the REC reaches operational maturity.

Another governance model that has gained traction is the PPPs model, in which RECs collaborate not only with ESCOs but also with local governments and municipal energy agencies. This model integrates public regulatory oversight, ensuring that REC's operations are aligned with national energy policies, while leveraging the technical expertise of ESCOs and private sector investments (Ameriekhtiar Abadi, 2023). The role of ESCOs in PPPs models typically involves infrastructure management, financial structuring and regulatory compliance, while municipalities provide policy support and subsidies (Laera et al., 2023).

A key function of ESCOs in RECs' governance is technical and operational management (FIRE, 2024). Unlike traditional energy cooperatives that rely solely on voluntary or community-led governance, RECs working with ESCOs benefit from professional energy management solutions. ESCOs manage the deployment of smart grids, optimisation of energy flows and maintenance of renewable energy infrastructure, ensuring long-term operational efficiency (GridX, 2024).

Another key role of ESCOs is financial supervision and investment facilitation. Many RECs struggle to secure initial capital investments or structure long-term revenue models. ESCOs assist by offering performance-based financing mechanisms, such as EPCs and PPAs, which allow RECs to generate cost savings without requiring large upfront investments (Celikyilmaz et al., n.d.). In practice, ESCOs assist with financial planning, which involves analysing investment options, securing funding opportunities, managing project budgets, optimising costs, and navigating financial risks. They also guide RECs through complex financial mechanisms such as energy performance contracting, subsidies, loans, or incentive programs.

From a regulatory perspective, ESCOs help RECs manage complex energy policies and market structures. Given the evolving landscape of EU energy directives and national legislation, compliance with legal frameworks represents a major challenge for many RECs (Boccardo, 2020). ESCOs act as intermediaries between RECs and regulators, ensuring that community-led energy initiatives align with broader policy objectives and take advantage of available subsidies or tax incentives.

Inter-organisational network theory highlights the strategic role of partnerships in energy governance. RECs can be viewed as hubs within a decentralised energy ecosystem, where collaboration ensures efficiency and resilience. Strategic alliances, particularly with ESCOs, provide access to specialized expertise in energy optimisation, financial structuring, and regulatory compliance.

The integration of ESCOs into RECs governance must be carefully managed to avoid undermining community autonomy. While ESCOs bring invaluable expertise, financial resources and operational efficiency, the governance structure must ensure that decision-making power remains in the hands of RECs' members.

One method of achieving this balance is through contractual clarity, defining the scope of the ESCO's commitment to legally binding agreements. Contracts should specify the roles, responsibilities and duration of ESCO involvement, ensuring that their participation does not lead to undue influence on governance decisions (Simari, 2024).

Transparency in financial transactions is also key. RECs should implement open reporting systems, where ESCOs are required to disclose financial transactions, cost structures and project performance metrics (FIRE, 2024). By maintaining financial transparency, communities can ensure that ESCO efforts remain aligned with their sustainability and social goals.

Another important factor is the flexibility of governance models. RECs should periodically reevaluate their governance structures to ensure that ESCO partnerships continue to serve the best interests of the community. Regular governance reviews and member feedback mechanisms can help adapt structures as needed, ensuring ESCOs remain aligned with RECs' objectives (Bertoni, 2023).

To summarise, the governance models adopted by RECs in collaboration with ESCOs must balance efficiency, financial sustainability and democratic control. While ESCOs provide critical expertise in energy management, financing and regulatory compliance, their involvement must be structured to ensure that community decision-making remains at the heart of REC governance.

Different governance models offer different levels of ESCO integration, from purely cooperative structures with external service agreements to more centralised management models where ESCOs take a leadership role. Regardless of the approach, transparency, participatory decision-making and contractual safeguards are essential to maintain the integrity and autonomy of RECs.

The effectiveness of collaboration between RECs and ESCOs depends on the adoption of governance frameworks that leverage ESCO expertise while ensuring that the principles of community ownership and democratic governance remain intact.

By applying inter-organisational theories, we gain deeper insights into how RECs function as networked entities where stakeholder collaboration, transparent governance, and strategic partnerships drive sustainability. The involvement of ESCOs in technical, financial, and regulatory capacities further strengthens the resilience of these communities, ensuring that they remain viable long-term solutions for decentralised energy production.

3.3. Introduction to Financial Analysis of RECs and Sustainable Finance

3.3.1. Definition and importance of ESG Financial Instruments

The financial sustainability of RECs is strongly linked to the evolving landscape of sustainable finance, particularly through the adoption of ESG financial tools. These tools have gained considerable popularity in recent years as financial markets and policymakers recognise the urgency of aligning investment strategies with sustainability goals (Buchner & Naran, 2024). ESG financial instruments serve as mechanisms to channel capital into projects that generate measurable positive environmental and social impacts, while adhering to sound governance practices.

In the context of RECs, ESG financial instruments provide essential financing to support infrastructure development, energy efficiency projects and long-term sustainability initiatives (OECD, 2023). By leveraging financial mechanisms that prioritise sustainability metrics, RECs can increase their credibility among investors, improve financial resilience and contribute to broader climate goals. Understanding the nature and importance of these financial instruments is critical to optimising their role in ensuring the long-term viability of community-led renewable energy projects.

ESG finance represents a paradigm shift in investment philosophy, moving beyond purely profit-oriented objectives to incorporate sustainability considerations. The underlying principle of ESG finance is that investments should not only generate financial returns, but also contribute to environmental sustainability, social equity and ethical governance (Liang & Renneboog, 2017). In practical terms, ESG finance increasingly influences how institutional investors, banks and governments allocate capital, making it a key factor in the transition to renewable energy.

The integration of ESG finance into RECs is in line with the fundamental pillars of sustainable finance:

- Environmental impact: direct investments towards projects that reduce GHGs emissions, promote the adoption of renewable energy and contribute to the circular economy.
- Social responsibility: ensure that financial resources support inclusive economic growth, access to energy and community development (Liang & Renneboog, 2017).
- Governance standards: implementation of transparent, ethical and responsible financial management practices that increase investor confidence and long-term stability.

Given the decentralised and cooperative nature of RECs, these three pillars serve as guiding principles for structuring financial models that are not only economically viable but also aligned with ethical investment criteria.

ESG financial instruments are investment and financing mechanisms that integrate non-financial performance factors –in particular, environmental sustainability, social responsibility and ethical governance– into capital allocation decisions. Unlike traditional financial instruments, which focus solely on profit maximization, ESG financial instruments balance financial returns with long-term positive impact on the planet and society (Banca d'Italia, 2022).

These tools are distinguished by their adherence to the three fundamental ESG pillars:

- Environmental (E): support investments in projects that reduce carbon emissions, promote clean energy, improve energy efficiency and mitigate climate risks.
- Social (S): ensuring fair labour practices, equitable access to clean energy and inclusiveness in decision-making within energy systems.
- Governance (G): emphasize transparency, ethical leadership and accountability in financial decision making, particularly in community-led initiatives (Driessen, 2021).

By integrating these three principles, ESG financial instruments improve the credibility, resilience and attractiveness of RECs, making them a priority for sustainable investors, financial institutions and public financing agencies.

Reason why ESG financial instruments are critical for RECs

Improving access to sustainable capital

Traditional funding models often perceive RECs as high-risk ventures due to their decentralised structure and reliance on community-based governance (Liang & Renneboog, 2017). ESG financial instruments counteract this bias by allowing RECs to attract funding from sustainability-minded investors who prioritise long-term environmental impact over short-term financial gains. ESG-linked investments offer capital at lower costs than conventional loans (Di Martino et al., 2024). Additionally, RECs can access dedicated ESG investment funds and sustainability-related grants. By aligning with ESG standards, they also expand their eligibility for green finance programs

Strengthening regulatory compliance and investor confidence

Financial markets are increasingly influenced by ESG reporting regulations, such as the EU Sustainable Financial Disclosure Regulation (SFDR) and the Task Force on

Climate-Related Financial Disclosures (TCFD) guidelines. By integrating ESG financial tools, RECs can:

- Comply with global sustainability regulations, reducing legal and political risks.
- Improve transparency and governance standards, attracting responsible investors.
- Leverage ESG-aligned reporting frameworks to showcase their impact, increasing funding opportunities (Panagopoulos & Tzionas, 2023).

Enhancing financial resilience and market stability

Investments guided by ESG principles are more resistant to market fluctuations, regulatory changes and environmental risks (Di Martino et al., 2024). ESG finance mitigates risks to RECs by ensuring the availability of long-term financing for renewable energy projects. It also reduces exposure to fossil fuel price volatility by prioritizing clean energy financing and aligns financing mechanisms with climate action policies, ensuring policy-backed financial support (Driessen, 2021).

It is therefore clear how ESG financial tools are transforming the financial ecosystem by incorporating sustainability into investment decision-making. For RECs, these tools provide a path to financial stability, greater investor confidence and regulatory alignment, ensuring that community-led renewable energy projects can thrive in a changing global energy landscape.

3.3.2. Green Finance and Their Role in Promoting RECs

The transition towards decentralised energy systems such as RECs requires innovative financial mechanisms that align with sustainability principles. Green finance plays a crucial role in enabling RECs to secure financing for renewable energy projects, improve financial resilience and comply with increasingly stringent climate policies (Gan et al., 2024). Unlike traditional financial models, green finance integrates ESG criteria, ensuring that investments contribute to long-term sustainability while maintaining financial sustainability (Panagopoulos & Tzionas, 2023).

The integration of green finance into the global financial system has emerged as a crucial factor in the transition to a low carbon, decentralised and sustainable energy future. Unlike traditional finance, which often neglects environmental impact, green finance specifically channels capital towards climate-positive investments, ensuring that financing supports projects that accelerate the energy transition (Gan et al., 2024).

Green finance refers to financial instruments and investment strategies explicitly designed to support environmentally beneficial projects (Banca d'Italia, 2022). In the energy sector, it facilitates the transition from fossil fuels to renewable energy by mobilizing capital for projects that prioritise emissions reduction, energy efficiency and community-led sustainability initiatives. Green finance is particularly relevant for RECs, which can overcome financial barriers, improve market competitiveness and contribute to the global shift towards decentralised clean energy models (Banca d'Italia, 2022).

At its core, green finance acts as a bridge between capital markets and sustainability goals, ensuring that investments are aligned with environmental imperatives. Within the RECs, green finance includes various financing mechanisms, in addition to those already examined there are also Climate Bonds and public subsidies (Sladaković & Tutić, 2024). These tools provide RECs with access to capital while incentivizing sustainable practices through regulatory benefits and financial incentives.

One of the key challenges faced by REC is the high upfront cost associated with renewable energy infrastructure. Unlike centralised energy utilities, which benefit from economies of scale, RECs often must secure financing through community-based investment models or specialized financing channels. Green finance offers tailor-made solutions that enable RECs to overcome these barriers, ensuring long-term financial stability and facilitating the development of decentralised energy systems (Buchner & Naran, 2024).

Green finance encompasses investment strategies, financial instruments and regulatory frameworks designed to promote environmental sustainability and climate resilience (Gan et al., 2024). It differs from ESG finance in its focus that is environmental impact, while ESG finance considers broader sustainability issues, including social and governance factors.

Key features of green finance include:

- Exclusive funding for climate-positive projects, such as renewable energy, energy efficiency and carbon reduction initiatives (Mai, 2024).
- Sustainability-aligned risk assessments, ensuring financial returns are in line with climate impact objectives.
- Incentives for businesses and communities to adopt green technologies, encouraging long-term participation in the clean energy economy (European Commission, 2024).

The role of green finance in RECs

Addressing capital constraints and investment gaps

RECs often face financial barriers, including high upfront capital costs for renewable energy infrastructure and limited access to institutional financing, as traditional banks are often hesitant to finance decentralised energy projects.

Green finance helps RECs overcome these obstacles by providing access to green bonds, climate bonds, and sustainability-linked loans (SLLs) tailored for renewable energy. It also attracts impact investors and institutional funds that prioritise clean energy projects (OECD, 2023), while unlocking PPPs that offer co-financing for energy transition initiatives.

Strengthening RECs' market competitiveness

Green finance strengthens the market position of RECs by offering long-term capital stability and reducing dependence on fluctuations in government subsidies (Nisi, 2024). It also encourages technological innovation, such as smart grids and decentralised energy storage solutions, while aligning REC financial models with international green finance regulations to improve investor confidence.

Driving policy compliance and regulatory integration

Green finance is deeply rooted in climate policy frameworks, including the EU Green Deal, which promotes investment in clean energy infrastructure, the United Nations SDGs, particularly Goal 7 (affordable and clean energy), and the Paris Agreement, which emphasizes mobilizing global finance for climate resilience (United Nations, n.d.).

By integrating green finance into their financial structures, RECs can guarantee public and private subsidies within sustainability policies, strengthen financial credibility by aligning with international climate finance standards, and improve long-term energy resilience, ensuring economic sustainability while promoting environmental impact.

Green finance goes beyond capital allocation, it directly influences the governance, operational efficiency and long-term sustainability of RECs. By securing financing through green financial instruments, RECs can expand their renewable energy infrastructure, optimise financial planning and align with evolving regulatory frameworks.

One of the most significant benefits of green finance is its ability to de-risk investments in RECs. Traditional financial institutions often perceive decentralised energy models as high risk due to their reliance on community participation and fluctuating energy market conditions (Gan et al., 2024). By integrating ESG criteria, green finance mitigates these risks by linking investment returns to sustainability performance, ensuring a more stable financial outlook.

The influence of green finance also extends to policy alignment and regulatory compliance. As governments around the world impose tougher emissions targets and renewable energy mandates, RECs must align their financial strategies with emerging regulatory frameworks (European Commission, 2024). Access to green finance allows RECs to remain competitive while benefiting from favourable policy environments that reward sustainability-focused investments.

Furthermore, green finance improves community engagement and inclusiveness, ensuring that financial decisions are aligned with local priorities. Many green finance models incorporate community-based investment platforms, allowing citizens to directly participate in REC financing (Driessen, 2021). This approach strengthens social cohesion, strengthens confidence in renewable energy initiatives and democratizes access to clean energy infrastructure.

Despite its benefits, integrating green finance into REC financial structures presents several challenges. Regulatory complexities remain a primary barrier, as green financial instruments often require strict adherence to ESG reporting standards and sustainability certification processes (IFC, 2023). Many small-scale RECs lack the financial expertise to meet these requirements, limiting their access to green financing opportunities.

Another significant limitation is market accessibility. Green bonds and SLLs are typically structured for large-scale institutional investments, making them less accessible to community-led initiatives (Safdie, 2024). To address this issue, financial institutions and policymakers must develop community-adapted financial products that meet the specific needs of RECs.

Additionally, the cost of compliance can be prohibitive for smaller RECs. Issuing green bonds, for example, requires rigorous impact assessments, third-party verifications and legal documentation, which adds financial and administrative burdens (IFC, 2023). Reducing transaction costs and streamlining reporting mechanisms would significantly improve accessibility to green finance for RECs.

To maximize the benefits of green finance, RECs must adopt strategic financial planning approaches that align with investor expectations and regulatory requirements. Several good practices can improve the effectiveness of green finance integration:

- Establish transparent governance structures to attract ESG-aligned investors.
- Develop clear sustainability impact metrics to demonstrate long-term environmental and social benefits (Gan et al., 2024).

- Partner with financial institutions specializing in sustainable finance to identify tailored financing opportunities.
- Incorporate cooperative investment models to increase community participation in financing renewable energy projects (Banca d'Italia, 2022).

What emerges is that green finance plays a pivotal role in the development of RECs, providing access to capital, mitigating financial risks and aligning energy projects with sustainability goals. Through its tools, RECs can secure stable funding sources while ensuring compliance with environmental policies.

Despite the challenges, strategic financial planning and strong governance structures can improve the integration of green finance into RECs operations. As the global transition to renewable energy accelerates, RECs that effectively leverage green finance will be better positioned to achieve long-term financial sustainability, expand their renewable energy capacity, and contribute to a more decentralised and democratic energy system.

3.3.3. Financial Instruments: Green Bonds, Climate Bonds, and Power-Purchase Agreements (PPAs)

The financial sustainability of RECs depends on innovative financing mechanisms that align with sustainability principles while ensuring long-term economic sustainability. Traditional financing models, often geared towards large-scale corporate energy projects, may not be accessible or suitable for community-led renewable energy initiatives.

In this context, green bonds, climate bonds, SLLs, impact investment funds, public grants and government incentives, as well as PPAs emerge as key financial instruments capable of providing RECs with the necessary capital, revenue stability and investment attractiveness (Circularity, 2020). These mechanisms not only facilitate the construction of renewable energy infrastructure but also contribute to the broader goal of decarbonising the energy sector in line with global climate goals.

Each of these financial instruments performs a specific function, addressing challenges related to access to capital, risk mitigation, revenue stability and investor confidence.

Green bonds are a category of fixed income securities designed to support investments in environmentally sustainable projects, including renewable energy, energy efficiency and climate resilience initiatives (Sladaković & Tutić, 2024). These bonds function similarly to traditional debt securities but are distinguished by their explicit commitment to financing green projects. Unlike traditional bonds, green bonds are subject to strict reporting requirements that ensure transparency and accountability (OECD, 2023). The International Capital Market Association (ICMA) has established the Green Bond Principles (GBP), which provide a voluntary framework to ensure transparency, impact reporting and the correct use of proceeds (ICMA, 2022).

For RECs, green bonds represent an opportunity to secure large-scale financing on relatively favourable terms. Given their growing demand among institutional investors with sustainability mandates, green bonds often attract lower interest rates than conventional bonds, making them a cost-effective financing tool for renewable energy initiatives (Circularity, 2020). The issuance of green bonds by RECs or municipal entities collaborating with RECs enables the development of solar parks, wind farms, energy storage solutions and smart grid technologies that improve energy self-sufficiency.

However, accessing the green bond market is not without its challenges. The high administrative and certification costs associated with issuing green bonds could be prohibitive for small-scale RECs. Additionally, investors often expect robust environmental impact reporting and compliance with internationally recognised sustainability standards, which require sophisticated data collection and audit capabilities. As a result, many RECs seek partnerships with local governments, development banks or larger cooperatives to facilitate bond issuance and meet reporting obligations.

A subset of green bonds, Climate Bonds are specifically designed to finance projects that contribute to climate change mitigation and adaptation. The Climate Bonds

Initiative (CBI) has developed a Climate Bond Standard (CBS) that establishes rigorous criteria for projects eligible for climate bond financing (Buchner & Naran, 2024). These standards ensure that climate bond proceeds directly support initiatives that reduce GHG emissions or improve climate resilience, such as wind farms, solar farms or microgrid installations that serve rural or disadvantaged communities.

For RECs, Climate Bonds offer an additional financing avenue, particularly for projects that contribute to national decarbonization goals or international climate commitments such as the Paris Agreement (United Nations, n.d.). Unlike general green bonds, which can finance a wide range of sustainability initiatives, Climate Bonds focus exclusively on projects with a measurable impact on reducing carbon footprints (Panagopoulos & Tzionas, 2023). This specificity makes them particularly attractive to multilateral development banks, climate-focused investment funds and sustainability-minded institutional investors.

Despite their advantages, climate bonds share some of the same challenges as green bonds, particularly in terms of certification complexity, administrative costs and investor due diligence requirements. Furthermore, access to the Climate Bond market is often limited to projects that can demonstrate significant and verifiable climate impact, making it essential for RECs to develop comprehensive impact assessment frameworks that align with investor expectations (Maino, 2022).

Another important ESG financial instrument is sustainability-linked lending, loan contracts that differ from green bonds due to their performance-based structure. Instead of limiting funds exclusively to green projects, SLLs offer financial incentives to borrowers who achieve pre-defined sustainability goals (Stephens, 2023). These goals typically include reducing carbon emissions, improving energy efficiency, or social impact goals.

SLLs are particularly beneficial to RECs as they encourage continuous performance improvement rather than simply providing start-up capital. The ability to link financial terms (such as interest rates) to sustainability performance metrics such as reducing CO_2 emissions or improving energy efficiency creates a strong incentive for RECs to adopt best practices in renewable energy generation, efficiency and governance (Hanson, 2024).

The flexibility of SLLs makes them suitable for a range of REC activities, including:

- Development of collective energy systems such as community solar and wind projects.
- Implementation of energy efficiency measures in public and residential buildings.
- Encourage stakeholder participation by linking financial benefits to community-driven sustainability outcomes.

While the SLL model represents an interesting opportunity for RECs, on the other hand it also introduces challenges, particularly in the measurement and verification of sustainability results (Stephens, 2023). Robust monitoring, reporting and verification (MRV) frameworks are essential to ensure that the sustainability parameters underlying the SLL are credible and enforceable.

Social impact investment funds have emerged as a crucial ESG financing tool, directing capital towards projects that generate both financial returns and measurable positive impacts. These funds, managed by institutional investors, venture capitalists and philanthropic organisations, are particularly suited to supporting RECs that require flexible financing structures (Garg, 2023).

Impact investment funds are private equity or venture capital funds that allocate capital to projects that demonstrate measurable social and environmental benefits alongside financial returns (Chen, 2025).

Unlike conventional investments, impact investing funds prioritise long-term sustainability over short-term profit maximization (Phillips, 2025). This makes them particularly compatible with RECs, whose financial models often emphasize community reinvestment and equitable benefit sharing.

Despite the various benefits, securing financing for social impact investments requires comprehensive impact measurement frameworks to demonstrate tangible environmental and social benefits. RECs seeking to leverage this tool must develop clear sustainability indicators and align with investor priorities related to climate action and social inclusion.

Government-backed financial mechanisms, such as grants, subsidies, and tax incentives, play a critical role in supporting RECs. Public financing is often essential to cover initial capital expenditures, particularly in communities where private investment is limited. Many governments and supranational organisations, including the EU, provide targeted funding to support community-led renewable energy initiatives.

These financial instruments are non-repayable financing mechanisms designed to support the adoption of renewable energy, energy efficiency programs and community-led sustainability initiatives (Wrenn, 2016).

PPPs further enhance funding opportunities by combining public resources with private sector expertise (European Union, n.d.). These collaborations allow RECs to leverage state-backed financing, while benefiting from the technical and operational capabilities of private financial institutions.

Unlike green bonds and climate bonds, which provide initial capital, PPAs function as long-term contracts that guarantee a stable revenue stream for renewable energy producers (Pexpark, n.d.). In a PPA, a renewable energy project developer such as a REC, agrees to sell electricity to a buyer at a predetermined price for an extended period, typically between 10 and 25 years (Drax, 2023). This contract-based model ensures revenue predictability, reducing financial risks associated with market price fluctuations and improving the overall bankability of REC projects.

PPAs are commonly used in large-scale renewable energy projects but are increasingly being adapted for community energy initiatives. There are two main types of PPAs relevant to RECs:

- Physical PPAs involve the direct delivery of electricity from the REC-operated renewable energy facility to a supplier, such as a municipality, corporate entity, or industrial consumer. These agreements are especially beneficial in locations where community energy projects can provide electricity to nearby businesses or public institutions.

- Virtual PPAs (vPPAs) function as financial contracts rather than physical electricity transactions. Under a vPPA, the REC sells the electricity generated on the wholesale market but guarantees a fixed price with a buyer. If market prices fluctuate, financial adjustments are made to ensure price stability for both parties (Pexpark, n.d.).

The main advantage of PPAs is their ability to attract investments and secure project financing. Financial institutions and investors are more likely to finance REC projects that guarantee certain long-term revenues, as this reduces perceived risks and improves the financial sustainability of the initiative. Additionally, PPAs can help RECs obtain competitive prices for electricity, providing cost stability for community members and reducing dependence on volatile energy markets.

However, structuring PPAs requires legal and financial expertise, as contractual terms must consider market fluctuations, regulatory changes and challenges related to network integration (Drax, 2023). Negotiating favourable terms can be complex, particularly for smaller RECs that may lack bargaining power compared to larger energy producers. To overcome these barriers, many RECs partner with municipalities, ESCOs or aggregators who can help structure and negotiate PPAs on their behalf.

Although they have great potential, ESG financial instruments face several challenges when applied to RECs. Regulatory complexities, high transaction costs and difficulties in measuring impact are among the main obstacles to be addressed.

One of the most significant challenges is the need for standardized impact reporting mechanisms. Investors and regulators require clear, consistent and verifiable data on the environmental and social performance of funded projects. However, many RECs operate locally with limited technical and financial resources, making compliance with rigorous ESG reporting requirements difficult (Panagopoulos & Tzionas, 2023).

Additionally, financial accessibility remains a concern. While ESG financial instruments offer attractive financing opportunities, many RECs lack the financial literacy and institutional capacity to structure investment proposals that meet investor criteria. Addressing this problem requires capacity-building initiatives, the support of institutions and local authorities, but also the participation of third parties such as ESCOs (Di Martino et al., 2024).

What emerges is that ESG financial instruments represent a pillar of sustainable finance, providing RECs with innovative pathways to access capital, while supporting environmental and social objectives. The successful implementation of these financial instruments requires careful planning, regulatory compliance and stakeholder coordination, as well as a deep understanding of the financial markets in which they operate.

As the transition to decentralised, community-driven energy models accelerate, leveraging green finance mechanisms will be essential for RECs to overcome financial barriers and promote sustainable energy innovation. By integrating these tools into their financial strategies, RECs can not only expand their renewable energy capacity, but also significantly contribute to the broader goals of climate resilience, energy sovereignty and economic sustainability.

3.4. Economic Analysis Tools for RECs

3.4.1. IRR, NPV, and PBT: Traditional Measures and Their Application to Self-Consumption Projects

The financial sustainability of RECs is one of the key determinants of their long-term sustainability and scalability. Since RECs require substantial up-front capital investment for infrastructure development, financial analysis tools play a critical role in assessing the feasibility, profitability and risk of self-consumption projects. Among the most used financial indicators in investment evaluation, net present value (NPV), internal rate of return (IRR) and payback time (PBT) provide structured methodologies for determining the economic efficiency of energy projects, ensuring rational decision-making for stakeholders, investors and community policymakers (Gallant, 2024).

These indicators offer complementary insights. NPV integrates the time value of money to evaluate long-term profitability, IRR helps compare alternative projects by identifying the rate at which an investment breaks even, and PBT determines the period required to recover the initial investment (Dai et al., 2022). In the specific context of RECs, the application of these financial measures allows interested parties to quantify the economic benefits of energy self-consumption, optimise resource allocation and attract potential investors interested in sustainable energy models.

Unlike traditional utility-driven energy models, RECs operate on community-driven financial structures that require accurate performance assessments to ensure economic sustainability. Financial analysis is essential for:

- Evaluate the profitability of self-consumption projects by comparing energy savings with initial capital investments.
- Assess the feasibility of financing options, including green bonds, climate bonds and PPAs.
- Optimise the capital structure by balancing community members' equity contributions with external funding sources.
- Minimise financial risks related to energy price fluctuations, political changes and regulatory compliance (Dai et al., 2022).

The adoption of traditional financial metrics ensures that REC projects maintain long-term financial sustainability by aligning with environmental and social impact objectives

The NPV refines investment valuation by incorporating the time value of money, recognizing that future cash flows are worth less than current capital. This principle is particularly important in REC projects, where investment returns materialize gradually over extended periods.

The NPV formula is expressed as follows:

$$NPV = \sum \frac{C_t}{(1+r)^t} - C_0$$

where:

- C_t represents the expected net cash inflow at time t.
- r is the discount rate, which reflects the cost of capital and market risks.
- C_0 is the initial capital investment.

If the NPV is positive, the investment is considered financially sustainable since it generates more value than its cost. Conversely, a negative NPV suggests that the project may not be economically justified (Fernando, 2024).

The NPV calculation accounts for discounted cash flows, ensuring an accurate assessment of long-term sustainability.

Integrating NPV into REC financial planning enables more informed investment decisions, particularly when comparing multiple power generation technologies or evaluating the impact of public subsidies and incentive programs (Gallant, 2024). Additionally, given the fluctuating nature of energy prices and market conditions, scenario analysis using NPV can help mitigate financial uncertainty.

The IRR complements the NPV by determining the discount rate at which an investment breaks even, meaning that the present value of future cash flows equals the initial investment. It is a financial metric widely used in project financing and investment evaluation, particularly when evaluating long-term infrastructure projects with fluctuating revenue streams (Fernando, n.d.).

Mathematically, IRR is the rate **r** that satisfies:

$$NPV = \sum \frac{C_t}{(1 + IRR)^t} - C_0$$

The IRR serves as an internal reference point for investment attractiveness. If the calculated IRR exceeds the project's required rate of return (often based on industry standards or the cost of capital), the investment is considered financially viable (Vipond, n.d.).

For RECs, the IRR provides valuable information on:

- The expected return on energy investments in self-consumption compared to alternative financing opportunities.
- The repayment period necessary to recover the initial capital.

- The comparative financial attractiveness of different renewable technologies, such as solar, wind or battery storage systems.

If the IRR exceeds standard financing rates (typically between 5-7% for renewable energy projects), the investment is considered profitable (Borsa Italiana, n.d.).

The PBT is a key metric in assessing the financial viability of REC investments, as it quantifies the time required to recoup the initial capital investment through accumulated energy savings and revenue streams (Kagan, 2024). Unlike NPV and IRR, which incorporate discounting and long-term profitability, PBT focuses exclusively on the capital recovery time horizon.

The PBT formula is defined as:

$$PBT = \frac{C_0}{\sum C_t}$$

where:

- C_0 is the initial investment cost.
- $\sum C_t$ represents the total annual savings or revenue from the project.

The PBT provides a straightforward assessment of how quickly an investment can recoup costs, it also helps investors and stakeholders gauge project feasibility before committing long-term capital (VanLeeuwen, 2025). A shorter payback period improves liquidity and financial resilience, particularly for community-driven projects.

TABLE 3.1

Metric	Key Purpose	Strengths	Limitations
PBT	Assesses time required to recover investment	Simple to calculate and useful for short-term planning	Does not consider post-payback cash flows or time value of money
NPV	Assesses long-term financial viability	Accounts for discounting and risk	Requires accurate forecasting and discount rate estimation
IRR	Determines investment return rate	Useful for comparing projects	Can be misleading for projects with non-uniform cash flows

SOURCE: OUR PRODUCTION

To ensure financial sustainability and scalability, RECs must integrate these financial measures into their investment decision-making frameworks (Dai et al., 2022). A comprehensive economic analysis should:

- Apply NPV to long-term investment planning, considering incentive programs and energy market fluctuations.
- Leverage IRR to secure financing, demonstrating the attractiveness of investments to institutional investors and government bodies.
- Use PBT to assess short-term financial feasibility, ensuring that self-consumption projects can generate returns within reasonable time frames.

Furthermore, a sensitivity analysis should be performed to evaluate the impact of variable factors such as electricity price volatility, maintenance costs and policy changes (Gallant, 2024). By incorporating these financial tools into their governance and operational planning, RECs can develop resilient and financially sound energy communities that contribute to decentralised energy transition goals.

To summarise, the use of NPV, IRR and PBT is essential for the financial analysis of self-consumption projects in RECs. These traditional economic metrics offer structured methodologies for evaluating profitability, financial sustainability and investment risk. While NPV integrates long-term economic feasibility, IRR allows for a comparative evaluation of investments and PBT provides insight into short-term capital recovery. Together, these tools create a robust financial assessment framework, guiding RECs in making informed investment decisions, securing sustainable financing and optimising their long-term economic resilience. By integrating rigorous financial planning into their operations, RECs can ensure their transition to renewable energy is economically feasible and environmentally sustainable.

3.4.2. Financial Simulation Models to Assess Economic Sustainability

Economic sustainability is a cornerstone of RECs, ensuring that community-led energy projects remain viable over time, attract investors and generate long-term financial and environmental benefits. The transition to decentralised energy systems requires a rigorous financial approach, given the capital-intensive nature of renewable energy facilities and the fluctuating nature of market dynamics. Financial simulation models serve as essential tools in this context, allowing RECs to evaluate different investment scenarios, assess risks and optimise decision-making processes (Nisi, 2024). These models are particularly relevant for analysing self-consumption strategies, determining the feasibility of new projects and ensuring financial resilience in an evolving regulatory landscape.

Financial simulation models provide a structured approach to quantify expected revenues, costs and investment returns, incorporating uncertainties such as fluctuating energy prices, changing political incentives and technological advances (Cunha et al., 2022). The most widely applied methodologies include Discounted Cash Flow (DCF) modelling, sensitivity analysis, and scenario-based financial modelling. Each of these methodologies serves a distinct purpose in financial planning and risk assessment, and their proper integration allows RECs to build sound financial strategies.

A fundamental method used to evaluate the feasibility of investments is the DCF model, which considers the time value of money by discounting future cash flows to their present value (Affari di Borsa, n.d.). Unlike basic payback time calculations, which only indicate the time needed to recoup an initial investment, DCF considers risk-adjusted cash flows, making it particularly suitable for capital-intensive energy projects.

The DCF model is based on the following formula:

$$DCF = \sum \frac{C_t}{(1+r)^t} - C_0$$

where:

- C_t = Expected cash inflows in year t
- r = Discount rate (representing the cost of capital or required rate of return)

- t = Time period (years)
- C_0 = Initial investment

This method is particularly useful in RECs when evaluating revenue generated from self-consumed energy, energy cost savings, excess energy sales, and financial incentives such as tax cuts or government subsidies (Barbieri, 2020).

For example, a REC investing in a solar PV system can use DCF analysis to determine whether the expected energy savings and government incentives offset the initial capital expenditure. Additionally, when multiple financing options are available (e.g., green bonds or bank loans), DCF modelling can compare various financing structures, selecting the one that optimises long-term economic sustainability.

A positive NPV, derived from the DCF model, suggests that the project is financially sustainable, while a negative NPV indicates that further adjustments, such as securing grants, renegotiating financing terms, or optimising the system design, may be needed to improve economic viability (Affari di Borsa, n.d.).

Given the dynamic nature of energy markets and policy frameworks, financial models must incorporate flexibility and adaptability. Sensitivity analysis is a technique that evaluates how changes in key financial inputs, such as electricity prices, regulatory incentives and capital costs, affect the overall profitability of a project (Breierova & Choudhari, 2001).

In a sensitivity analysis, several input parameters are adjusted to test the financial strength of an investment. For example, a REC evaluating the feasibility of a solar cooperative can test different hypotheses about electricity prices to determine how future rate reductions would affect revenue. If the financial model reveals that a 10% decline in electricity prices leads to a 50% decline in project profitability, the REC may need to explore alternative financing strategies or renegotiate supply agreements to mitigate the risk.

Sensitivity analysis also plays a crucial role in assessing the impact of policy changes (Looss & Saltelli, 2015). Many RECs benefit from government incentives, including feed-in tariffs, tax credits and subsidies, all subject to policy adjustments. By simulating scenarios where subsidies are reduced or eliminated, RECs can develop alternative revenue strategies, such as selling energy directly to businesses or participating in peer-to-peer energy trading platforms.

While individual financial models provide valuable insights, a comprehensive financial strategy requires an integrated approach that considers multiple potential future scenarios. Scenario-based financial modelling allows RECs to analyse different strategic paths, adapting key assumptions based on regulatory trends, market conditions and technological developments (Jackson, 2023).

This method involves developing multiple alternative financial scenarios, such as:

- Best-case scenario: assumes favourable market conditions, including higher electricity prices, strong policy support and low capital costs.
- Base scenario: uses conservative assumptions, maintaining current electricity tariffs and investment conditions.
- Worst-case scenario: evaluate the impact of policy reversals, interest rate increases and falling energy prices, ensuring financial resilience even in adverse conditions (McGuire, 2022).

For example, a REC planning a hybrid solar storage project can build scenarios that reflect different battery price trajectories as storage technology costs are expected to decline over the next decade. Scenario-based modelling allows RECs to align their financial strategies with long-term sustainability goals while remaining adaptable to market uncertainties (Jackson, 2023). By integrating economic, technical and regulatory factors into a single decision-making framework, RECs can optimise investment decisions and ensure financial resilience.

To conclude, the application of financial simulation models is essential to ensure the economic sustainability of RECs, as it allows a rigorous assessment of investment feasibility, risk exposure and financial performance under various market conditions. Traditional metrics such as DCF, LCOE and sensitivity analysis provide complementary insights, allowing RECs to optimise their financial strategies and ensure long-term economic stability.

By integrating these methodologies into decision-making processes, RECs can overcome financial uncertainties, attract investments and improve economic resilience, ultimately ensuring that community-led renewable energy projects effectively contribute to the global energy transition.

3.5. ESG Framework Applied to RECs

3.5.1. ESG Indicators to Evaluate Environmental, Social, and Governance Benefits

Integrating ESG indicators into RECs represents a key approach to measuring sustainability performance, ensuring transparency and attracting investments aligned with climate and social objectives (Banca d'Italia, 2022). ESG frameworks provide a structured methodology for assessing the contribution of RECs to the energy transition, community well-being and ethical governance. As decentralised energy models gain prominence, ESG indicators become essential tools for assessing their long-term sustainability, financial attractiveness and social fairness.

This section explores the critical role of ESG indicators in RECs, detailing the methodologies used to measure environmental, social and governance performance. By examining the application of these indicators, the section provides insights into how ESG frameworks can strengthen accountability, facilitate investment decisions and ensure compliance with international sustainability standards.

The need for ESG indicators within RECs stems from the growing demand for sustainable energy solutions that prioritise both environmental integrity and community participation. Unlike traditional energy projects, which often operate under centralised ownership structures, RECs emphasize collective governance, economic redistribution and social inclusion (Panagopoulos & Tzionas, 2023). The ESG framework, therefore, provides a means to quantify these contributions, ensuring that RECs meet sustainability expectations while remaining financially sustainable.

In the financial sector, ESG indicators have become increasingly relevant as investors and policy makers push for green finance mechanisms that integrate sustainability criteria. Institutional investors are prioritizing projects with strong ESG compliance, making the ability to report ESG performance a key factor in investment attractiveness (Di Martino et al., 2024). Similarly, regulatory bodies, such as the European Union's SFDR, require entities to disclose ESG-related risks and impacts, reinforcing the need for a robust ESG reporting system within RECs.

In this context, the implementation of ESG indicators allows RECs to:

- Assess their environmental impact, particularly in terms of carbon reduction and energy efficiency.
- Measure their social contribution, ensuring the achievement of energy democratization and equity objectives.
- Strengthen governance structures, promoting transparency, ethical management and participatory decision-making (Miller & Peterdy, n.d.).

Environmental impact assessment of RECs requires the use of performance indicators that quantify carbon footprint reduction, use of renewable energy and resource efficiency. The main objective of environmental measurements is to ensure that RECs contribute effectively to climate change mitigation, sustainable use of resources and conservation of biodiversity (US EPA, n.d.).

A key indicator in this category is the carbon footprint reduction metric, which evaluates the amount of CO_2 emissions avoided through renewable energy production. The calculation considers the difference between grid-supplied electricity emissions and REC-generated renewable energy, providing a quantitative assessment of the community's contribution to decarbonization (Gopal, n.d.).

Another key environmental parameter is the renewable energy penetration rate, which measures the percentage of total electricity demand met by locally produced renewable energy (Driessen, 2021). This indicator is particularly relevant for assessing the extent to which RECs achieve self-sufficiency and resilience to external fluctuations in energy prices.

The efficiency of energy storage systems also plays a crucial role in determining the sustainability of RECs. Since energy production from solar and wind sources varies with weather conditions, the ability to store and manage excess energy effectively is essential to maintaining its reliability (Ma et al., 2023). Measuring energy storage usage rates allows RECs to evaluate their ability to optimise the use of renewable energy, reducing dependence on external grid sources.

The social dimension of ESG indicators in RECs extends beyond energy production to ensure inclusiveness, affordability and equitable access to sustainable energy resources. Given that RECs are community-led initiatives, the effectiveness of their governance and operational frameworks depends on the level of engagement, participation and social impact they generate.

One of the most significant social indicators is energy cost savings for REC members, which measures the difference between conventional energy costs and the price paid by REC participants (IEA, 2025). Reducing energy costs improves the economic resilience of households and businesses, while strengthening the financial attractiveness of community-led renewable energy projects.

Similarly, the participation rate of local stakeholders serves as a key parameter to evaluate the extent to which a REC is socially inclusive and representative of community interests (Miller & Peterdy, n.d.). A high participation rate indicates that the REC is successfully involving residents, businesses and institutions in its governance and operational processes.

A further parameter of social relevance is the number of jobs created per megawatt of installed capacity, which reflects the contribution of RECs to local employment and economic development (see Graph 3.2). Renewable energy projects, particularly community-led initiatives, have the potential to generate sustainable employment opportunities, including roles in installation, maintenance and energy efficiency consultancy (IEA, 2025).

Governance indicators are essential to evaluate a REC's ability to maintain ethical leadership, financial transparency and participatory decision-making (Stiftung, n.d.). Strong governance structures are key to ensuring that RECs remain democratically controlled, financially accountable and aligned with sustainability goals.

One of the key governance indicators is financial transparency, measured by the extent to which RECs disclose financial performance, investment allocations and revenue distribution (Banca d'Italia, 2022). Transparency in financial management fosters trust between REC members and external stakeholders, strengthening the credibility of the project in the long term.

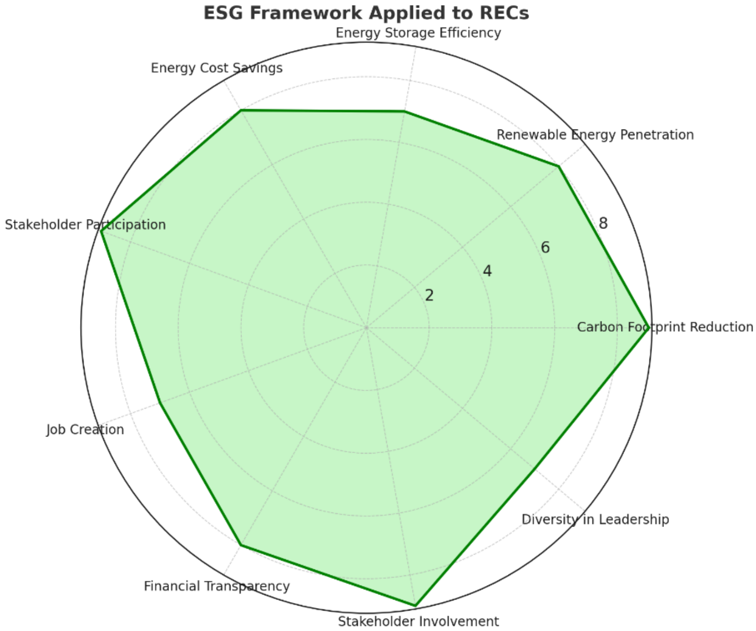
Another governance parameter is stakeholder involvement, which evaluates the frequency and effectiveness of participatory decision-making mechanisms. RECs that maintain regular member consultations, open governance structures and democratic voting processes tend to exhibit higher levels of stakeholder trust and commitment (Driessen, 2021).

An equally important governance indicator is gender and diversity representation in leadership roles, which assesses the extent to which RECs support inclusive governance structures (World Bank, n.d.). Given that gender diversity and equitable representation help improve decision-making and institutional resilience, monitoring this metric is critical to ensuring that RECs maintain socially responsible leadership models.

Integrating ESG indicators into REC performance evaluation is essential to ensure financial sustainability, social inclusion and environmental responsibility. By applying quantifiable metrics for carbon footprint reduction, energy affordability, stakeholder engagement and governance transparency, RECs can improve their long-term sustainability while attracting investment and regulatory support.

As green finance and sustainable investment frameworks continue to evolve, RECs' ability to demonstrate measurable ESG results will be instrumental in securing financing, expanding operations and contributing to global climate and social equity goals. The adoption of ESG indicators not only strengthens the credibility of RECs but also consolidates their role as key drivers of the decentralised energy transition.

GRAPH 3.2



SOURCE: OUR ELABORATION

The radar chart illustrates the ESG performance of RECs across key environmental, social, and governance indicators. High scores in carbon footprint reduction, stakeholder participation, and financial transparency highlight strong sustainability and community engagement. Moderate scores in energy storage efficiency and diversity in leadership suggest areas for improvement. Overall, the ESG framework ensures RECs align with climate goals, social inclusion, and ethical governance.

3.5.2. Impact of Adhering to ESG standards on Financing and Stakeholders

The transition to sustainable and decentralised energy systems requires not only technological innovation, but also a solid financial and governance framework capable of ensuring long-term sustainability (May et al., 2024). RECs sit at the intersection of energy transition and social innovation, requiring adherence to ESG standards to secure financial support, foster stakeholder trust and align with evolving regulatory landscapes (Bertoni, 2023). The role of ESG compliance in RECs is multifaceted and influences investment attractiveness, financing mechanisms, risk management and stakeholder relationships.

As the financial sector increasingly prioritises sustainability, adherence to ESG principles has become a prerequisite for accessing capital and ensuring economic resilience (Driessen, 2021). Investors, regulators and policymakers demand transparency and accountability in energy projects, making ESG-aligned RECs more attractive to financial markets and institutional investors. At the same time, ESG principles promote stronger community bonds and democratic governance models, strengthening the social legitimacy of RECs and ensuring their long-term success (Sladaković & Tutić, 2024).

The evolution of financial markets has seen a significant shift towards sustainable investment instruments, with green finance playing a key role in supporting energy transition initiatives. For RECs, adherence to ESG principles has a direct impact on their ability to access capital from various sources, including green bonds, SLLs, impact investing funds and public incentives (Gärttner et al., 2018). ESG compliance is not simply an ethical or strategic choice; it is an essential condition to guarantee financial support.

Financial institutions, impact investors and government financing programs prioritise projects that contribute to climate resilience, social inclusion and governance transparency (Miller & Peterdy, n.d.). In contrast, projects that do not meet ESG standards often face higher financing costs, limited investment opportunities and regulatory hurdles (Di Martino et al., 2024).

One of the key benefits of ESG compliance is its role in reducing the cost of capital. Financial institutions and investors associate ESG-aligned projects with lower risk profiles, making RECs more eligible for favourable lending terms, reduced interest rates and extended repayment periods. Issuing green bonds, for example, requires RECs to demonstrate compliance with sustainability reporting standards such as the GBP or the CBS. Meeting these criteria increases credibility in the financial sector, attracting a wider range of investors interested in sustainable energy projects (Circularity, 2020).

Furthermore, ESG-aligned RECs benefit from public and private investment funds specially designed for sustainable projects. Governments and supranational organisations, such as the EU, are increasingly channelling resources towards ESG-compliant energy initiatives, offering subsidies, tax incentives and preferential financing conditions (ICMA, 2022). The EU Regulation on Green Taxonomy and SFDR further reinforces the importance of ESG-aligned investments, guiding financial institutions in directing capital towards projects that contribute to carbon neutrality and social inclusion (European Commission, 2021).

In addition to institutional financing, adherence to ESG criteria facilitates access to community-driven investment mechanisms, such as crowdfunding platforms and cooperative financing models (Chen, 2025). Individuals and organisations with a vested interest in sustainability are more likely to support projects that demonstrate strong environmental and social commitment, ensuring RECs can diversify their funding sources and reduce dependence on traditional financial markets.

Beyond its role in attracting financial resources, adherence to ESG criteria serves as a strategic risk management tool, ensuring RECs remain resilient in a rapidly evolving energy landscape. By integrating environmental, social and governance considerations into decision-making processes, RECs can anticipate and mitigate financial, operational and reputational risks.

The environmental dimension of ESG focuses on climate-related risks, which are particularly relevant for RECs operating in the renewable energy sector. Climate variability, extreme weather events and policy changes related to carbon pricing can have a significant impact on energy production and financial performance (Climate Bonds Initiative, n.d.). ESG compliance encourages RECs to implement climate risk assessments, energy efficiency measures and adaptive infrastructure investments, reducing exposure to market volatility and regulatory uncertainty (FIRE, n.d.).

The social component of ESG is equally critical in mitigating risks at the community level. RECs are inherently participatory organisations, meaning that their success depends on the commitment and trust of their members. Transparent governance structures, fair energy pricing models and fair distribution of benefits improve social cohesion and prevent conflicts that could compromise the long-term sustainability of the community (Liang & Renneboog, 2020). Mitigating social risk also involves ensuring inclusive access to energy, prioritizing low-income families and vulnerable populations to prevent economic disparities in energy consumption (Panagopoulos & Tzionas, 2023).

The governance aspect of ESG focuses on internal organisational integrity, emphasizing transparency, accountability and ethical decision making. RECs that adhere to best governance practices are less likely to face regulatory scrutiny, financial mismanagement, or stakeholder disengagement (Hendricks, 2022). Establishing clear decision-making frameworks, democratic participation mechanisms and regular sustainability reporting ensures that REC leadership remains accountable to its members, whilst aligning with wider regulatory requirements.

One of the defining characteristics of RECs is their strong emphasis on stakeholder participation and community-led governance. Adherence to ESG criteria strengthens these foundations by promoting inclusive decision-making processes, equitable energy distribution and long-term social impact assessment (Capper et al., 2022). Unlike conventional energy models, where consumers play a passive role, ESG-aligned RECs encourage the active participation of citizens, businesses and local institutions, ensuring that all stakeholders benefit equally from the energy transition.

ESG standards provide structured methodologies for measuring social impact, ensuring that RECs contribute not only to environmental sustainability but also to economic and social resilience (Hispa, 2023). Metrics such as energy cost savings, job creation, gender diversity in governance and access to energy for vulnerable groups serve as critical benchmarks to evaluate REC success beyond financial performance (MASE, 2024). These indicators strengthen the legitimacy of RECs as models of decentralised and participatory energy governance, encouraging further stakeholder involvement and political support.

Additionally, PPPs are increasingly structured around ESG principles, facilitating collaboration between RECs, municipalities and corporate entities committed to sustainability. Local governments and businesses are more likely to partner with ESG-compliant RECs, as they align with CSR goals and municipal sustainability goals (Dawes Farquha & Deigh, 2024). This dynamic strengthens the policy environment for RECs, providing additional funding opportunities, regulatory support and operational synergies.

In an era where sustainability regulations are becoming increasingly stringent, adherence to ESG criteria is essential to ensure compliance with national and international policy frameworks. Governments and financial regulators are progressively implementing mandatory ESG reporting requirements, making transparency and accountability key prerequisites for REC operations.

Major regulatory frameworks, such as the EU Green Deal, the REDII and the CSRD, require energy cooperatives and community energy projects to demonstrate environmental and social responsibility (Barbini, 2025). Compliance with these standards increases the credibility of the REC, facilitates grant eligibility and ensures long-term political support.

Additionally, the regulatory alignment strengthens REC's positioning in emerging carbon markets and energy certification programs. ESG-aligned RECs can participate in carbon credit trading, sustainability certification schemes and climate resilience initiatives, opening new revenue streams while strengthening their commitment to the energy transition (Cisma et al., 2024).

In synthesis, the integration of ESG principles into RECs is no longer optional but a strategic necessity to ensure financial sustainability, mitigate risks and promote long-term stakeholder trust. ESG compliance improves access to sustainable financial mechanisms, reducing capital costs and improving investment attractiveness. It also serves as a risk mitigation framework, helping RECs address climate, social and governance challenges in a volatile energy landscape.

Furthermore, adherence to ESG criteria strengthens community engagement, governance transparency and policy alignment, ensuring that RECs operate as inclusive, participatory and resilient entities. As regulatory frameworks continue to evolve, RECs that proactively integrate ESG best practices will secure a competitive advantage in the renewable energy sector, strengthening their role as key players in the global energy transition.

By embracing ESG as a comprehensive framework for sustainability, RECs not only achieve financial sustainability, but also contribute to a more democratic, equitable and environmentally responsible energy future.

CHAPTER IV – CASE STUDY: OBJECTIVE AND METHODOLOGY

4.1. Objectives and Relevance of Research

The transition to renewable energy is happening on a global scale, fuelled by the need to address climate change, requiring not only technological changes, but also sophisticated predictions of the organisational and financial models that support it. RECs are an example of decentralisation and environmental resilience and have the potential to shape the future of energy (Wikipedia, 2025). Individual citizen groups, businesses and local governments are limited in jointly developing, applying and implementing renewable energy technology, so an integrated approach that into consideration both the organisational and governance aspect as well as the financial dimension is needed.

4.1.1. Interdisciplinary Study of Organisation and Finance Within the Context of RECs.

The collective nature of RECs provides the capacity for local action to regulate energy production and use. However, the organisational model of these communities is not limited to the implementation of renewable energy technologies, but also to the creation of governance structures, decision-making methods and operational methods that are in harmony with the common goals of the community (Calado et al., 2025).

Cooperation is a central feature of RECs in the sense that individuals and institutions cooperate to achieve common goals. This model is in stark contrast to conventional energy systems that are typically centralised and controlled by large utility companies. This shift to decentralised energy systems involves a paradigm shift in the production, distribution and use of energy. Descriptive evidence on how different organisational and governance frameworks can be used to shape and modify RECs can be found in the corpus of organisational theory (Soda, 1999). The fundamental actions related to RECs are those related to the methods of implementing collective action, stakeholder interaction and participatory governance. Achieving the right structure and governance is therefore of the utmost importance.

In practice, RECs need good leadership and good governance structures so that decision-making is participatory, transparent and accountable. Effective leadership in these communities is typically decentralised and involves more than one stakeholder group in designing the strategic direction of the REC (De Vidovich et al., 2023). Furthermore, the leadership must consider the variety of members' interests, including monetary gain or environmental soundness. Furthermore, the organisational climate in RECs plays a key role, as it drives the community's long-term resilience, adaptability and sustainability.

The main function of the REC mechanism lies in the involvement of ESCOs, which act as the opposite end of the technology supply chain, which increasingly plays the role of intermediary between technology providers, financial providers and the stakeholder ecosystem. ESCOs could be involved in the design and maintenance of energy consumption systems based on renewable energy, in the assessment of financial risks and in the optimal use of the energy produced (Tosi, n.d.). Therefore, the structure of RECs is strongly rooted in the financial practices that support those RECs.

When considering financial issues, RECs are not overly complex, nor can their corresponding organisational structures be. However, as exciting as the promise of locally generated, emissions-free energy may be, the financial models underlying RECs must be cautious enough to ensure long-term sustainability (Ahmed & Măgurean, 2024). The upfront costs required require access to capital and can be a significant barrier to entry for many communities, especially low-income or resource-constrained localities.

The elimination of emerging financial issues for RECs is due to the trade-off between the cost of entry capital and the costs of day-to-day management and total revenue generation (Buchner & Naran, 2024). To address this issue, various financing mechanisms have been developed, ranging from public grants and subsidies to private equity investments and community crowdfunding initiatives.

State subsidies or grants represent one of the most important bases for supporting the initial operation of the REC. In several countries, the provision of renewable energy facilities occurs through policy-driven measures (e.g. feed-in tariffs, tax credits, low-interest loans for renovated houses) (Cunha et al., 2022). However, it is hardly acceptable that public funds are used as the only means to cover the overall cost of such massive REC projects. As a result, private sector investments must also bridge the financing gap.

Equity, loans and venture capital are private capital that can be used for RECs (Wrenn, 2016). However, the economic sustainability of these models depends on the price of energy, the legal/regulatory context and the possibility that RECs become accessible to a wide community of participants. The risks are high, and investors must have a clear idea of both the possibilities of profit and loss.

This transdisciplinary perspective, which integrates the field of organisational theory with financial analysis, is essential to effectively design and implement RECs. Organisational thought leaders also provide valuable insights into governance structures, leadership styles, and community behaviour that contribute to the potential advancement of RECs. Meanwhile, the practical experience of financial entrepreneurs also has the potential to inform the knowledge that is developing around the design of tradable financial products, the fundraising process and risk control (Hayes, 2024). Further considerations on the development and administration of RECs can be envisaged, considering these opinions, which promote maximum organisational efficiency in combination with the sound financial sustainability of RECs.

Furthermore, the transdisciplinary approach in creating RECs requires the participation within multiple fields. Policy makers, energy developers, financial bodies and local/community stakeholders will all need to work together to create an environment suitable for the successful functioning of RECs (Hendricks, 2022). Working together in such a consortium requires understanding the legal, regulatory and financial context in which RECs function, but also understanding the social and environmental factors that give rise to the production of RECs.

What emerges is the need of a holistic approach to RECs. Studies that combine organisation and finance at the intersection of the REC paradigm create a challenging question of how to design a truly sustainable and economically feasible decentralised electricity system. When communities want greater control over energy production and consumption, they are challenged to take steps to bring together stakeholders, secure financing, and take advantage of technical advances. The performance of RECs will depend on the company's success in reconciling these organisational and financial constraints while managing cross-sector cooperation. Such energy systems can be designed through an interdisciplinary approach that is not only environmentally friendly but also financially sustainable and socially equitable.

4.1.2. The Strategic Role of ESCOs and Innovation in the Design and Management of RECs.

The emergence of RECs offers a window of opportunity to change the energy paradigm for its sustainability, local skills accumulation and economic resilience. These models are based on the principle of shared ownership/shared responsibility, and it is possible to leverage local communities to guide their energy destiny (Febranzah & Krisprimandoyo, n.d.). However, despite capturing the imagination of researchers and engineers, the development of RECs relies on careful and efficient management of both ESCOs and technological advances.

In this framework, ESCOs are instrumental in the design, commissioning and maintenance of energy-efficient systems and renewable energy facilities in RECs (Bertoni, 2023). These companies create unique software expertise and management capabilities and eliminate technological and financial barriers in energy projects. Their strategic role goes beyond the provision of services: ESCOs are catalysts of innovation, bringing advanced technologies to RECs to optimise energy efficiency and financial performance (Bertoldi & Boza-Kiss, 2017).

At the same time, technological and managerial innovation is not only the key to the success and reproducibility of RECs. The rapid pace of development of renewable energy technologies, digital systems and business models allows communities to function more effectively, save costs and conduct new types of collaboration (Di Silvestre et al., 2018). The convergence of these developments allows RECs to provide energy to the community in a clean and cost-effective manner.

ESCOs are particularly relevant to the establishment of RECs due to their ability to provide the technical expertise and management skills needed to address issues related to the construction and support of renewable energy infrastructure on a community scale (FIRE, 2024).

As it stands, one of the main purposes of ESCOs, when dealing with RECs, is to reduce the complexity of renewable energy projects. They manage the acquisition, configuration and operation of technologies, including solar panels, wind turbines and energy storage units, making cutting-edge technologies available to the community without the need for advanced technical knowledge or experience. This is very important as some communities initiating REC projects may not have the technical skills or experience to deal with the complexities involved in renewable energy systems (Tosi, n.d.).

ESCOs are also taking the lead in securing funding for REC projects, playing a critical role in the design and operation of the financial models underlying RECs, such as selecting the right financing, managing cash loads and maintaining the affordability of community energy production (Cebekhulu et al., 2024). In this context, ESCOs facilitate the signing of contracts, such as PPAs and other financial instruments, both of which are critical for long-term revenue streams. The ability of ESCOs to attract capital and create strong financial structures is essential for the sustainability of RECs, as many renewable energy projects have significantly high initial capital costs (Pexpark, n.d.).

In addition to their technical and economic functions, ESCOs also play a role in managing risks related to energy production. Discrepancies in renewable energy pose a major challenge to supply reliability and financial sustainability. ESCOs minimise this risk as they use future technologies for energy storage, demand response and grid management (Febranzah & Krisprimandoyo, n.d.). These advances ensure that whenever production is high, the energy produced will be stored for periods of high demand. In this way ESCOs help stabilize RECs, regulatory operational risk and community energy demand are continuously met.

Innovation is at the heart of the operation and growth of RECs. Technological progress in the production, storage and distribution of renewable energy allows RECs to be managed more effectively and at lower costs. With the introduction of innovative technologies, the performance of RECs with respect to the environment improves to the extent that RECs can be implemented such that sustainability goals can be realised at the community level and RECs can participate in even broader climate change mitigation activities (IRENA, 2019).

One of the driving forces behind the triumph of RECs is the emergence of smart grid technology, time-varying networks that enable real-time energy usage monitoring and wireless optimisation of community-associated energy resources. They provide detailed data on energy use patterns, which can be used to adjust production and consumption levels accordingly (IEA, n.d.). The ability of RECs to operate at such granular levels of energy management allows them to minimise waste, reduce expenses and use energy in the most efficient way.

A disruptive innovation is the integration of energy storage devices into RECs. Using storage devices or batteries, communities can store excess energy produced when there is high renewable energy production. This stored energy can then be used when demand is high and renewable production is low (Gomstyn & Jonker, 2024). To reduce dependence on the grid and therefore increase energy autonomy, the storage units contribute to making the use of RECs financially sustainable. Furthermore, they improve the robustness and flexibility of the system as they guarantee a constant energy supply even in the presence of intermittent renewable generation.

Furthermore, blockchain technology is also proposed as a novelty to be implemented within RECs, both in the context of its financial and operational management (Union of Concerned Scientists, 2021). Blockchain's decentralised, open and secure ledger technology makes peer-to-peer energy trading and the direct buying and selling of excess energy by local community members possible. This innovation reduces transaction costs and improves the liquidity of energy markets within the community. It also increases transparency as all transactions are recorded on the blockchain, allowing members to verify the historical record of energy transfer and verify the financial accuracy of the ledger (Hayes, 2024).

On the other hand, the management of energy credits, payments and other financial processes could be made more efficient using blockchain technology, which would lead to a further reduction in administrative expenses and increase the efficiency of work within the community (McKinsey, 2024).

Further innovations, data analytics and AI, while promising to improve the operation and management of RECs, each have some potential to improve performance. AI can plan energy distribution throughout the community so that energy resources are used efficiently and economically, it can also be applied to identify energy system inefficiencies, such as energy losses or idle resources, and suggest solutions (Yasar, 2024). Data analytics also helps predict future trends in energy production and consumption, which in turn can help inform future investment decisions and support overall REC project planning.

The integration of ESCOs and technological developments in the provision of RECs create a potentially superlative compound that translates into greater operational and financial productivity of these communities. The combination of ESCO and technological innovations makes it possible to create better, larger and more versatile RECs to improve current performance, expand the service base and meet long-term community needs (Celikyilmaz et al., n.d.).

By using advanced energy management devices, it is possible to minimise operating costs, improve energy reliability and allow RECs to better match supply with demand. Additionally, technological advancements such as blockchain and AI facilitate the proper processing of energy transactions, appeals processes, and administrative practices to be more efficient (IRENA, 2019).

Furthermore, the participatory nature of RECs is well suited to the benefits of ESCOs and emerging technologies. Participation of local citizens in the energy use system is facilitated by smart technologies, blockchain and a data-driven decision-making mechanism where they can manage energy use and jointly contribute to the success of the system (Laera et al., 2023). Through this participatory approach it is argued that there is a high sense of ownership, responsibility and therefore sustainability of the community energy system.

To summarize, the strategic role of ESCOs and technological innovation is indispensable in the design and management of RECs. ESCOs provide essential services, expertise and financing, enabling communities to address the complexities of renewable energy systems and ensuring their projects remain financially sustainable and operationally effective. Innovations in energy management, energy storage, blockchain and AI further improve the performance of RECs, in terms of greater efficiency, robustness and sustainability.

The future of RECs lies in the full integration of all these features, where ESCOs and new technologies integrate and combine to build decentralised, community-based energy systems that are environmentally and economically sustainable. As the energy transition accelerates on a global scale, lessons learned in the design and operation of RECs, in line with ESCOs and technological development, will serve as a design model for future energy systems, a guide for the path to a sustainable and resilient energy world.

4.2. Methodology and Integrated Approach

4.2.1. Qualitative Methods: Normative and Project Analysis

The rapidly evolving energy landscape, driven by the planetary need to address climate change, has led to a rethink of energy production, use and control. RECs represent a key component of this challenge, offering a decentralised and environmentally responsible alternative to traditional energy infrastructure (Ceschin et al., 2018). But technological breakthroughs and capital investments are not the only determinant of the success of RECs, this implies some form of conceptual understanding of the underlying social, political and cultural power structures and systems that generate and sustain them (Cavallaro et al., 2023). To address these complexities, qualitative methods, particularly normative analysis and project analysis, have provided a valuable contribution to evaluating and guiding the development of RECs.

Normative and design analysis are both qualitative techniques, each offering insight into the values, purposes, and assumptions surrounding the design and implementation of RECs (K. E. H. Jenkins & Martiskainen, 2018). These methods are not simply based on the analysis of the feasibility of individual projects, but also on the regulatory context in which energy policy and practice are placed. Applied to the analysis of RECs, these methods can also be used to explore the social dimensions of the energy transition, community dynamics, how communities are organised and how communities manage their energy system.

Normative analysis is a research effort to understand the values, principles, and potentially ethics of decision-making procedures in RECs (ANCI, 2024). Within this framework, the social and environmental objectives for which RECs are established and managed are examined and assumptions relating to energy production, use and supply are discussed. Normative analysis is needed to understand what communities define as sustainability, equity and justice regarding the energy transition.

One of the central questions in the normative analysis of RECs is how communities balance competing values, such as environmental sustainability, social equity, and economic viability. Specifically, most RECs are driven by a strong commitment to decarbonization, which includes, among other things, reducing GHG emissions and promoting the use of clean, renewable energy (Angelucci et al., 2020). But achieving these environmental goals may amount to compromising economic efficiency due to the high upfront investments needed in renewable energy technologies. Furthermore, communities may have problems distributing the cost of energy production equitably among all community members, particularly if some members of a community have limited access to resources or limited decision-making capacity (Bout et al., 2018).

Regulatory analysis can also shed light on RECs' policy. The implementation and management of RECs are usually limited and controlled by national and regional energy policies, legal acts and financial programmes. These rules are consistent with broader political beliefs and power relations in politics, which determine the agendas and priorities of different actors (including governments, businesses and neighbourhood groups) (Ciana & Vacca, 2024). Through comparative testing of these regulatory frameworks, we can also gain a more accurate conceptual notion of the design and impact of energy transition policy on the feasibility of RECs.

While regulatory analysis provides insights into the principles and values that influenced the design of RECs, exposure to project analysis addresses how renewable energy projects are implemented at a community scale (Joshi et al., 2016). In this methodology, the evaluation of individual REC programs is carried out based on their role as potential drivers of performance, efficiency and outcomes at the local community level, as well as at the energy system level and of renewable energy as an addition to the energy system (TimesPro, n.d.).

However, the technical, economic and organisational aspects of a REC project are initially judged in the REC process analysis. This involves evaluating the existing potential of renewable energy, including solar, wind and biomass, as well as choosing the technology for the community. It also includes estimates of the financial feasibility of the project, including identification of funding sources, cost breakdown and potential revenue (Awork, n.d.). Project analysis is a critical step toward identifying potential risks and issues (e.g., technical failures, cost overruns, and access to financing) and developing solutions to address those risks.

A key component of project analysis is stakeholder involvement. Successful RECs will require the collaboration of a wide range of different actors, including local people, municipal government, energy producers and investors. The purpose of the project analysis is to provide a description of, among other things, each stakeholder's roles and behavioural roles, decision management and conflict resolution, and information sharing (Gurnov, n.d.). It is of great importance to consider the needs and aspirations of various stakeholders to ensure the success and sustainable management of REC projects.

In addition to technical and economic considerations, the social and environmental implications of REC projects are considered in the project review. For example, the design and development of renewable energy plants can have important impacts on the terrestrial environment, land use and public health (Just Energy, 2023). The analysis of the project involves the evaluation of the following potential effects and the achievement of the first ones within the limits imposed by the required environmental and social controls. Equally, this involves evaluating whether REC projects will be beneficial, including job creation, energy security and GHG emissions mitigation, as well as ensuring that these added values are collective equitably across the community (4-Energy, 2023).

Monitoring and evaluation are one of the main parts of project evaluation. If REC projects are implemented, they must be monitored to assess how they are progressing and whether the desired objectives are being achieved. This is evident in the production of such data into critical performance indices (energy production, community benefit, profit, community satisfaction) as well as in the use of the generated data for optimisation or improvement (Aggeli et al., 2022). Monitoring and evaluation are, in turn, an opportunity to gain insights into both the lessons already learned from previous projects and the development and implementation of improved REC programs in the future.

By combining standard analysis with project analysis, an overall framework for the design and implementation of REC is established. Together with the combined results of the two approaches, it is now possible to design more useful and economically viable REC projects that can be introduced more gracefully into community assessment and perception, and at the same time consider the practical issues involved in their implementation.

Regulatory analysis, as an example of a case study, can provide decision-makers with an indication of what value or principle should guide the project, like environmental sustainability, social justice, and economic sustainability (K. E. H. Jenkins & Martiskainen, 2018). On the other hand, project analysis can provide the technical, financial and organisational backbone to translate these values into action (Awork, n.d.). When combined, these techniques can then ensure the sustainability of REC project planning and implementation that is technically and financially feasible, whilst meeting the wider social, ethical and environmental needs of the community.

Furthermore, the combination of these methods can promote stakeholder participation and involvement. By incorporating normative factors into project planning and decision-making activities, community diversity can ensure that all stakeholders are present, that their concerns are discussed with a sense of voice, and that their needs are considered (Aggeli et al., 2022). This can also be used for building trust, teamwork and to help enable greater sustainability of REC projects.

In short, quantitative and qualitative approaches like regulatory analysis and project analysis, are of fundamental value for the design, management and evaluation of RECs. By leveraging the values, principles and assumptions that guide the REC design process and addressing the challenges and opportunities presented by the implementation of renewable energy systems, these methods offer the opportunity to gain insights into the dynamics of the energy transition. Through both regulatory and design analysis, it is in fact possible to more accurately evaluate the social, political, financial and technical characteristics of RECs, and thus contribute to creating more sustainable, equitable and effective energy systems. By using these qualitative methodologies, scientists and practitioners can be better equipped to address energy transition issues to build renewable energy systems that benefit people in the local community and the outside world.

4.2.2. Quantitative Methods: Financial Analysis and Use of Databases for Simulations

As the global footprint of RECs continues to expand, the lack of a science-based quantitative method to assess the financial sustainability and sustained resilience of RECs is striking. While the quantitative analytical literature is replete with data on the organisational, social and technical dynamics of RECs, a quantitative analytical model of these community-based energy interventions is a real golden goose. Financial analysis, using large databases and simulation software, can be used to provide relevant information needed by stakeholders to make decisions regarding investment and financing models and project feasibility (Cunha et al., 2022).

Financial analysis is a valuable tool for guiding the decision of RECs. At the heart of financial analysis is the evaluation of the feasibility, solvency and long-term sustainability of the company (Tuovila, 2024). In the case of RECs, this involves deciding on the initial capital expenditure for renewable energy equipment and deciding on the possible revenue from that equipment. From a more elaborate point of view, therefore, the best approach to adopt for financial analysis considers the project maintenance costs, capital expenditure, profit/benefit ratio, ROI and contribution to the community or investor (Buchner & Naran, 2024).

By using different financial analysis methods, for example, you get a DCF analysis, an IRR, a PBT analysis and a sensitivity analysis. These methods allow, on the one hand, to estimate the risk and return of REs and, on the other, decision makers to decide whether a REC is a potentially valid investment.

Discounted cash flow analysis

DCF analysis is one of the most widely used financial modelling techniques for predicting the value of a project, based on its future cash flows discounted by the time value of money. The DCF can also be used to attempt to currently estimate the valuation of expected revenues from energy sales and/or community/donor donation flows and as in the case of RECs (Barbieri, 2020). With a discount rate (a function of investment risk), the DCF provides a direct formula for the NPV of an investment. A positive NPV indicates that the project is financially viable, while a negative NPV means that it may not be worth it (Affari di Borsa, n.d.).

Internal rate of return

The IRR is the discount rate that sets at zero the sum of the present value of the money earned (i.e. of the project) equal to the sum of the discounted cash flows. It represents the annualized rate of investment gains and losses, which is a key component of an investment. For RECs it is a good signal to generate a high IRR, since it also implies a good ROI for the community or investor (Vipond, n.d.). The difference between the IRR and the cost of capital is an indication of the financial attractiveness of a REC.

Payback time

It is the period of the project within which the original capital outlay is recovered from the net cash flow, called the backlog period. This metric is particularly useful for RECs, as it allows stakeholders to estimate the amount of time the community will need to recover from the financial challenge of renewing renewable energy technologies (VanLeeuwen, 2025). Although it may seem attractive to the investor, efforts must be made to maintain the balance between shorter payback times, sustainability (long-term stability) and social impact.

Sensitivity analysis

SA is used to study the effects of fluctuations in key inputs (energy prices, operating costs, or financing terms) on the overall financial outcome of a project. It is used to identify how unknown factors (e.g., government cash subsidies, environmental market conditions, and technology) have changed and led to changes in RECs (Looss & Saltelli, 2015). SA, although based on parameter variations, provides the user with information about the risk and scope of a REC project and prepares all stakeholders to be ready to design a basket of outcome contingencies that need to be addressed.

Financial analysis is a timely assessment of the potential success of a REC, while simulations allow for a more dynamic and holistic assessment of the nature and impact that different factors could have over time. Simulations, supported by databases, allow us to simulate a sequence of financial events and predict how the main input parameters change in a company's financial result (Tuovila, 2024). These agents can be particularly useful for complex systems, such as RECs, where there is a complex interaction of factors such as energy production, energy use, financing, legal and regulatory conditions, politics and economics.

Energy production and use are the main inputs for financial simulations that form the basis for generating robust and consistent estimates. Information from databases on production, weather, and energy consumption is an important part that is used to build models that accurately represent energy production and consumption in RECs. Based on current data analysis, stakeholders will be able to make a better prediction on the trend of energy production and consumption, which has significant practical value for revenue forecasting and identifying potential energy supply-demand imbalance issues (Ahmed & Măgurean, 2024).

Energy production from energy sources such as PV solar cells can be intermittent due to weather fluctuations. Through historical weather data (e.g. weather databases) and/or energy consumption simulations (monitoring systems), it is possible to somehow incorporate seasonal effects, weather conditions and other exogenous variables that have been shown to influence energy production (Abbas et al., 2023). This is an example of the fact that even financial forecasts can be taken seriously if you simply make some more reasonable assumptions to the financial models, thus increasing the robustness and confidence of the financial models.

Financial models also use databases of capital costs, financing and risk factors. These databases may contain data, such as the cost of renewable applications, applications containing costs, loan provisions, interest and/or grants or subsidies. Including such data in financial models allows the entities involved to compare different options for raising capital (financing option), calculate and estimate the financial risk associated with particular investment structures, and so on (European Union, n.d.). Simulations can be used to evaluate the effect of a variety of financings (e.g., equity financing, debt financing, community-based crowdfunding) on the financial consequences of the REC.

Financial modelling and quantitative analysis not only allow to understand the financial risk and opportunities at play, but they also help to design a roadmap towards REC data viability. By modelling a series of financial scenarios, stakeholders can then assess risk related to energy price fluctuations, regulatory innovation and technology

(Stephens, 2023). Furthermore, simulation can also identify potential solutions to improve the financial performance of a REC, for example, to improve consumption patterns, to reduce operating costs or to secure lending rates.

Specifically, in the context of REC valuation, risk assessment is of great importance for the financial management of RECs. As decentralised electricity grids, RECs are subject to various threats that can have adverse effects on the economic sustainability of RECs, including market volatility and political changes. Quantifying and accounting for these risks in the simulation allows stakeholders to gain a more detailed understanding of the risks associated with a REC and make informed decisions about how to avoid further net losses (Laera et al., 2023). This could involve reworking the business model, seeking other revenue streams or repositioning the energy generation portfolio, to reduce dependence on the dominant technology.

Quantitative methods based on financial parameters and databases for modelling RECs are also important to discover and manage the heterogeneity that characterizes RECs. Financial analysis tools, including DCF, IRR and sensitivity analysis, provide insights into the feasibility of financing REC projects and simulations, when supported on a robust database, enable dynamic modelling of various financial scenarios (United Nations, n.d.). These tools allow stakeholders to evaluate the risk, benefits, long-term risk and feasibility of RECs and enable investment decisions and improvements to renewable energy systems deployed in communities. Following developments in renewable energy transitions, quantitative methods will become increasingly relevant to ensure the financial and operational soundness of RECs, and therefore an important part of the future of a sustainable and decentralised energy system.

4.2.3. Laddering Method: Interviews to Pilot Project's Participants

The laddering method is a qualitative research technique that allows researchers to delve into participants' motivations, values, and deepest decision-making processes. In the context of RECs and the role of ESCOs, this method is particularly useful for understanding the drivers, barriers, and expectations of individuals and organisations involved in pilot projects (NewtonX, 2023). Given the interdisciplinary nature of this research, which combines organisational theory, financial analysis, and sustainability principles, the laddering method provides structured insights into stakeholder perspectives.

Through in-depth semi-structured interviews, this approach allows the researcher to explore how participants perceive the REC model, the financial sustainability of community-based renewable energy systems, and the role of ESCOs in facilitating the energy transition (The Marketing Theorist, 2019). By uncovering both functional and psychological factors that influence stakeholder decisions, the laddering method improves the depth of qualitative analysis, ensuring a more complete understanding of the complexities inherent in the transition to decentralised energy models (Cullen & Kaciak, 2009).

Before applying the laddering method in-depth, preliminary interviews were conducted to gather a general understanding of stakeholder experiences, perceptions, and concerns regarding RECs and ESCO involvement. These initial discussions provided a broad framework to identify key themes for further exploration through the laddering method. The preliminary interviews followed a three-level questioning approach, characteristic of laddering techniques but focused more on establishing foundational insights rather than uncovering deep psychological motivations.

- What specific financial or organisational benefits do you associate with RECs?
- What role do ESCOs play in your experience with this project?
- How does ESCO involvement impact the operational efficiency and sustainability of the REC?
- What obstacles or challenges have you encountered in implementing the REC model?
- What broader goals or values influenced your decision to engage in this project?

- How do you believe RECs contribute to the energy transition and local economic development?

These initial interviews provided essential background knowledge on how participants viewed RECs and ESCOs. However, while they captured key themes, they did not yet provide a structured, hierarchical understanding of motivations and decision-making processes. This necessitated the use of the laddering method in a more structured manner.

Following the preliminary phase, the laddering method was applied in a structured manner to systematically analyse the deeper motivations behind stakeholder decisions. The laddering technique originates from means-end theory, a psychological approach used in consumer behaviour research to identify cognitive structures that link specific attributes to higher-level goals or values (Cullen et al., 2010). The technique consists of a series of structured but flexible questions designed to explore how respondents' choices are influenced by their deepest beliefs and priorities (Reynolds & Gutman, 1988).

In this phase, participants were asked progressively layered questions, moving from functional attributes to personal values. This method ensured that responses revealed not only what stakeholders valued but also why those values were significant to them (Bagozzi et al., 2006). The structured laddering interview approach followed this format:

- What motivated you to participate in or support this REC initiative?
- Regarding the motivations that led you to participate in the REC, how important do you consider each of them? Could you rank them from the most relevant to the least relevant?
- Why do you consider each of these motivations important? And for what reason is this relevant to you?

To ensure data consistency and a structured understanding, interview responses were categorized based on recurring themes. The responses were mapped onto a hierarchical structure, illustrating the logical connections between initial motivations and broader values. These findings, presented in Appendix A, illustrate the interconnected nature of financial, environmental, and strategic motivations in stakeholder decision-making. Importantly, the laddering method confirmed that while financial incentives remain a primary motivator, deeper values such as sustainability commitment and community impact play a crucial role in long-term engagement with RECs.

By progressively moving from specific attributes to deeper values, this method reveals the underlying motivations, concerns, and aspirations of stakeholders, offering valuable insights for REC design and financial sustainability. The structured laddering analysis thus complements the preliminary interviews, ensuring a comprehensive understanding of both surface-level considerations and fundamental decision-making drivers.

In summary, the integration of the laddering method into the research process provided a structured approach to understanding stakeholder motivations, a hierarchical mapping of decision-making rationales, clear differentiation between economic, environmental, and strategic drivers, and actionable insights for improving REC engagement and governance. By using the laddering method in conjunction with preliminary interviews, this research ensures that both immediate concerns and long-term values are captured, providing a robust qualitative framework for assessing REC stakeholder engagement (see Fig. 4.1).

FIG. 4.1

We would like you to express your reason for participating in the Motogiro event. For the questions below, please follow this sequence: 1. List five reasons for wanting to participate in the Motogiro and place these in the boxes in the first column. 2. Take your first reason and think of why it is important to you. Place your answer in the box adjacent to your first reason in the second column. 3. After answering why your first reason is important, think about why the answer given is, in turn, important, and put your response in the box in the third column. 4. Repeat steps 2 and 3 for each remaining reason in the first column. We have placed numbers in the left corners of each box to remind you of the sequence to follow.		
Reasons	**Why - 1?**	**Why - 2**
For Participating In The Event	**Why Is It Important for You**	**Why Is It Important for You?**
1. I have the opportunity to see old friends.	6. It makes me feel like I am part of a larger group.	7. We can share emotions, stories, dreams….
2. It's the main passion I have!	8. I can embrace freedom by riding my bike.	9. It helps me feel really alive.
3. My motorcycle is like a woman. I love it!	10. Passion, passion, passion!!	11. The joy I feel is indescribable.
4. I have so many friends here with whom I feel good.	12. It is important for everyone to have time for relaxation.	13. It makes people happier and more open to others.
5. I have the opportunity to visit many places in Italy.	14. It has beautiful streets andviews. You know Italy.	15. My country doesn't have all the resources you have here.

SOURCE: MARKET RESEARCH METHODOLOGIES: MULTI-METHOD AND QUALITATIVE APPROACHES

4.3. Introduction to the Case Study

4.3.1. Description of the Pilot Project and Operational Context

The REC Caserta pilot project represents one of the first REC development initiatives in Italy, in line with national and EU strategies to promote self-consumption, decentralised energy production and industrial sustainability. Developed by AESI, the ESCO of AXPO Italia, the project is based in Caserta, Campania, and is conceived as a scalable model of energy sharing that initially involves a limited number of participants with the ambition of expanding over time. This pilot initiative aims to create a replicable model that balances economic feasibility, regulatory compliance and corporate environmental responsibility, demonstrating the feasibility of self-sufficient industrial energy ecosystems within the Italian energy market.

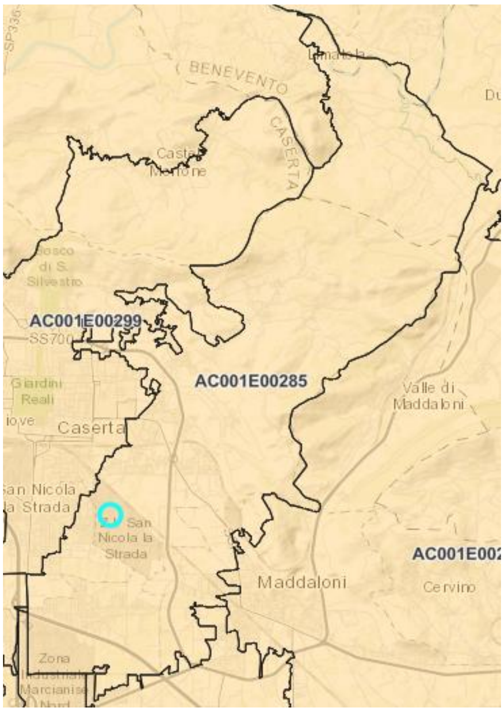
The Caserta Project is conceived as an energy sharing system for self-consumption for industrial participants, addressing key priorities in terms of energy efficiency, decarbonisation and cost optimisation. The project's infrastructure is built around a solar PV system with a total installed capacity of 100 kW, expandable up to 1 MW, ensuring a stable supply of clean electricity to its participants. The plant is expected to generate 116,797 kWh/year, significantly offsetting the energy demand of the companies involved and allowing excess energy to be fed into the grid (70,635 kWh/year).

From a financial point of view, the initial investment of approximately 70,000 euros is privately financed by AESI, with the aim of integrating public incentives and green finance mechanisms to improve its long-term sustainability. The financing model reflects a hybrid approach, where private capital is complemented by government incentives, ensuring the project remains viable while leveraging regulatory support for RECs.

The main objectives of the project include:

- Maximize self-consumption efficiency, reduce dependence on the electricity grid and improve economic sustainability for participants.
- Improve energy independence, enabling industrial entities to ensure a stable, clean and cost-effective power supply.
- Establish a scalable and replicable model, demonstrating the feasibility of industrial RECs.
- Reduce carbon emissions, supporting decarbonisation policies at national and community level.

FIG. 4.2



SOURCE: GSE

The REC's governance structure reflects a public-private model, with AESI playing a central role in the execution, regulation and management of the project. Key stakeholders are:

- The main participant, the first company to join and promote the project.
- AESI, which acts as both an ESCO and a regulatory entity, overseeing compliance, financial structuring and technical operations.
- The other industrial companies, currently participating as self-consumers, benefiting from optimised energy costs and sustainability benefits.

Currently, AESI assumes full management of the REC, with a governance structure that is expected to evolve as participation expands. Future iterations of the project are likely to introduce formalised decision-making processes, ensuring transparency and stakeholder involvement through a structured participation framework.

The project operates according to a grid-connected model, allowing excess energy to be reinjected into the national grid, contributing to financial returns and the overall efficiency of the system. While the integration of battery storage has yet to be confirmed, its potential incorporation could increase self-consumption rates and mitigate dependence on grid energy. Furthermore, discussions are underway on the implementation of smart grid technologies and IoT-based monitoring systems, which would enable real-time energy monitoring, demand management and predictive consumption modelling.

From an operational point of view, the infrastructure is structured to maximize energy self-sufficiency through on-site renewable generation, reduce dependence on external energy suppliers, leading to financial stability of participants, provide flexibility in scaling capacity, allowing for future participant inclusion, and potentially integrate smart grid solutions, optimising energy efficiency and distribution.

Financial sustainability is based on a multi-tiered financing model that incorporates private capital from the outset, with plans to leverage government incentives and sustainability-related financial instruments in the future. The primary financial strategy revolves around maximizing cost savings by reducing dependence on conventional energy suppliers, while also taking advantage of public incentives to subsidize infrastructure costs and operating expenses. Furthermore, there is a clear emphasis on exploring alternative financing mechanisms to ensure the long-term scalability of the initiative. Economic benefits for participating companies include not only reduced energy costs but also greater price stability and enhanced energy security, all of which align closely with broader corporate sustainability goals.

The project currently serves four companies, with the ambition of expanding its participant base as the model proves viable. Although it is an industry-focused initiative, it is expected to yield significant environmental benefits, including an estimated annual CO_2 reduction of 26 tonnes. In broader socioeconomic terms, the project is designed to encourage the adoption of renewable energy in industrial applications, thereby reducing dependence on fossil fuels and improving the economic resilience of participating businesses through more stable energy costs. Additionally, it is poised to serve as a model for similar RECs by demonstrating both scalability and financial sustainability. While energy equity for low-income participants is not its primary objective, the project indirectly advances climate action and corporate responsibility initiatives by positioning itself as a sustainable energy alternative for industrial operations.

The REC Caserta is structured in compliance with the Italian REC legislation, guaranteeing compliance with both national and community directives. The project is in line with:

- The EU RED II, supporting decentralised energy production.
- National incentives for energy communities, maximizing available regulatory benefits.
- Future policy frameworks, ensuring long-term alignment with evolving energy laws.

As the project evolves, regulatory adjustments may be necessary to streamline administrative procedures and optimise incentive structures, ensuring that the REC remains fully compliant and financially sustainable.

In conclusion, this is a clear example of an industrial REC, integrating technical innovation, financial sustainability and strategic regulatory alignment. By optimising self-consumption, reducing dependence on external energy suppliers and leveraging a scalable infrastructure, the project sets a benchmark for future REC developments. Moving forward, expanding participation, incorporating additional financial mechanisms and refining governance structures will be crucial to long-term success.

4.3.2. Data Collection and Use of Financial Simulation Methods and Technical Evaluation

A rigorous evaluation of the Caserta pilot project requires a structured approach to data collection, financial simulations and technical evaluation. The project evaluation incorporates key operational parameters, including PV system efficiency, self-consumption rates, financial sustainability indicators and revenue forecasts. The goal is to ensure long-term sustainability by evaluating investment returns, cost efficiency and energy optimisation strategies.

This section explains where and how data is collected, how financial simulation models are applied, and the technical evaluation methods used to evaluate the energy performance and economic feasibility of the REC. Given the nature of energy markets and the variability of self-consumption, the study uses sensitivity analysis and scenario-based models to test the robustness of financial assumptions under different conditions.

The effectiveness of financial and technical assessment depends on the availability and accuracy of real-time monitoring data, historical financial records and policy information. The data collection methodology follows a structured approach to ensure accuracy, replicability and comparability (Tuovila, 2024).

To conduct an adequate evaluation, the widest possible variety of data should be collected.

Energy production and consumption data

Energy performance is evaluated through smart meters and monitoring platforms, which provide real-time monitoring of electricity production, self-consumption and feeding into the grid. Additional data sources enable projection of expected PV production, as well as historical consumption data used to analyse participants' demand patterns and identify peak load behaviours. This data is crucial to understand how much energy is used directly within the REC and how much is resold to the grid, forming the basis for financial simulations.

Financial and economic data

Economic feasibility is assessed using operational and investment cost breakdowns, revenue generation from energy cost savings and potential incentives for on-network sales, and electricity market price trends, which consider changes in energy tariffs and market exposure. Additionally, government incentives and regulatory benefits are analysed to assess their long-term impact on financial sustainability. These economic parameters form the inputs for financial scenario modelling and sensitivity analysis, helping to predict how different market conditions affect financial returns.

Regulatory and policy data

To ensure compliance and assess financial risks related to political changes, the project integrates EU and Italian REC regulations, defining eligibility for incentives and operational constraints. Baseline data from other REC initiatives is also analysed to ensure performance is evaluated against industry standards, while future policy projections are examined to assess potential changes in subsidies, taxation and carbon pricing. These inputs help shape realistic financial projections and risk mitigation strategies.

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Sensitivity analysis to measure financial resilience

Since financial projections depend on assumptions about energy prices, self-consumption rates and investment costs, sensitivity analysis is used to examine how changes in these factors impact key financial parameters such as IRR and NPV. In the sensitivity analysis the following variables are tested: fluctuations in the price of electricity, evaluating how changes in electricity grid tariffs affect project returns; changes in the self-consumption ratio, verification of financial feasibility at different levels of energy autonomy; investment cost overruns, which measures the impact of higher-than-expected OPEX on financial returns; and changes in public incentives, assessing dependency on public subsidies and their effect on profitability.

By adjusting each of these parameters, the analysis identifies financial break-even points and critical risk factors, ensuring the project remains sustainable under various economic conditions (European Commission, 2014).

Scenario-based modelling to assess strategic alternatives

Unlike sensitivity analysis, which isolates variables, scenario-based modelling creates comprehensive financial projections based on several strategic assumptions.

The baseline scenario assumes stable self-consumption ratios, moderate inflation in electricity prices and the maintenance of public incentives. Optimistic scenario models have increased self-consumption efficiency through better demand management, favourable government incentives, and lower operating costs through efficiency improvements. The pessimistic scenario considers the decline in self-consumption, potential reductions in public incentives and higher OPEX due to unexpected adjustments in investments.

By analysing project performance under these different conditions, the financial model provides a risk-adjusted assessment, helping stakeholders make informed operational and investment decisions.

Energy self-consumption and grid integration

A critical factor in determining the economic performance of the REC is the percentage of energy generated that is used directly compared to that fed into the grid. The self-consumption index is calculated using real-time energy monitoring data, measuring the percentage of electricity produced consumed internally. The self-consumption ratio is calculated as follows:

$$Self - Consumption\ ratio = \frac{Energy\ used\ within\ the\ REC}{Total\ energy\ generated} \times 100$$

For the REC of Caserta this value is equal to 39.5%, which means that almost 40% of the energy generated is consumed within the community, while 60% is fed into the grid.

A higher self-consumption ratio leads to greater cost savings for participants, less exposure to electricity market price fluctuations and greater overall financial stability.

Long-term panel performance and efficiency loss

Due to the natural degradation of solar panels, a 0.55% annual decline in energy production is factored into financial projections. This reduction affects long-term economic calculations and requires accurate forecasting to maintain financial stability.

By integrating scenario-based financial models and sensitivity analyses, the assessment provides a comprehensive perspective on the long-term sustainability of the project, also analysing the impact of the expansion on financial and operational efficiency (Awork, n.d.).

The data collection methodology and financial simulation techniques described in this section ensure that the Caserta project is rigorously evaluated in terms of economic and technical sustainability. Using real-time monitoring, structured financial modelling and energy performance assessments, project risk factors, investment feasibility and operational efficiency are systematically analysed. Through these methods REC Caserta positions itself as a scalable and financially resilient model, strengthening its role in the energy transition underway in Italy.

4.4. Data Structuring and Sources

4.4.1. Requirements for Building the Database

The construction of a robust database is a fundamental step in the empirical analysis of the Caserta pilot project, as it ensures accurate data collection, structured organisation and reliable computational simulations. The database must integrate technical, economic and regulatory data to allow a comprehensive assessment of the energy and financial performance of the REC. Given the complexity of distributed energy systems, data architecture must be designed to support multiple analytical perspectives, including energy production, self-consumption rates, financial sustainability and policy impact (Ruano & Ruano, 2024).

A well-structured database serves multiple purposes, including facilitating energy and financial simulations, supporting decision-making processes, ensuring compliance with national and European regulations, and providing a basis for scalability analysis. This section outlines the key requirements for structuring the database, ensuring consistency with the methodological framework already established in the previous chapters.

Core requirements for database structuring

Data categorization and segmentation

The database must be structured to accommodate a diverse set of data points, ensuring that each category aligns with the objectives of the study. In this context, primary segmentation covers several key areas (Tuovila, 2024). First, technical data is gathered to capture information on PV capacity, solar irradiation levels, system efficiency, degradation rates, and the integration with smart grid technologies.

Alongside this, energy production and consumption data are monitored in real time, tracking electricity production, self-consumption ratios, and both feed-in and demand-side patterns across the participating entities. Economic and financial data is also essential; it encompasses investment costs, OPEX, CAPEX, incentive structures, financing mechanisms, and the expected ROI.

Moreover, the database includes regulatory and policy data that integrates legal compliance frameworks, national incentives, and EU-level directives, such as RED II, as well as evolving market regulations that influence REC business models. In addition, stakeholder and governance data is collected, detailing ownership models, decision-making frameworks, revenue-sharing agreements, and contractual obligations between participants and the ESCO. This structured approach ensures that all data is categorized efficiently, reducing redundancy and enhancing analytical precision.

Data standardization and consistency

For accurate simulations and comparative analyses, it is crucial that data inputs are standardized across different categories. This means ensuring unit consistency, so that all energy values are expressed in kWh or MWh, financial figures in €, and time data follows a consistent framework—whether monthly or annual.

Additionally, normalization techniques play a vital role by adjusting the data to account for seasonal fluctuations, inflationary impacts on financial models, and by standardizing costs across various REC projects for effective benchmarking. Equally important are robust data cleaning protocols, which identify and eliminate any inconsistencies, missing values, or erroneous inputs that could otherwise distort the simulation results.

Standardized datasets improve comparability between different REC projects, enabling more precise sensitivity analyses and scenario-based financial models (Jackson, 2023).

Integration with external data sources

To strengthen the robustness of the database, it is necessary to integrate external data sources. Weather and solar radiation databases, for instance, provide accurate forecasts of PV generation by leveraging both historical and real-time weather conditions. Alongside this, incorporating electricity market data, which captures price fluctuations, energy tariff structures, and demand forecasts that influence financial projections, ensures that financial models are grounded in current market realities.

In addition, databases on public and private investments can help evaluate potential financing mechanisms and financial incentives available at both national and community levels (OECD, n.d.).

Seamless integration with these diverse sources ultimately guarantees that REC's financial simulations accurately reflect real-world economic and environmental conditions.

Data security and accessibility

Given the sensitivity of financial and operational data, the database must incorporate robust security mechanisms, including:

- Access control mechanisms: ensure that only authorized stakeholders can modify or extract critical data.
- Backup and recovery protocols: prevent data loss due to technical failures or cyber threats.
- Encryption standards: protect confidential financial transactions and investment details.

Furthermore, the database should be designed with accessibility in mind, allowing key stakeholders, including ESCOs, regulatory bodies and project participants, to interact with relevant datasets through a secure and easy-to-use interface.

As the REC Caserta expands, the database structure is expected to support additional participants, incorporate new energy resources, and adapt to evolving regulatory frameworks. To meet these scalability requirements, a modular data architecture is essential, as it allows for the continuous addition of new datasets without disrupting the existing structure.

A cloud-based infrastructure further enhances this setup by facilitating remote access, enabling real-time updates, and ensuring secure data sharing among multiple stakeholders.

Moreover, implementing version control and archiving historical data is crucial, since it enables comparative analysis across different operational periods, which is essential for evaluating long-term financial and energy trends.

Essentially, scalability ensures that the REC can effectively accommodate future growth and increasing workloads, while consistently maintaining both data integrity and optimal analytical efficiency.

4.4.2. Main Sources: Energy Operators, Open-Source Datasets, Local Surveys

The accuracy and reliability of the case study analysis depends on the quality of the data sources used for the financial and technical evaluation. The REC Caserta database integrates multiple data streams, combining real-time energy monitoring, financial records, regulatory frameworks and external market information.

By gathering information from energy operators, open-source datasets and local surveys, the study ensures that financial simulations and energy performance assessments are based on empirical evidence rather than theoretical assumptions.

This section describes the main data sources, their role in the analysis and the methodologies used to validate and integrate them into the financial and technical modelling of the REC.

Energy operators and market data

Energy operators provide real-time production and consumption data, along with electricity price trends and regulatory compliance reports, drawing from a range of primary sources for energy-related data.

For instance, smart meters and monitoring platforms play a crucial role in this process by continuously tracking energy production, self-consumption, and feed-in to the grid, ensuring that energy models accurately mirror actual operational performance (Ghorbani & Takhar-Lail, 2014).

In addition, electricity market exchanges, such as Italy's GME (Gestore Mercati Energetici), offer detailed data on hourly and annual electricity prices, which in turn influence revenue forecasts derived from grid-powered energy sales. Complementing these sources, TSO and DSO reports provide valuable insights into grid stability, transmission tariffs, and the regulatory frameworks governing grid interaction, all of which impact the overall profitability of energy communities.

Moreover, AESI, serving as the project's responsible ESCO, contributes comprehensive financial breakdowns, including OPEX/CAPEX structures and incentive distribution frameworks.

Open-source datasets and external market intelligence

To ensure comprehensive financial simulations, open-source datasets are incorporated that enable comparative analyses and macroeconomic assessments. Major sources include:

- EU and Italian government energy reports (e.g. GSE, ARERA, Terna): provide policy guidelines, incentive structures and national statistics on REC adoption.
- Solar radiation and meteorological datasets (PV-GS, Meteonorm, ISPRA): used to predict long-term energy performance fluctuations based on climate conditions.
- Academic and industry research papers: Support benchmarking efforts by ensuring financial models are aligned with best practices observed in other RECs.
- REC public registers and energy cooperative reports: facilitate comparative analysis of performance between Caserta and similar projects in Italy and the EU (Cunha et al., 2022).

Local surveys and community engagement data

Although REC Caserta is initially an industrial energy community, its long-term vision includes expansion to other participants. To assess feasibility, qualitative and quantitative data are collected through surveys on the energy demand of participating companies, which involve acquiring historical consumption trends and predicting future needs. In parallel, interviews with REC's stakeholders are conducted to understand governance challenges, financial expectations, and policy compliance concerns. Additionally, local municipality reports, and policy consultations are utilized to assess regional interest in REC expansion, as well as to identify available subsidies and regulatory support mechanisms.

Data validation and integration

Given the diverse nature of these sources, a data validation protocol is implemented to ensure accuracy and consistency. The steps include:

- Cross-referencing smart meter readings with market price reports to ensure alignment between production levels and revenue calculations.
- Standardize financial data by adjusting for inflation, currency changes, and political changes that impact incentive structures.
- Ensure consistency of technical performance data by integrating multiple sources, reducing the risk of measurement errors.
- Comparative benchmarking compared to existing RECs to verify that self-consumption indices, grid feed efficiency and financial returns are in line with sector trends (TimesPro, n.d.).

The integration of real-time operational data, open-source policy reports and local stakeholder insights enables a holistic assessment of the REC Caserta, supporting accurate financial simulations and technical performance assessments.

In conclusion, the use of multiple data sources, including energy operators, open-source datasets and local surveys, ensures that the case study analysis is empirically grounded and methodologically sound. The database construction integrates real-time monitoring, regulatory compliance frameworks and financial market intelligence, providing a comprehensive basis for assessing REC scalability, risk exposure and financial sustainability.

CHAPTER V – CASE STUDY ANALYSIS: REC CASERTA

5.1. Motivations and Framework for REC Caserta

5.1.1. The Establishment of the Renewable Energy Community Caserta: Mechanisms and Procedural Framework

The establishment of the REC Caserta follows a structured, multi-level process, guided by national regulations, contractual agreements and governance mechanisms that ensure economic sustainability and operational efficiency. REC Caserta is established as a legally recognised body that facilitates the collective self-consumption of renewable energy by promoting social, economic and environmental benefits for its members. D. Lgs. no. 199/2021, which implements the European RED II, together with the TIAD issued by ARERA, acts as the primary regulatory framework by defining the operating principles and incentive structures.

The first step for the establishment of REC Caserta is the formal establishment of an association, pursuant to articles. 36 et seq. of the Italian civil code. The REC operates as a non-profit association, ensuring that its primary objectives remain community-oriented rather than commercial. The Statute of the REC Caserta Association and the Internal Regulations constitute the fundamental legal documents that govern the structure and operational framework of the community, guaranteeing compliance with national and European regulations.

REC Caserta is organised around the primary electrical station serving the defined geographical area, ensuring that all energy production and consumption points fall within this perimeter. This structural requirement allows the REC to benefit from economic incentives and tariff benefits as provided by the TIAD. In cases where REC does not directly own the energy production facilities, formal agreements must be signed with third-party producers, ensuring that such facilities are managed in line with REC Caserta's operational principles.

REC Caserta operates under a structured governance system designed to ensure effective decision-making, financial oversight, and operational efficiency. The governance structure comprises a General Assembly, a Board of Directors, a President, a Secretary-Treasurer, and, when necessary, a Supervisory Body.

The General Assembly, which includes all REC members, is responsible for defining long-term strategic objectives, approving financial reports, and electing board representatives. This body guarantees that all stakeholders have a voice in the decision-making process, promoting democratic governance within the REC.

The Board of Directors manages the operational implementation of the REC projects, ensuring compliance with legal and contractual obligations. The President serves as the official representative of the REC in external and institutional affairs, while the Secretary-Treasurer is responsible for financial management, regulatory compliance, and administrative coordination.

Membership in REC Caserta is open to private individuals, SMEs, municipalities, research institutions, religious organisations, and non-profit entities. To qualify, applicants must have an energy consumption or production point within the geographic area covered by REC Caserta. Admission requires:

- Submission of a formal request to the Board of Directors.
- Verification of eligibility criteria based on national legislation.
- A financial contribution to shared infrastructure and operational costs.

Membership is indefinite unless terminated by voluntary withdrawal, non-compliance with REC regulations, or structural changes affecting participation.

To ensure long-term economic viability, REC Caserta follows a structured financial model based on:

- Technical specifications of PV systems, considering installed capacity and estimated energy production.
- Investment and operational costs, covering infrastructure maintenance, administrative expenses, and network service fees.

- Projected self-consumption levels, based on historical energy demand patterns from its members.
- State-provided incentives such as TIP and ARERA contributions, which support energy sharing mechanisms.

This structured approach ensures that REC Caserta remains economically sustainable throughout its 20-year operational period, balancing investment costs, distributing returns fairly among members, and reinvesting excess revenues into infrastructure improvements and community development projects

REC Caserta's activity is regulated by contractual agreements with AESI, which acts as designated supplier for the energy infrastructure. The Plant Availability and Maintenance Contract specifies:

- The conditions of energy availability for REC Caserta members.
- Maintenance and monitoring of the PV system, ensuring its efficiency and compliance with regulatory standards.
- The appointment of the REC referent, responsible for relations with the regulatory authorities and for the management of financial transactions with the GSE.

The Contract plays a fundamental role in ensuring that REC Caserta respects its legal, financial and technical obligations. This person has the task of submitting requests for incentives, ensuring the correct distribution of economic benefits and guaranteeing regulatory compliance.

A key advantage of REC Caserta is its structured incentive system, designed to promote self-consumption of energy. Financial benefits include:

- An incentive rate guaranteed for 20 years, applicable from the date of activation of the PV system.
- Bonuses based on energy sharing percentages, with a minimum threshold of 55% of shared energy required to be entitled to further financial benefits.

- Distribution of revenues among members, based on predefined economic distribution models.

The economic benefits are assigned following the REC Caserta Economic Model, guaranteeing transparency and fairness in economic distributions. If energy production exceeds internal consumption needs, REC Caserta can sell excess energy to third parties, improving financial stability.

REC Caserta members have the right to withdraw, if they respect all pending financial commitments linked to their participation. Requests for withdrawal must be submitted in writing and approved by the Board of Directors. The dissolution of REC Caserta may occur if:

- The General Assembly votes to end operations.
- REC Caserta no longer meets the eligibility criteria for the incentives provided by national legislation.
- The community is no longer financially sustainable.

In the event of dissolution, the remaining assets will be allocated to social or environmental projects, ensuring that the REC's original sustainability mission continues beyond its operational life.

In conclusion, the creation of REC Caserta represents a highly structured and regulated process that integrates legal compliance, governance stability and financial planning to create a sustainable energy sharing model. From forming a non-profit association to implementing an economic strategy, REC Caserta ensures that community-based renewable energy production is economically sustainable and has a social impact. The integration of strategic contracts, state incentives and participatory governance make REC Caserta an exemplary model of decentralised energy management. REC Caserta's long-term success is based on continued regulatory support, technological adaptation and member engagement, positioning it as a key pillar in the transition to a decentralised, community-driven energy future.

5.1.2. Main Drivers for Participation in a REC

The decision to join a REC is influenced by multiple economic, environmental and social factors, which vary depending on the profile of the participants, ranging from businesses and industries to individual consumers. Understanding the key factors that motivate participation is critical to both the development and scaling of these models. This section explores the key incentives for stakeholders to engage in RECs, leveraging insights from empirical findings and stakeholder feedback.

One of the most compelling reasons to join a REC is the potential for financial benefits. While RECs are designed to promote decentralised energy production and community self-consumption, they also offer economic benefits that are attractive to both businesses and individual members (Di Silvestre et al., 2021).

REC participants benefit from reduced electricity costs thanks to collective self-consumption mechanisms that allow them to use locally produced renewable energy at a lower cost than standard grid electricity. The tariff incentives offered by regulatory frameworks, such as those defined by the Italian D. Lgs. 199/2021, further enhance the attractiveness of participation. These include:

- Feed-in tariffs and incentives: Participants receive a financial return for jointly produced energy, with feed-in tariffs that vary based on system capacity and zonal energy prices.
- Grid tariff reductions: RECs benefit from exemptions or reductions in transmission and distribution tariffs, making energy consumption more affordable.
- Capital cost compensation: REC members can take advantage of government grants and low-interest financing programs to cover initial installation costs.

Furthermore, a significant advantage for traders is the ability to engage in a low-risk investment environment. ESCOs often play a crucial role in reducing financial burdens by taking responsibility for the installation, maintenance and technical management of energy systems (Tosi, n.d.). This model allows businesses to benefit from energy savings without the need for substantial upfront capital investments.

Furthermore, risk minimisation is a key factor, as participants do not bear the financial and operational risks associated with owning renewable energy infrastructure. Instead, they enter into agreements with the REC that guarantee economic returns with limited exposure to market volatility.

Beyond financial incentives, participation in a REC aligns with corporate sustainability goals, particularly for companies seeking to improve their environmental responsibility (European Commission, 2014). Businesses recognise the growing importance of ESG factors, which influence both market competitiveness and stakeholder perceptions.

RECs offer direct environmental benefits by reducing GHG emissions, in line with both national and European sustainability goals. Self-consumption of locally produced renewable energy significantly reduces dependence on fossil fuels, thus reducing the overall carbon footprint of participating entities. With reference to the REC Caserta project the estimated CO_2 reduction for REC projects of this scale is approximately 30,420 kg per year.

In general, participation in RECs supports alignment with international climate goals, such as the European Green Deal and the UN SDGs (United Nations, n.d.). In addition, reduced emissions and cleaner energy sources help improve local air quality, promoting healthier urban and industrial environments.

For businesses, joining REC represents a strategic advantage in terms of corporate reputation. Association with sustainable energy initiatives improves branding and market positioning, often leading to greater customer loyalty and increased business opportunities.

- Companies can leverage their involvement in REC to obtain environmental certifications, such as ISO 50001 for energy management.
- Public recognition of sustainability efforts can improve relationships with regulators, investors and consumers.
- In some cases, participation in a REC improves eligibility for government subsidies, tax benefits and green financing.

A key component of RECs is their community-oriented model, which promotes collective engagement in the energy transition. The social and economic impacts of RECs go beyond individual financial gains, contributing to regional energy independence and community development (OECD, 2020).

Although the core members of many RECs are businesses rather than households, their participation indirectly supports local economic growth. By investing in regional renewable energy infrastructure, RECs contribute to:

- The development of new job opportunities in the renewable energy sector, particularly in engineering, technical maintenance and administrative roles.
- The empowerment of local businesses through access to affordable and sustainable energy.
- Encourage new business models related to energy sharing, storage and demand management solutions.

The shift towards decentralised energy production ensures greater energy security by reducing dependence on external suppliers and fluctuations in the national grid (May et al., 2024). In times of market instability or geopolitical tensions impacting energy supply, locally produced energy within a REC provides a stable and predictable cost structure, mitigating the risks of price volatility.

Many participants are also driven by the opportunity to actively contribute to energy transition efforts. Being part of a REC allows interested parties to do this:

- Engage in peer-to-peer energy sharing, increasing community resilience.
- Demonstrate leadership in sustainable practices, encouraging wider adoption across all sectors.
- Support social impact initiatives, as some RECs direct excess revenue towards education programs, energy poverty reduction or reinvestment in community projects.

The evolution of energy legislation, that introduced by D. Lgs. 199/2021 in Italy, has created strong political incentives that facilitate the participation of the REC (Trevisan et al., 2023). These political factors include:

- Simplified administrative processes: legislative updates have streamlined the creation and management of RECs, reducing bureaucratic barriers.
- Zonal tariff structures: Energy pricing mechanisms that encourage self-consumption within specific zones of the network provide economic incentives for members.
- Legal recognition of RECs as active market participants: Recent regulatory frameworks position RECs as legitimate energy entities, allowing them to access wholesale electricity markets and capacity remuneration mechanisms.

Additionally, ESCOs play a critical role in regulatory compliance, ensuring RECs meet legal and technical standards while optimising financial returns.

Participation in a REC is driven by a combination of economic, environmental, social and political incentives (Moretti & Stamponi, 2023). Businesses and stakeholders are motivated not only by financial savings and investment returns, but also by broader strategic benefits, including improved sustainability performance, enhanced corporate reputation and regulatory benefits.

Furthermore, the risk-free engagement facilitated by ESCOs, coupled with the long-term revenue generation potential, makes RECs an attractive model for companies looking to transition to sustainable energy without taking on excessive financial burdens. At the same time, the social and environmental impact of RECs contributes to broader energy transition goals, making them a key pillar of future energy systems.

Going forward, increasing political support, refining economic models and ensuring greater community participation will be key to maximizing the effectiveness and scalability of RECs, consolidating their role in the transition towards a decentralised, sustainable and inclusive energy future (Bergami & Morandin, 2013).

5.2. Data Analysis and Energy-Financial Simulations

5.2.1. Energy Models: Calculating Production, Self-Consumption, and CO_2 Reductions

The evaluation of energy models plays a fundamental role in evaluating the technical and economic performance of RECs. Through detailed calculations of production capacity, self-consumption levels and CO_2 reductions, it is possible to determine the sustainability and efficiency of decentralised energy production systems (European Commission, n.d.). In the context of REC Caserta, these indicators not only measure the effectiveness of the project but also contribute to the broader goal of optimising energy use and reducing carbon emissions.

The total energy production for REC Caserta was calculated using PV-GS simulation models, which consider solar radiation levels, system efficiency and local climate conditions. Based on these estimates, the community is expected to generate 116,797 kWh per year. This value is obtained using the following formula:

$$\text{Installed PV power} * \text{Producibility factor}$$

where the installed PV power amounts to 99.74 kWp, and the producibility factor is estimated at 1,171.07 kWh/kWp year. The producibility factor is a key parameter that reflects the energy efficiency of the system, considering aspects such as panel performance, losses due to shading and seasonal variations in solar radiation. These factors ensure a realistic estimate of energy production, which is critical for REC financial planning and feasibility studies.

A fundamental aspect of RECs is the ability to maximize the self-consumption of locally generated renewable energy. Self-consumption is fundamental in determining the financial sustainability of the community, as it has a direct impact on energy cost savings and reduces dependence on the electricity grid. In the case of REC Caserta, the calculated self-consumption percentages are as follows:

- 2.1%
- 14.7%
- 13.4%
- 9.3%
- Total aggregated self-consumption: 39.5%

This total self-consumption rate of 39.5% indicates that a significant portion of the energy produced is consumed directly by the community, improving local energy resilience and ensuring that energy costs remain low for REC participants. Increasing self-consumption levels through demand management strategies, smart grid technologies and storage solutions can further improve REC Caserta's financial returns and energy independence.

The quantification of carbon savings is a crucial parameter for measuring the environmental impact of RECs. REC Caserta's CO_2 reduction potential was calculated using the standard emission factor for the electricity grid in Italy. 260g/kWh of CO_2 represents the average carbon intensity of the national electricity mix. Considering the total annual energy production of 116,797 kWh, this translates into a total annual CO_2 reduction of 30,420 kg.

This reduction in carbon emissions highlights the important role of decentralised renewable energy systems in mitigating climate change and supporting EU decarbonisation policies (Nuccitelli, 2024). By generating clean energy locally, REC Caserta actively contributes to achieving national and European sustainability goals, reducing dependence on fossil fuels and supporting the transition towards a low-carbon economy.

The results of the energy model calculations demonstrate the strong potential of REC Caserta as a viable model for renewable energy production and self-consumption. However, further measures can be taken to improve their performance and economic sustainability. Several key areas should be considered for optimisation and future expansion.

Enhancing self-consumption through energy storage solutions

Integrating battery storage systems would allow excess energy generated during peak sunlight hours when demand is high to be stored and used, thus increasing the self-consumption rate above 39.5%. In addition, storage solutions would also contribute to greater grid stability, reducing peak demand fluctuations and improving overall system resilience.

Optimising demand-side management

Implementing real-time EMS can improve efficiency by dynamically adjusting energy loads in response to real-time production levels. Smart meters and predictive analytics could help consumers optimise energy use, minimise waste and maximize on-site consumption (Badrudeen et al., 2024).

Expanding REC participation and grid interaction

Increasing the number of participants within the REC could lead to a more balanced supply-demand relationship, improving the economic viability of the community. Strengthening collaborations with grid operators to improve local energy trading capabilities would further support economic sustainability and market integration.

Broader implications for the energy transition

The results of REC Caserta's energy modelling and performance indicators highlight the role of RECs in promoting the broader energy transition. The project is aligned with the strategic objectives of Italy and the EU, strengthening the following key priorities:

- Decentralisation of energy systems: reduce dependence on large-scale power plants and strengthen the democratization of energy.
- Carbon neutrality targets: directly support national emissions reduction targets, in line with the European Green Deal.
- Economic and social benefits: reducing electricity costs for participants, promoting local employment opportunities and promoting sustainable economic development in regional communities.

The successful implementation of REC Caserta serves as a scalable model that can be replicated in other regional and national renewable energy projects, helping to accelerate Europe's transition to a net-zero emissions energy system.

In conclusion, the analysis of REC Caserta's production capacity, self-consumption efficiency and CO_2 reductions demonstrates the substantial impact of RECs in achieving energy autonomy and sustainability. With a calculated annual production of 116,797 kWh, a self-consumption rate of 39.5% and an annual CO_2 reduction of 30,420 kg, the project already achieves a high level of operational efficiency. However, further investments in energy storage, smart grid technology and demand response strategies could further improve economic sustainability and enhance the community's overall contribution to decarbonization efforts.

As Europe moves towards a sustainable energy future, projects like REC Caserta offer replicable solutions that integrate local energy production, community participation and technological innovation. The expansion of such initiatives will be critical to achieving renewable energy goals, promoting energy independence and ensuring a just and inclusive energy transition for all stakeholders involved.

5.2.2. Financial Simulations, Key Metrics and Scenario Development

The financial simulation process for REC Caserta was designed to analyse the economic sustainability of different operational configurations. The main objective was to evaluate how key parameters, including self-consumption rates, producibility levels and revenue distribution mechanisms, impact the financial sustainability of the project. To achieve this, several scenarios have been developed, each modifying specific input parameters while holding other variables constant to isolate their financial effects.

This section describes the methodological approach used to build each simulation, detailing the changes applied to the main financial and technical indicators and explaining the logic behind each change.

Self-consumption rate variations

Self-consumption is one of the most critical parameters influencing the financial performance of a REC. A higher self-consumption rate allows a greater amount of locally generated energy to be consumed directly by members, reducing dependence on grid electricity and increasing economic returns through incentives for self-consumption. To evaluate its impact, the self-consumption tariff was modified as follows:

- Baseline (39.5%) – Represents the original estimate based on energy consumption patterns predicted by REC members.

- Maximized self-consumption (55%) – This scenario assumes greater efficiency in demand management, potentially through behavioural changes, load optimisation or integration of small-scale energy storage. It is also the one that consents to obtain the greatest possible incentives.
- Higher self-consumption (70%) – This represents an upper limit scenario, where much of the energy produced is used directly, through load shifting, increased participation by new members, or improved real-time energy management. In this case, however, the incentive remains at the same level as the previous scenario.
- Reduction of self-consumption (25%) – A worst-case scenario in which a significant share of the energy generated is exported to the grid, reducing the economic benefits for REC members.

By changing this parameter, we could determine economic turning points where increasing or decreasing self-consumption optimally balances financial and technical constraints.

Producibility modifications

Another important factor that influences the economic sustainability of the REC is the producibility of the solar PV system, measured in kWh/kWp per year. Manufacturability depends on multiple factors, including solar irradiance, panel efficiency, system degradation and local weather conditions. To evaluate its impact, the following scenarios were introduced:

- Reduced producibility (1,054 kWh/kWp) – This accounts for a potential reduction in efficiency due to factors such as suboptimal weather conditions, higher-than-expected panel degradation or partial shading.
- Baseline producibility (1,171 kWh/kWp) – Represents the expected average producibility derived from PV-GS simulations.
- Higher producibility (1,288 kWh/kWp) – This presupposes a higher solar yield, which can be achieved through advanced tracking systems, improvements in panel cleaning or optimised panel orientation.

Understanding how fluctuations in producibility affect long-term economic outcomes is critical, as it helps mitigate risks associated with lower-than-expected solar production.

Energy sale price adjustment

Although self-consumed energy offers the greatest financial return, excess energy must still be exported to the grid. The financial return on this exported energy depends on the market price at which it is sold. The following evaluation scenarios were tested:

- Standard selling price (0.06 €/kWh) – Represents the typical market price for excess electricity under current regulatory conditions.
- Improved sales price (0.15 €/kWh) – This scenario explores the possibility of a higher remuneration for exported energy, due to favourable market conditions, greater political support or participation in specialized energy markets.

The difference between these two pricing structures plays a crucial role in determining whether a REC should focus on maximizing self-consumption or whether exporting energy could be a viable revenue stream.

Redistribution of incentives between AESI and the REC

A final set of simulations was conducted to analyse how changes in the internal distribution of incentives affect the profitability of REC members. In the basic model, incentives were assigned as follows: 80% to AESI (as main project developer and investor) and 20% to REC community members.

To evaluate the financial impact of redistributing incentives, a second scenario was introduced: 50% to AESI, 50% to REC members – A more balanced incentive structure that increases direct financial benefits for community participants.

This redistribution experiment allows us to evaluate whether a greater share of financial incentives for REC members leads to more favourable economic outcomes, potentially making community participation more attractive and promoting further investment in renewable technologies.

Cash flow analysis and long-term financial stability

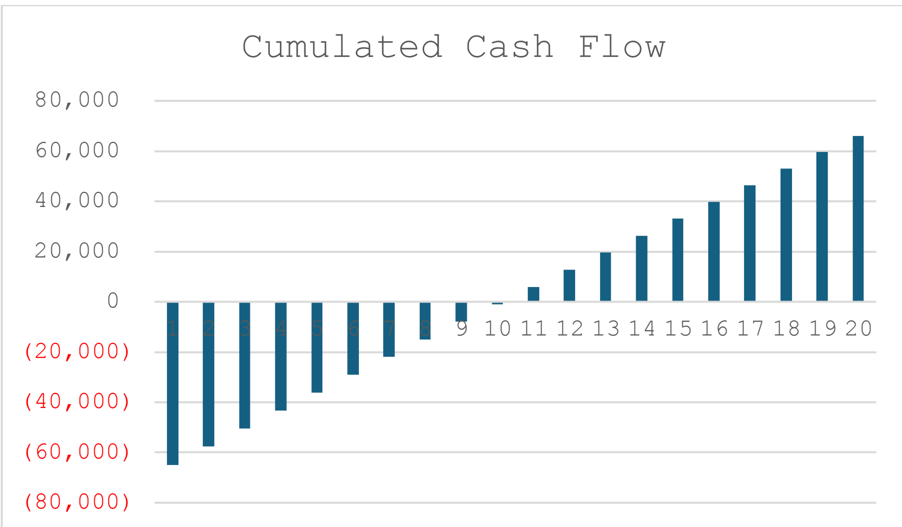
One of the key elements in assessing the sustainability of the REC Caserta project is the cumulative cash flow analysis, which provides information on when the project reaches break-even and starts generating positive net revenue.

The Graph 5.1 illustrates the cumulative cash flow trajectory over a 20-year period, showing the initial investment burden, the gradual payback phase and the eventual profitability of the project:

This analysis highlights several important financial trends:

- The project has negative cash flow for the first 10 years, reflecting initial capital expenditure and operating costs.
- The break-even point is reached in year 11, i.e. from this moment on REC Caserta begins to generate positive net revenues.
- By year 20, total cumulative cash flow reaches a projected surplus, strengthening the long-term viability of the REC model.

GRAPH 5.1



SOURCE: OUR PRODUCTION

The variations applied in these simulations provide a detailed understanding of the financial mechanisms of REC Caserta. By systematically modifying self-consumption, producibility, energy sales prices and the assignment of incentives, we can identify the most favourable economic conditions for REC participants. Cash flow analysis further validates the long-term sustainability of the project, demonstrating that while initial investments lead to temporary financial deficits, the REC model transitions to a positive net position over time.

5.3. Results and Interpretations

5.3.1. Comparison of Scenarios, Results Evaluation, and Visualization of Results via Charts and Dashboards

The financial simulations outlined in the previous section provided an in-depth assessment of the economic feasibility of REC Caserta under different operating conditions. This section presents a comparative analysis of these scenarios, evaluating key performance parameters across different self-consumption rates, producibility levels and pricing mechanisms. The objective is to identify the most financially advantageous conditions, highlight potential risks and provide strategic recommendations based on comparative results.

The different simulated scenarios highlight the financial sensitivities associated with changes in self-consumption rates, energy production and revenue distribution mechanisms. The following subsections provide a structured comparison of the most relevant financial indicators: IRR, NPV, PBT and annual savings.

One of the most influential factors in the REC economy is the rate of self-consumption, which directly affects revenue by generating savings on purchased electricity and influencing. Key scenarios tested included the baseline scenario (39.5%), optimised self-consumption (55%) associated to the highest level of incentive, higher self-consumption, (70%) and lower self-consumption (25%) (see Table 5.1).

TABLE 5.1

Scenario	Self-Consumption (%)	Producibility (h/a)	Grid Sale Value (€/kWh)	Incentives (€/kWh)	IRR (%)	NPV (€)	PBT	Consumer Revenues (€)
Baseline	39.5	1,171	0.060	0.120	7.4	14,165	10.28	1,596
Maximized Self-Consumption	55.0	1,171	0.060	0.120	9.6	28,221	8.76	2,221
Higher Self-Consumption	70.0	1,171	0.060	0.120	9.6	28,221	8.76	2,406
Lower Self-Consumption	25.0	1,171	0.060	0.120	5.2	997	12.26	1,010

SOURCE: OUR PRODUCTION

The results indicate that increasing self-consumption from 39.5% to 55% leads to substantial financial benefits, almost doubling the NPV and reducing payback times. However, a further increase in self-consumption to 70% does not produce further financial gains, demonstrating a profitability saturation point. Conversely, reducing self-consumption to 25% translates into a significant deterioration in financial performance, underlining the importance of maintaining high levels of self-consumption. The lack of further NPV increase beyond 55% self-consumption suggests that the benefit from incentives reaches a maximum threshold, beyond which additional energy savings do not generate further financial gains.

The producibility factor, which represents the yield of solar energy (kWh/kWp), is crucial in determining total energy production and associated revenues. Within the scope of this project three scenarios were analysed: reduced producibility (1,054 kWh/kWp), standard producibility (1,171 kWh/kWp) and increased producibility (1,288 kWh/kWp) (see Table 5.2).

TABLE 5.2

Scenario	Self-Consumption (%)	Producibility (h/a)	Grid Sale Value (€/kWh)	Incentives (€/kWh)	IRR (%)	NPV (€)	PBT	Consumer Revenues (€)
Reduced Producibility	39.5	1,054	0.060	0.120	5.8	4,900	11.60	1,436
Standard Producibility	39.5	1,171	0.060	0.120	7.4	14,165	10.28	1,596
Increased Producibility	39.5	1,288	0.060	0.120	8.9	23,430	9.23	1,755

SOURCE: OUR PRODUCTION

A higher producibility factor directly enhances financial performance by increasing IRR and NPV, while reducing PBT. This important finding emphasizes the critical need for optimal and regular system maintenance, accurate adjustments to panel orientation, and careful selection of installation locations to maximize solar energy yield. It also highlights the strategic importance of regular performance monitoring practices to ensure that the system continuously operates at its peak efficiency, maximizing financial returns.

The price at which surplus energy is sold back to the grid can significantly influence the overall profitability of the REC project. In this analysis, two distinct scenarios were considered: a standard selling price of surplus energy (0.06 €/kWh), and an alternative, higher selling price scenario (0.15 €/kWh) (see Table 5.3).

TABLE 5.3

Scenario	Self-Consumption (%)	Producibility (h/a)	Grid Sale Value (€/kWh)	Incentives (€/kWh)	IRR (%)	NPV (€)	PBT	Consumer Revenues (€)
Standard Sale Price	39.5	1,171	0.060	0.120	7.4	14,165	10.28	1,596
Higher Sale Price	39.5	1,171	0.150	0.110	20.3	99,581	5.11	1,503

SOURCE: OUR PRODUCTION

An increase in the sales price of surplus energy significantly improves financial sustainability, transforming external energy sales into a highly profitable revenue stream. This suggests that advocating for better feed-in tariffs and supportive energy pricing policies could represent a strategic and effective pathway to improve the sustainability and attractiveness of the REC.

A final simulation was carried out to specifically examine how different approaches in redistributing incentives between AESI and REC's members can significantly impact the overall financial outcomes and profitability of the project (see Table 5.4).

TABLE 5.4

Scenario	Self-Consumption (%)	Producibility (h/a)	Grid Sale Value (€/kWh)	Incentives (€/kWh)	IRR (%)	NPV (€)	PBT	Consumer Revenues (€)
Baseline (80% AESI, 20% REC)	39.5	1,171	0.150	0.110	20.3	99,581	5.11	1,503
Equal Distribution (50% AESI, 50% REC)	39.5	1,171	0.150	0.110	17.5	83,976	5.53	3,027

SOURCE: OUR PRODUCTION

Adjusting the distribution of incentives in favour of REC members translates into higher annual savings per participant, increasing the attractiveness and acceptance of the project at community level. However, this redistribution strategy comes at the expense of a lower overall NPV, indicating a trade-off between maximizing collective project value and increasing direct benefits received by participants.

What emerges is that optimising self-consumption to 55% is fundamental to maximizing financial returns, maintaining high levels of producibility improves the feasibility of investments and higher energy sales prices significantly improve the profitability of the project.

Furthermore, a more balanced distribution of incentives improves direct economic benefits for REC members, making participation more attractive, while political commitment is essential to ensure better tariffs and financial incentives.

This comparative analysis clearly confirms that the REC Caserta represents a financially sustainable project under optimal conditions related to self-consumption levels, solar energy producibility, and surplus energy selling prices. Moreover, by integrating advanced energy management strategies, securing targeted policy support, and strategically restructuring incentive distribution, the financial resilience and overall attractiveness of the REC model can be significantly enhanced. These insights provide a robust foundation for making strategic decisions aimed at ensuring not only the project's long-term economic viability but also its environmental sustainability and community acceptance. In Table 5.5 is a summary table presenting the key results and comparative scenarios.

TABLE 5.5

Scenario	Self-Consumption (%)	Producibility (h/a)	Grid Sale Value (€/kWh)	Incentives (€/kWh)	IRR (%)	NPV (€)	PBT	Consumer Revenues (€)
Baseline	39.5	1,171	0.060	0.120	7.4	14,165	10.28	1,596
Maximized Self-Consumption	55.0	1,171	0.060	0.120	9.6	28,221	8.76	2,221
Higher Self-Consumption	70.0	1,171	0.060	0.120	9.6	28,221	8.76	2,406
Lower Self-Consumption	25.0	1,171	0.060	0.120	5.2	997	12.26	1,010
Reduced Producibility	39.5	1,054	0.060	0.120	5.8	4,900	11.60	1,436
Increased Producibility	39.5	1,288	0.060	0.120	8.9	23,430	9.23	1,755
Higher Energy Sale Price	39.5	1,171	0.150	0.110	20.3	99,581	5.11	1,503
Redistributed Incentives	39.5	1,171	0.150	0.110	17.5	83,976	5.53	3,027

SOURCE: OUR PRODUCTION

5.3.2. Scalability of the REC model

The scalability of a REC is a crucial factor in determining its long-term economic sustainability and replication potential. Expanding a REC means not only increasing its installed capacity but also evaluating the economic benefits and feasibility of integrating a greater number of participants. This section evaluates the scalability of the REC model by comparing a baseline scenario with a 1 MW scaled-up system, analysing cost savings, economic performance and overall feasibility.

To assess the impact of scaling up the REC model, the following key modifications, illustrated in Table 5.6, were applied:

- Number of modules: the number of installed PV modules increased from 183 in the base case to 1,830 in the expanded scenario. This substantial increase in system size directly affects total energy production and the allocation of capital expenditures.
- System unit cost (CAPEX per kWh): The unit cost of installation was reduced from €700/kWh in the smallest system to €600/kWh in the 1 MW scenario, demonstrating cost efficiency through economies of scale and mass procurement benefits.
- Unit OPEX (operating expenses per kWh/year): Operation and maintenance costs decreased from €20/kWh/year to €10/kWh/year, reflecting better resource utilization and better distribution of costs across a larger system.

Other parameters, such as installed capacity, producibility, self-consumption tariff, network sales value and incentives, remain consistent between the two cases. However, due to the larger system size and increased cost efficiency, financial performance metrics, including IRR, NPV and PBT, are expected to improve considerably.

TABLE 5.6

Parameter	Number of Modules	Unit Cost of the System (€/kWh)	Unit OPEX (€/kWh/year)	Installed Capacity
Baseline REC	183	700	20	1kW
1 MW REC (Scalability Scenario)	1830	600	10	1 MW

SOURCE: OUR PRODUCTION

One of the main advantages resulting from the expansion of the REC model is the reduction of unit costs. As shown in Table 5.6, the unit cost of the system decreases from €700/kWh to €600/kWh, and the OPEX decreases from €20/kWh/year to €10/kWh/year. These reductions occur because:

- Fixed costs are better spread over greater energy production capacity.
- Economies of scale reduce equipment procurement costs.
- Operational efficiency leads to lower maintenance costs per unit of energy produced.

As a result, the financial performance of the REC improves significantly, with:

- An increase in IRR from 7.4% to 11.3%.
- A substantial increase in NPV from €14,165 to €341,503.
- A reduction in Payback Time from 10.28 years to 7.80 years.

These indicators, illustrated in Table 5.7, confirm that the scalability of the REC model leads to higher profitability and faster capital recovery.

Another key factor in scalability is the economic return for consumers. As shown in Table 5.7, the revenue generated for consumers in the enlarged model increases significantly to €15,958. This is due to the greater installed capacity and better efficiency of the system, which translates into greater overall energy savings and greater revenues from incentive mechanisms and economic benefits.

To further explore the benefits of scalability, a sensitivity analysis was conducted comparing the financial feasibility of the basic REC and the 1 MW REC. The analysis focuses on key financial indicators, examining how changes in costs, manufacturability and incentives influence project outcomes.

TABLE 5.7

Scenario	Self-Consumption (%)	Producibility (h/a)	Grid Sale Value (€/kWh)	Incentives (€/kWh)	IRR (%)	NPV (€)	PBT	Consumer Revenues (€)
Baseline REC	39.5%	1,171	0.060	0.120	7.4%	14,165	10.28	1,596
1 MW REC	39.5%	1,171	0.060	0.120	11.3%	341,5	7.80	15,958

SOURCE: OUR PRODUCTION

This comparison highlights the superior economic performance of the broader REC model, demonstrating that increasing scale leads to greater financial sustainability and better consumer benefits.

The scalability analysis of the REC model demonstrates that expanding to a 1 MW installation results in significant cost reductions, improved financial performance and greater economic returns for consumers. The reduction in CAPEX and OPEX per unit, combined with improved financial indicators such as a higher IRR and NPV, confirms that scalability strengthens the economic viability of the REC model.

These results suggest that increasing RECs should be a priority to maximize financial sustainability. Future research could further explore larger-scale deployments, evaluating whether even greater economic efficiencies can be achieved with multi-megawatt REC projects.

5.3.3. Practical Implications and Performance Indicators: Economic, Environmental, and Social

The transition towards RECs represents a fundamental step towards sustainable energy systems. The creation of RECs introduces both opportunities and challenges across multiple dimensions, requiring careful evaluation of their real-world implications. This section delves into the practical implications of implementing RECs, focusing on economic, environmental and social performance indicators. By analysing these dimensions, the thesis aims to provide a comprehensive understanding of the benefits and challenges associated with RECs, offering insights into their real-world applications and impacts.

Economic performance indicators

Key financial metrics

The implementation of a REC requires a thorough assessment of its financial sustainability. To determine whether a REC project is sustainable and beneficial for its participants, the main financial parameters to analyse are the IRR, which evaluates the profitability of the REC (the higher the better), the NPV which indicates the long-term profitability of the project, the PBT, which measures the time needed for the initial investment to be recovered through net cash inflows, and consumer savings, which reflects the reduction in energy costs for participants, highlighting the direct financial benefits for the community (Dai et al., 2022).

These metrics collectively provide a comprehensive overview of the REC's financial health, guiding stakeholders in decision-making processes.

Financial projections and revenue streams

A sustainable REC model is supported by diversified and reliable revenue streams. The financial projections that should be considered include energy sales, which are revenues generated from the sale of excess energy to the grid or to third parties, and incentives and subsidies, which represent the financial support from government bodies aimed at promoting the adoption of renewable energy.

Such projections should be based on conservative estimates to ensure financial stability and resilience to market fluctuations.

Barriers and challenges

Despite the financial potential of RECs, there are several obstacles and challenges that must be addressed to ensure their success:

- Administrative complexity: the process of creating a REC involves navigating complex bureaucratic procedures, which can be time-consuming and discouraging for communities.
- Regulatory ambiguities: inconsistencies and uncertainties within the regulatory framework can create confusion, discouraging investment and participation.
- Financial Constraints: high initial capital expenditures and operational costs present significant challenges, especially for smaller communities with limited access to financing.

Addressing these challenges requires coordinated efforts by policymakers, financial institutions and community leaders to create an enabling environment for RECs.

Environmental performance indicators

CO_2 emissions reduction

One of the main environmental benefits of RECs is the significant reduction of CO_2 emissions. By switching from fossil fuel-based energy sources to renewable sources, RECs help reduce the community's carbon footprint. In this case, the implementation of the REC resulted in a total annual CO_2 reduction of 30,420 kg, demonstrating a tangible environmental benefit.

Contribution to national and European climate goals

RECs play a critical role in aligning local energy practices with broader climate goals. In Italy, the integration of RECs supports the national commitment to increase the consumption of renewable energy, thus contributing to the general objectives of the EU to reduce GHG emissions and promote the sustainable use of energy (Carbon Gap, n.d.).

Environmental trade-offs

While RECs offer numerous benefits, it is essential to recognise potential environmental trade-offs:

- Land use and habitat disturbance: installing renewable energy infrastructure, such as wind turbines and solar panels, can lead to habitat loss and fragmentation, affecting local biodiversity.
- Resource extraction: the production of renewable energy technologies often requires the extraction of minerals, which can have negative environmental impacts if not managed responsibly.

Mitigating these trade-offs requires careful planning, assessing environmental impacts, and adopting best practices to minimise ecological disturbance.

Social performance indicators

Energy affordability and community engagement

RECs have the potential to significantly improve energy accessibility by reducing overall costs through increased local renewable energy production. By producing energy closer to the actual point of consumption, transmission and distribution losses are minimised, resulting in greater system efficiency and considerable cost savings for community participants.

Enhancement of corporate image and leadership

For business-oriented RECs, participation can lead to improved corporate image. By adopting sustainable energy practices, companies set a positive example, encouraging others to pursue similar initiatives and contributing to a culture of environmental responsibility. This can also improve consumer trust and brand reputation by strengthening CSR initiatives.

Policy and regulatory framework

The success of RECs is strongly influenced by the existing policy and regulatory environment. Supportive policies can facilitate REC's development by providing clear guidelines, financial incentives and streamlined administrative processes. Conversely, regulatory obstacles can impede progress, underscoring the need for ongoing policy evaluations and reforms.

Energy independence and price stability

By generating energy locally, RECs increase energy independence, reducing dependence on external suppliers and exposure to volatile energy markets. This autonomy contributes to price stability, offering communities more predictable and potentially lower energy costs. Energy independence also strengthens resilience against market fluctuations, protecting REC members from sudden increases in energy prices and geopolitical risks associated with energy imports.

The implementation of RECs presents multi-faceted benefits across economic, environmental, and social dimensions. Financial viability, environmental sustainability, and community engagement are key pillars in determining the long-term success of RECs. However, overcoming administrative, regulatory, and financial barriers remains essential to unlocking the full potential of decentralised renewable energy systems.

Future research and policy frameworks should focus on optimising REC governance structures, enhancing financial incentives, and addressing environmental trade-offs to facilitate broader adoption and scalability.

5.4. The Role of RECs in the Energy Transition and Organisational Challenges

5.4.1. Contribution to the Energy Transition

The transition to a sustainable energy system is an urgent and multifaceted challenge that requires structural changes in energy production, distribution and consumption. Achieving carbon neutrality by reducing dependence on fossil fuels is central to the European Union's long-term climate strategies, with policies focused on decarbonization, decentralisation and energy security. In this context, RECs have emerged as a crucial tool, enabling communities to generate, share and consume locally produced renewable energy (Giordano, 2024). These decentralised systems contribute to a cleaner energy landscape, while promoting resilience against energy market volatility and strengthening local commitment to sustainability efforts.

This section explores the contribution of the REC model to the energy transition, with particular attention to its environmental impact, role in decentralisation and long-term sustainability. While the REC was designed to support localised energy independence, its benefits extend well beyond its direct participants, aligning with broader national and European goals for a cleaner and more resilient energy infrastructure.

Environmental impact

Localised carbon emission reduction

The implementation of RECs directly influences the reduction of carbon emissions by promoting the use of RES at the community level. By generating energy locally, RECs minimise dependence on fossil fuels, thereby decreasing GHG emissions (European Commission, n.d.). In the case study analysed, the REC achieved a total annual CO_2 reduction of 30,420 kg. This significant decrease underlines the potential of RECs to effectively contribute to local environmental sustainability and achieve Italy's and the European Union's net zero emissions targets (Fischer, 2021).

Lifetime CO_2 reduction

Beyond annual metrics, assessing the lifetime impact of RECs provides a comprehensive understanding of their environmental benefits. Assuming the REC operates efficiently over an expected lifespan of 20 years, the cumulative CO_2 reduction would amount to approximately 608,400 kg. This long-term perspective highlights the lasting positive effects of RECs on the environment, strengthening their role in sustainable energy strategies.

Biodiversity protection and sustainable land use

While large-scale renewable projects can sometimes conflict with land conservation efforts, RECs offer a model that minimises such trade-offs. By prioritizing rooftop solar panels, parking installations and redeveloped industrial areas, REC infrastructures avoid encroaching on natural habitats and agricultural land. This strategy is in line with sustainable land use practices, protecting biodiversity and still allowing a wide diffusion of renewable energy. Additionally, REC projects can complement green infrastructure, such as urban tree planting and ecosystem restoration, further supporting carbon sequestration and local biodiversity.

Additional environmental benefits

The environmental benefits of RECs go beyond reducing carbon emissions. Localised energy production reduces the need for extensive transmission networks, thereby reducing energy losses and improving overall system efficiency. It also reduces harmful pollutants associated with traditional energy production. Fossil fuel plants are responsible for emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2) and particulate matter (PM), which contribute to air pollution, respiratory diseases and acid rain (CarbonBudget, 2024).

Furthermore, by decreasing dependence on centralised fossil fuel-based power plants, RECs help improve air quality, with direct benefits for community health. The integration of green spaces and the preservation of local ecosystems during the development of REC infrastructure further support the protection of biodiversity, promoting a harmonious balance between human activities and nature.

Energy decentralisation and security

Enhancing grid stability

The decentralised nature of RECs plays a crucial role in strengthening the stability of the network. By distributing energy production across multiple localised units, RECs reduce the load on centralised grids, particularly during peak demand periods. This deployment mitigates the risk of widespread disruptions and improves the resilience of the energy supply system. In Italy, the integration of RECs has been associated with a notable improvement in grid reliability, as localised energy sources can respond promptly to fluctuations in supply and demand.

While this REC relies on relatively simple EMS, mainly Excel databases and basic monitoring tools, future advances could include smart grid integrations, automated energy trading platforms, and AI-based demand-response systems, further improving grid resilience and energy balance.

Energy management systems

The effective operation of RECs is often supported by advanced EMS. These systems facilitate optimal coordination of energy production and consumption within the community. In our case study, the REC employs a basic EMS that uses tools such as databases and Excel-based portals to monitor energy flows and manage data. While these tools are relatively simple, they provide a foundation for future upgrades to more sophisticated digital platforms and applications. EMS allows participants to monitor their energy consumption in real time, make informed consumption decisions and identify opportunities for efficiency improvements (Ruano & Ruano, 2024). This proactive approach not only improves the sustainability of REC but also allows community members to take an active role in energy management.

Mitigating energy losses

One of the inherent advantages of RECs is the proximity of energy generation to points of consumption. This proximity significantly reduces transmission and distribution losses prevalent in centralised power systems. A key but often overlooked benefit of RECs is their role in improving energy efficiency by reducing transmission and distribution losses. In traditional energy systems, electricity is produced in large-scale power plants and transported over large distances before reaching end users. This process involves energy dissipation, with losses that can vary from 5% to 10% depending on network conditions.

Studies show that RECs generate energy closer to the point of consumption, significantly minimising these losses and optimising the overall efficiency of energy use (Ceschin et al., 2018). By generating energy closer to where it is consumed, decentralised systems improve overall energy efficiency, further contributing to sustainability goals. This efficiency not only saves energy but also results in cost savings for consumers and reduces the environmental impact associated with energy distribution infrastructure.

Socio-economic impact

Energy autonomy

RECs enable communities to achieve greater energy independence by enabling the local production and consumption of REs. This autonomy reduces dependence on external energy suppliers and insulates communities from exposure to market instabilities. In Italy, where dependence on energy imports remains a challenge, the adoption of RECs could contribute to a more resilient energy economy, reducing national dependence on imported fossil fuels while ensuring stable energy prices for communities. This self-sufficiency promotes a sense of ownership and responsibility among community members, encouraging further participation in sustainable practices and initiatives.

Economic opportunities

The creation of RECs can stimulate local economies by creating jobs in the renewable energy sector, including roles in the installation, maintenance and management of energy systems. Furthermore, RECs can attract investments and promote the development of local businesses in line with sustainable practices (Campagnoli, n.d.). While specific data on new economic opportunities within our REC is limited, the broader trend indicates that such communities can serve as catalysts for economic revitalization. By promoting a local energy market, RECs can also encourage innovation and entrepreneurship, leading to the development of new technologies and services that benefit the community.

Despite their advantages, RECs face challenges related to competitiveness and market expansion. Regulatory complexities and insufficient financial incentives can hinder the growth of RECs. In Italy, navigating the bureaucratic landscape to establish a REC requires significant effort and current incentive structures may not adequately support widespread adoption (Adelekan et al., 2024). Addressing these obstacles requires policy reforms that streamline administrative processes and provide robust financial support to encourage the proliferation of RECs. Furthermore, while policy frameworks exist to support decentralised energy models, market mechanisms do not always scale equally with community-led initiatives, leaving RECs at a competitive disadvantage compared to larger energy providers.

Future legislative efforts should focus on streamlining bureaucratic processes, providing more favourable incentives, and ensuring equitable market access for RECs. Collaborative efforts between government bodies, private sector stakeholders and community organisations are essential to creating an enabling environment for RECs to thrive.

The scalability and replicability of the REC model are key to its contribution to the broader energy transition. While detailed projections are beyond the scope of this section, it is evident that with supportive policies and community involvement, the REC model promises expansion into several regions. Future research should focus on developing frameworks that facilitate the adaptation of the REC model to various socio-economic and geographic contexts, ensuring that the benefits of localised renewable energy are accessible to a wider population. This includes exploring innovative financing mechanisms, promoting partnerships between the public and private sectors and leveraging technological advances to improve the efficiency and attractiveness of RECs.

In conclusion, RECs represent a significant advance in the transition towards decentralised, sustainable and resilient energy systems. By reducing carbon emissions, increasing energy independence and promoting socioeconomic development, RECs play a crucial role in shaping the future of the energy landscape. While challenges such as regulatory barriers and financial constraints persist, addressing these issues through policy innovation and stakeholder collaboration will be critical to unlocking the full potential of RECs. Looking to the future, continued research and technological advances will further strengthen the role of RECs in achieving a greener and fairer energy transition.

5.4.2. Organisational Challenges and Adaptation in the REC Caserta: Governance, Participation, and Operational Frameworks

The REC model represents a fundamental shift in how local energy systems are designed, managed and governed. The case of the REC Caserta provides valuable insights into the organisational complexities and adaptation strategies necessary for the successful establishment and long-term sustainability of such initiatives. This section explores the key organisational factors, challenges and adaptation strategies that have shaped the governance structure, stakeholder engagement and operational mechanisms within REC Caserta.

REC Caserta's organisational framework is designed around a participatory and decentralised governance model, ensuring that decision-making processes remain inclusive while maintaining operational efficiency. As detailed in the previous sections, the governance structure includes a General Assembly, a Board of Directors, a President and a partner ESCO (AESI), which acts as a key technical and administrative facilitator.

However, despite its structured approach, the case study highlights some challenges in adapting governance. One of the key challenges was ensuring a balance between democratic decision-making and operational efficiency. While broad community participation is encouraged, the complexity of energy regulations, financial structuring and infrastructure management requires a high level of expertise, often beyond the capabilities of individual participants. This has necessitated greater reliance on the ESCO, which, whilst beneficial in terms of technical and administrative support, also raises questions about the degree of community control versus the influence of external management.

To address this issue, the REC has implemented hybrid governance mechanisms, where strategic decisions remain in the hands of community members, but day-to-day technical and administrative operations are managed by the ESCO. This approach ensures that REC members maintain authority and ownership over the project while leveraging the expertise of an external professional entity.

The participation model in REC Caserta follows a structured but evolving approach. Initially established with four major industrial participants, the REC membership framework is designed to be scalable, allowing for the gradual inclusion of new participants, including SMEs and residential consumers. However, one of the key organisational challenges observed was varying levels of stakeholder engagement.

Although industrial participants recognise the economic benefits of self-consumption and tariff incentives, broader community involvement has been slower than expected, mainly due to limited public awareness of the REC model and its financial sustainability. This highlighted the need for strengthened communication strategies and the creation of clearer incentive structures to encourage wider participation.

Furthermore, the role of ESCOs in promoting member engagement has proven to be both a strength and a limitation. On the one hand, the AESI facilitated participation by managing complex administrative processes, but on the other it reduced the need for direct involvement from members, potentially weakening the community's long-term commitment and self-sufficiency. Future iterations of the REC governance model may need to explore more capacity-building initiatives, such as training programs, member training workshops, and financial transparency mechanisms to encourage more active participation in decision-making.

Qualitative analysis of interview responses provides a comprehensive understanding of how different stakeholder groups perceive the effectiveness, challenges and opportunities of RECs.

Motivations for participation in RECs

The laddering method reveals that participants join RECs due to:

- Economic benefits, such as lower energy costs and potential revenue from excess energy production.
- Environmental concerns, particularly the desire to contribute to climate action and reducing carbon footprint.
- Community involvement, where individuals and businesses value participation in cooperative energy governance.

Role of ESCOs in the development of RECs

ESCOs are identified as crucial facilitators in several areas:

- Technical expertise: ensure efficient energy production, storage and distribution.
- Financial structuring: developing sustainable business models, securing financing and optimising cost structures.
- Regulatory support: navigate legal frameworks and ensure compliance with sustainability standards.

Barriers to financial sustainability in RECs

Laddering interviews highlight key financial and organisational barriers that impact the scalability and sustainability of RECs. One of the primary challenges is regulatory uncertainty, particularly concerning the stability and consistency of government incentives and the evolving framework of energy pricing structures. The lack of clear and long-term policies creates hesitation among investors and stakeholders, limiting the potential for expansion.

Additionally, operational challenges pose significant obstacles, including the complexities of integrating RES into the existing grid infrastructure and managing fluctuations in energy demand. These issues require tailored solutions that balance financial feasibility with technical efficiency, ensuring that RECs remain both economically viable and functionally sustainable in the long term.

Interviews conducted through the laddering method provide data-driven recommendations to optimise REC's financial models and organisational strategies. Below are the most important takeaways highlighted.

Improve community awareness and financial literacy

Developing educational programs is essential to ensure that community members fully understand the financial and technical implications of joining a REC. Additionally, simplifying ESCO contractual structures can enhance transparency and trust in financial agreements.

Optimising ESCO-REC partnerships

To improve the efficiency and effectiveness of REC partnerships, it is crucial to implement performance-based ESCO contracts, where financial incentives align with energy efficiency and sustainability objectives. Furthermore, increasing stakeholder involvement in ESCO decision-making processes helps prevent conflicts of interest and ensures that community members maintain influence over strategic decisions.

Strengthen financial mechanisms for scaling the REC

Expanding access to green financial instruments, such as green bonds and SLLs, will support REC growth and enhance financial sustainability. Moreover, ensuring stable regulatory frameworks is key to providing long-term political support for decentralised energy models, fostering confidence among investors and stakeholders.

By translating qualitative insights into actionable strategies, the Laddering method improves the practical relevance of the thesis, ensuring its applicability in real-world REC development.

We can conclude that the laddering method constitutes a highly effective qualitative research tool for examining stakeholder motivations, financial barriers and the role of ESCOs in REC projects. Through structured interviews with pilot participants, this approach provides insights into the economic, social and organisational factors that determine the success of RECs.

By integrating qualitative and quantitative financial analysis, this research bridges the gap between financial sustainability and community participation in decentralised energy models. The findings reinforce the importance of strategic financing mechanisms, transparent governance structures and strong ESCO-REC collaborations in scaling RECs as a viable alternative to centralised energy systems.

In summary, the Laddering method provides valuable information that contributes to the design, financing and operational success of RECs, ensuring they remain financially sustainable, socially inclusive and environmentally impactful.

One of the most critical organisational considerations at REC Caserta was the transition from the initial implementation phase to long-term operational sustainability. Initial challenges included overcoming bureaucratic complexities, securing financial incentives and structuring an energy sharing agreement that ensured equitable distribution of benefits among members.

To address these issues, the REC has adopted a phased operational strategy, where:

- Phase 1 focused on defining the legal and administrative framework, securing initial financial support and building the PV infrastructure.
- Phase 2 involved optimising self-consumption rates, refining governance mechanisms and integrating new stakeholders.
- Phase 3, still ongoing, aims to improve technology integration (e.g., smart grids, IoT-based monitoring), financial sustainability (e.g., leveraging additional incentive schemes) and operational scalability.

This structured and adaptive approach ensures that REC Caserta remains flexible in responding to regulatory changes, market dynamics and member needs. However, there remains a long-term challenge in maintaining institutional memory and leadership continuity, especially given the voluntary nature of governance roles. The ESCO's role as a long-term technical and administrative partner is likely to be critical to ensuring the operational stability of the REC.

From an organisational perspective, the REC Caserta offers key lessons for future community energy projects:

- The need for strong intermediary organisations (such as ESCOs) to manage technical, financial and administrative complexities.
- The importance of governance structures that balance inclusiveness and efficiency, ensuring both broad participation and professional management.
- The need for evolving engagement models, where initial dependence on professional entities gradually transitions to greater community autonomy through capacity building initiatives.
- The value of phased implementation strategies, which enable gradual expansion, technical refinements and financial optimisations.

Furthermore, the interaction between organisational and financial dimensions in REC Caserta highlights that operational success depends not only on well-structured governance but also on sustainable economic models. Without adequate financial incentives and risk-sharing mechanisms, participation levels could decline, leading to potential project stagnation.

This analysis highlights the fundamental role of organisational design and adaptation in the success of RECs. The case of REC Caserta demonstrates that organisational resilience, strategic governance structures and adaptive operational mechanisms are as crucial as financial and technological factors in ensuring long-term sustainability.

Going forward, the ability of RECs to expand and integrate into national energy frameworks will largely depend on the flexibility of their organisational models, the effectiveness of their governance mechanisms, and their ability to balance community-driven decision-making with professional management structures. REC Caserta serves as a replicable model for similar initiatives, providing a valuable organisational model for energy communities aiming to achieve both environmental and economic sustainability in the energy transition landscape.

CHAPTER VI – DISCUSSION AND CONCLUSIONS

6.1. Summary and Reflection on Results

6.1.1. Analysis of Key Organisational and Financial Outcomes

Evaluation of the REC model requires an in-depth analysis of its organisational structure and financial performance, which together determine the efficiency, long-term sustainability and scalability of the project. This section examines the governance framework, operational structure, financial metrics, revenue streams and economic viability of the REC, providing insights into its strengths, challenges and areas for improvement.

The REC Caserta follows a structured governance model that allows for democratic participation and fair decision-making among its members. According to the association's statute, the REC is formally structured as a non-profit organisation under the Italian legal framework, ensuring that benefits are redistributed among members rather than being concentrated in a single entity. This is in line with Europe's RED II, which encourages citizen participation in renewable energy production.

As already mentioned, the governance framework includes the General Assembly (composed of all members of the REC), the Board of Directors, the President and Treasurer and the ESCO.

The involvement of an ESCO provides a professionalized approach to REC management, reducing technical and financial burdens on community members while ensuring efficient energy distribution. This is where the decentralisation of decision-making takes place, allowing community members to actively engage in shaping the REC's energy strategy. However, this also creates a dependence on external actors, which could pose challenges in maintaining community autonomy in the long term. The need for continuous engagement and knowledge transfer between ESCO and REC members is critical to prevent asymmetries in decision-making power and technical expertise.

In addition to governance, another key challenge lies in regulatory compliance. The REC must adhere to national and European legislative frameworks, including RED II, which sets guidelines for community-led renewable energy initiatives. While these policies support the creation of RECs, they also impose administrative burdens that can delay project implementation and increase costs.

The REC's financial success is measured using key financial indicators; for the analysis of this project, the key financial indicators used to evaluate its economic feasibility include:

- NPV: €14,165, which indicates the total profitability of the REC during its operational life.
- IRR: 7.4%, demonstrating the attractiveness of the project for investors.
- PBT: 10.28 years, which represents the time needed to recover the initial investments.
- Revenue flows: generated by self-consumption incentives, energy sales and network services, ensuring diversified sources of income.

One of the most critical financial considerations for REC is the balance between initial capital investment and long-term profitability. In this case, the initial capital investment required for the REC infrastructure was partially mitigated by the ESCO intervention, allowing the financial risk for community members to be reduced. ESCO’s role in the financing and management of energy infrastructure ensures professional oversight but also introduces contractual obligations that require careful financial planning. The use of government incentives and subsidies also plays a crucial role in determining financial sustainability, as direct revenues from energy sales alone may not be sufficient to cover operating and maintenance costs.

The REC generates income through a combination of:

- Incentives for self-consumption: members benefit from lower energy costs and government incentives for consuming locally produced energy, reducing dependence on external electricity suppliers.

- Sale of energy to the grid: excess energy is sold at the market price of €0.06/kWh, providing additional income.
- Incentive mechanisms: the REC receives €120/MWh for shared energy production below 200 kW, with additional financial benefits for members.

From a cost perspective, operational expenses include system maintenance, administrative expenses, and regulatory compliance costs. To optimise financial performance, the REC has implemented a cost-sharing mechanism, distributing maintenance and management expenses equally among participants. However, ensuring a stable long-term revenue stream remains a key challenge, as market fluctuations in energy prices and changes in incentive systems could impact expected financial results.

While the REC model has a solid financial foundation, some risks and uncertainties could impact on its long-term success:

- Market volatility: fluctuations in energy prices may impact expected revenues.
- Regulatory changes: policy adjustments at national or European level can alter incentive structures.
- Investment risks: the REC relies on long-term financial projections and unexpected economic conditions could impact its sustainability.

Mitigation strategies include conducting a sensitivity analysis to evaluate the impact of changing self-consumption tariffs and network sales values on financial returns. A diversified financial approach, integrating community reinvestment and strategic partnerships, could further strengthen economic resilience.

This REC model demonstrates a competitive financial outlook, with a moderate IRR and stable revenue streams. However, improvements in self-consumption efficiency and the integration of energy storage could further improve financial performance. European RECs operating under different policy frameworks and incentive schemes provide useful benchmarks to refine the model and explore best practices.

The REC model has significant potential for scalability and replicability. Expanding the project to include additional members, larger solar installations or storage solutions could increase financial sustainability.

Future developments could include:

- Intelligent EMS: implementation of advanced digital platforms to optimise consumption and distribution.
- Expanded member participation: Encourage new members to join and benefit from lower energy costs.
- Partnerships with municipalities and businesses: creating synergies to enhance community-level sustainability efforts and to secure political support and additional funding.

Given the growing importance of decentralised energy systems, further research should focus on how to integrate RECs into national energy strategies to maximize their environmental and economic contribution.

As the REC continues to develop, policy alignment and regulatory adaptation will be crucial to shaping its future. The European Green Deal and national energy transition plans offer opportunities for further financial support and expanded community energy models. The role of ESCOs in facilitating the transition to decentralised energy systems will become even more significant, underlining the need for clear governance frameworks and long-term financial planning.

The REC's governance and financial model demonstrate a sustainable path to local energy autonomy, strengthening its role as a model for future decentralised energy initiatives. Next steps should focus on increasing self-consumption rates, optimising the use of incentives and expanding the REC's participation model, ensuring its continued contribution to the broader energy transition.

The analysis of the main organisational and financial results of the REC Caserta underlines the importance of a well-structured governance model and solid financial planning and highlights its economic feasibility, governance efficiency and long-term sustainability potential. While challenges exist in terms of financial risks and market dependencies, the overall structure remains robust and adaptable. Future developments should focus on improving self-consumption strategies, optimising the use of incentives and expanding the scope of REC to maximize its contribution to the clean energy transition. By refining these elements, the REC can serve as a replicable and scalable solution to promote energy democracy and accelerate the transition to clean energy across Europe.

6.1.2. Role of ESCOs and the Potential of RECs for the Energy Transition

The integration of ESCOs within RECs has emerged as a transformative force in the global energy transition. As decentralised energy systems gain traction, the skills, financial capabilities and technological solutions offered by ESCOs play an increasingly critical role in facilitating the implementation and efficient management of community-led renewable energy projects. This section examines the nuanced role of ESCOs in RECs, their financial and operational contributions, and the potential of RECs in driving a sustainable energy transition.

ESCOs act as key enablers in the REC model by offering a range of services that improve operational efficiency, financial sustainability and regulatory compliance. Their involvement is particularly beneficial to communities that lack the technical expertise or financial resources needed to create and maintain energy infrastructure. The main roles of ESCOs within RECs can be classified as follows.

Technical expertise and infrastructure development

ESCOs are tasked with identifying the best locations for installing PV systems, conducting pre-sizing studies and using specialized software to estimate energy production. They contribute to the design, implementation and maintenance of renewable energy infrastructure and integrate smart grid technologies, operate energy storage solutions and oversee grid interactions to maximize efficiency and self-consumption rates within RECs.

Financial structuring and investment facilitation

Many RECs have difficulty securing start-up capital for renewable energy projects. ESCOs can act as investors, financing infrastructure to ease the financial burden on REC members. Economic benefits are shared between the ESCO and the community, with the financial returns allocated to the ESCO as the main investor, while community members benefit from reduced energy costs and incentives.

Regulatory compliance and policy navigation

Given the complexity of energy regulations at national and community level, ESCOs act as a legal and administrative point of reference for the REC. Their experience ensures compliance with legal frameworks, maximization of available subsidies and alignment with national energy transition strategies.

Aggregation of energy demand and supply

ESCOs play a key role in optimising energy flows by aggregating multiple consumers and producers within RECs. This allows for better load balance, greater efficiency and greater economic profitability for participating members. In some cases, they may function as a legal representative or contract manager, particularly when REC members lack the expertise to manage regulatory requirements.

The governance model adopted by a REC directly influences and determines both the extent and nature of ESCO involvement, as well as the overall degree of decision-making autonomy exercised by the community itself. There are three main models of ESCO-REC integration available, each offering different balances between external expertise and community control.

Model led by ESCO

In this structure, ESCOs take a central role in managing REC operations, making key decisions regarding infrastructure, financial planning and regulatory compliance. While this model offers professional management and financial stability, it requires clear contractual agreements to ensure that community members retain decision-making power over key aspects.

Collaborative governance model

This model balances ESCO expertise with community-led governance. The REC maintains an independent governing body by leveraging ESCOs as consultants or service providers. This ensures that technical and financial expertise is accessible while preserving democratic control over strategic decisions.

Public-private partnership model.

In this hybrid model, ESCOs collaborate with local municipalities and public bodies to manage and finance RECs. This approach leverages public policy support, subsidies and municipal oversight, making it particularly effective for large-scale REC projects with long-term policy objectives.

The economic sustainability of RECs is significantly improved through ESCO partnerships. Some of the major financial benefits include:

- Reduction of capital expenditure: by exploiting the investment and financing mechanisms of ESCOs, RECs can implement renewable infrastructure with lower initial financial burdens.
- Optimised operating expenses: ESCOs implement advanced monitoring and maintenance strategies, reducing long-term operating costs.
- Revenue generation through energy sharing: ESCOs facilitate the trading of excess energy within the REC and with external markets, increasing profitability for community members.

- Risk Mitigation: ESCOs' professional risk assessment capabilities help RECs address market volatility, regulatory changes and financial uncertainties.

From a technical point of view, ESCOs promote the efficiency and sustainability of RECs:

- Smart grid and demand-response systems: ESCOs implement smart meters, real-time monitoring and demand management strategies to optimise energy distribution.
- Energy storage solutions: by integrating battery storage, ESCOs improve energy reliability and minimise grid dependency, ensuring stability during peak demand periods.
- Lifecycle management: ESCOs oversee the entire lifecycle of renewable energy assets, ensuring maximum performance and durability.

In terms of environmental impact, ESCO-supported RECs contribute to substantial CO2 reductions by replacing fossil fuel-based energy sources with clean alternatives. These communities also promote biodiversity conservation, improved air quality and resource efficiency through decentralised and locally managed production of renewable energy.

Despite the significant benefits of involving ESCOs, several challenges remain:

- Balancing ESCO's influence and community autonomy: ensuring that REC members maintain control over decision-making while benefiting from the ESCO's expertise requires well-defined governance structures.
- Regulatory uncertainty: variations in national policies and incentive structures create uncertainties in long-term planning for both ESCOs and RECs.

- Financial viability and revenue uncertainty: while ESCOs provide financial solutions, ensuring consistent revenue generation from RECs remains a challenge in highly variable energy markets.
- Technical adaptation challenges: deploying smart grids and demand management tools requires continuous adaptation and investment in emerging technologies.

Looking ahead, ESCOs and RECs are poised to play a transformative role in the broader energy transition. Key trends shaping their future include:

- Integration with digital technologies: the adoption of AI-based EMS, blockchain-based energy trading and predictive analytics will further improve the efficiency and scalability of REC.
- Expanding policy support: as governments intensify their commitment to climate goals, additional subsidies, tax incentives and regulatory frameworks are expected to drive the expansion of RECs.
- Scalability and replicability: successful REC-ESCO models can be scaled and replicated across various regions, facilitating widespread adoption and contributing to national and EU decarbonization goals.
- Corporate and industrial collaboration: in addition to residential communities, ESCOs are increasingly collaborating with industrial clusters and commercial sectors to create large-scale RECs, leveraging their financial and technical expertise.

In conclusion, ESCOs serve as catalysts in the development and long-term success of RECs by filling technical, financial and regulatory gaps. Their involvement improves the financial sustainability, efficiency and scalability of RECs, making them valid contributors to the energy transition. However, achieving an optimal balance between ESCO expertise and community autonomy remains essential to preserve the decentralised and democratic nature of RECs. With continued advances in technology, policy support and innovative business models, ESCOs and RECs will continue to play a crucial role in reshaping the future of decentralised renewable energy systems. The next step to maximizing this potential involves refining governance structures, increasing public-private collaboration, and leveraging emerging digital tools to further drive the expansion and sustainability of the REC model.

6.1.3. Importance of an Integrated Approach Between Organisation and Finance for Distributed Self-Consumption

The growing adoption of distributed self-consumption models within RECs requires a holistic approach that integrates both the organisational and financial dimensions. Self-consumption is fundamental to the economic viability of decentralised energy systems. A well-structured organisational framework, combined with a solid financial strategy, ensures that self-consumption is not only technically feasible but also economically sustainable. This section explores the critical interaction between governance structures, financial mechanisms and operational strategies in maximizing the benefits of distributed self-consumption.

The organisational model of a REC plays a fundamental role in enabling efficient energy self-consumption. A well-defined governance framework ensures equal participation, transparency and financial accountability. In this context, ESCOs are key actors who facilitate the technical, financial and legal structuring of RECs by providing investment support, technological integration and optimisation of self-consumption strategies. While energy consumers and producers are the stakeholders who actively participate in the self-consumption model, ensuring that energy is distributed efficiently within the community. The balance between production and consumption within the REC has a direct impact on the financial results and energy independence of the community.

Decentralised decision-making fosters community participation and ensures that financial resources are allocated efficiently. However, the balance between community-driven decision-making and reliance on external entities such as ESCOs requires careful planning to maintain operational autonomy while leveraging external expertise. This synergy ensures that financial decisions are aligned with the community's energy needs and investment priorities.

The financial sustainability of self-consumption models depends on a wide range of financing mechanisms and revenue streams. These include:

- Incentives for self-consumption: in Italy the economic benefits are granted based on the percentage of energy consumed within the REC. The tariff premium may vary, with a basic incentive of €80/MWh and a maximum of €120/MWh, depending on geographical factors and system efficiency.
- Capital grants (PNRR Grants): up to 40% of eligible investment costs can be subsidized for communities in municipalities with fewer than 5,000 residents.
- Market revenue from network sales: excess energy not self-consumed is sold to the network at an average market price of €0.06/kWh, generating additional revenue for the REC.
- Reduction of network tariffs: self-consumed energy benefits from the elimination of transmission and distribution costs, resulting in an increase in financial returns.

The interaction of these financial mechanisms determines the economic feasibility of a self-consumption model. Effective financial planning, particularly in balancing self-consumption tariffs with network sales, is essential to maximizing returns for REC participants.

A fundamental aspect of an effective self-consumption model is the perfect integration between governance structures and financial strategies. The financial sustainability of a REC depends on how well its organisational model can support investment decisions, risk management and revenue distribution. Key areas of integration include:

- Decision making and financial planning: the Board of Directors and General Assembly must align financial decisions with community needs, ensuring that investments in renewable infrastructure, EMS and storage solutions are strategically allocated.
- ESCO collaboration: ESCOs not only provide technical expertise but also shape the financial structure of the REC. Their role extends beyond project financing and extends to optimising incentive systems, evaluating cost reduction opportunities and improving revenue distribution mechanisms.
- Revenue sharing and member participation: the governance framework must establish clear guidelines for the distribution of financial benefits among members. Through reduced energy costs, direct financial returns, or reinvestment in community projects, the organisational model determines how financial benefits are leveraged.
- Long-term sustainability strategies: a forward-looking financial strategy should consider expansion opportunities, risk mitigation and policy adaptation. The governance structure plays a key role in ensuring that regulatory changes and market fluctuations do not undermine financial stability.

The effectiveness of a REC depends not only on its financial solidity but also on its ability to integrate economic management with a structured and efficient governance model. This synergy between organisational and financial aspects allows the optimisation of resources, guarantees a fair distribution of benefits and facilitates long-term sustainability.

The organisational framework of the REC directly influences economic management and financial decision-making. A clear and transparent governance model is essential to ensure that community members have a say in fund management, resource allocation and strategic planning.

A well-structured governance model prevents conflicts between members and ensures efficient and participatory management of resources.

The financial sustainability of the REC is based on the correct management of the distribution of incentives and the generation of revenues from energy sales. Several strategies can be implemented to maximize the financial value of the community:

- Standard Model: 80% of the incentives are intended for the ESCO, which covered the initial investment, while the remaining 20% is distributed among the REC members.
- Alternative model: a 50-50 split between ESCO and community could increase the attractiveness of the REC, encouraging greater participation and fostering a stronger sense of belonging among its members.
- Revenue reinvestment: some RECs reinvest their revenues in new installations, energy storage systems, or educational programs to raise awareness about energy efficiency.

The objective is to find a balance between financial sustainability and benefits for community members, maximizing self-consumption and minimising losses in economic value.

Another key aspect of integrating organisational and financial elements is financial transparency, which helps maintain trust among members and investors.

- The use of digital platforms for monitoring financial flows can improve reporting processes and allow members to monitor the economic performance of the REC in real time.
- Regular financial reports and information sessions with community members raise awareness about resource allocation.
- An internal or external control system ensures responsible management of funds and prevents accounting discrepancies.

These tools enable the active participation of stakeholders and promote a more equitable and sustainable management model.

In this framework, ESCOs play a critical role in ensuring the financial and operational efficiency of RECs by conducting feasibility studies and implementing intelligent energy management solutions to maximize self-consumption, creating synergies that enhance collective self-consumption and improve load adaptation, and by sharing financial risks with REC members while ensuring long-term economic sustainability.

Furthermore, the adoption of digital platforms and EMS allows for real-time monitoring and optimisation. Technologies such as smart meters, predictive demand forecasting and battery storage integration improve energy efficiency and increase self-consumption rates, reducing dependence on external grid energy.

The effectiveness of distributed self-consumption models is significantly influenced by regulatory frameworks. Italy's implementation of the RED II Directive (D. Lgs. 199/2021) establishes the legal bases for RECs, defining criteria for the eligibility of incentives, energy sharing mechanisms and financial compensation structures. However, regulatory barriers remain, including:

- Complex administrative procedures: lengthy approval processes for REC registration and incentive applications create delays in implementation.
- Tariff volatility: the fluctuation of electricity market prices affects the predictability of financial returns.
- Power sharing limitations: the requirement that RECs operate within a primary substation area limits scalability and potential expansion.

Addressing these challenges through policy reforms, such as simplifying registration procedures, introducing dynamic pricing structures and expanding geographic eligibility for RECs, could further improve the financial sustainability of self-consumption models.

To ensure long-term sustainability, future developments in distributed self-consumption should focus on:

- Incentive optimisation: review incentive structures to encourage higher self-consumption rates, such as increasing the tariff premium for communities achieving more than 55% self-consumption.
- Expanding REC participation: encourage large-scale participation by allowing inter-municipal RECs to share infrastructure and financial benefits.
- Advanced energy storage solutions: integrate battery storage at the community level to improve energy independence and reduce grid dependency.
- Integration with green financing models: leverage mechanisms such as green bonds and cooperative financing to support long-term investments in decentralised energy infrastructure.

A successful distributed self-consumption model requires an integrated approach that aligns organisational governance with financial planning. By promoting strong governance structures, leveraging financial incentives and adopting innovative energy management technologies, RECs can optimise self-consumption, improve economic sustainability and contribute to broader sustainability goals.

The role of ESCOs remains crucial in facilitating technical implementation and investment, but regulatory refinements and policy advances are essential to unlock the full potential of distributed self-consumption. Going forward, aligning financial incentives with self-consumption goals and expanding participation frameworks will be critical to ensuring the scalability and long-term impact of RECs in the transition to a decentralised energy system.

6.2. Practical and Academic Implications

The transition to a sustainable energy system requires global policies and strategic interventions from both policy makers and local stakeholders. RECs represent a transformative model for decentralised energy production, enabling local governments to efficiently generate, consume and distribute renewable energy. However, several regulatory, financial, technical and social challenges need to be addressed to improve their scalability and effectiveness. This section outlines key recommendations for policy makers and local stakeholders to promote the development of RECs as a cornerstone of the energy transition and explores possible improvements, such as alternative incentive redistribution models and higher grid sales prices to increase the attractiveness of RECs.

6.2.1. Recommendations for Policymakers and Local Stakeholders

One of the main challenges for RECs is the lack of a clear and harmonized regulatory framework that supports their long-term sustainability. To address this issue, politicians must clarify and simplify legal structures by establishing a standardized legal definition of RECs at both the national and EU levels, thereby reducing bureaucratic complexity and streamlining administrative procedures. They should also facilitate access to the grid by ensuring that RECs are granted guaranteed and prioritised entry under transparent and fair tariffs that adequately reflect their contribution to local energy resilience.

Moreover, it is essential to improve long-term regulatory stability through the implementation of consistent policies that provide certainty for REC investors, thus avoiding abrupt changes in fee structures, incentives, or taxation. Local authorities, particularly municipalities, should be encouraged to support the formation of RECs by offering logistical assistance, regulatory relief, and access to public spaces for renewable energy installations.

Finally, policymakers need to address the complexity of the incentive mechanism by ensuring that the incentive structures remain financially sustainable, with clear definitions related to self-consumption thresholds, feed-in tariffs, and capital contributions; the implementation of predictable and fair zonal tariffs could further enhance investor confidence and stimulate broader participation, while alternative benefit-sharing models—such as adjusting the incentive redistribution rate—may render RECs more attractive to both investors and participants.

Financial barriers remain one of the most significant obstacles to REC expansion. Policymakers and financial institutions should expand public subsidies and tax incentives by introducing dedicated grants, tax credits, or low-interest loans to reduce initial capital expenditures and encourage community participation. At the same time, innovative financing mechanisms need to be developed through alternative models such as green bonds, cooperative financing schemes, or PPPs to support REC development

It is also essential to encourage ESCO participation by strengthening policies that incentivize these companies to invest in REC infrastructure, leveraging their technical expertise and financial capacity. Moreover, introducing market-based incentives that provide higher remuneration for the excess renewable energy fed into the grid can ensure financial sustainability and a satisfactory ROI. A flexible tariff system must be facilitated as well; reconsidering the current variation of feed-in tariffs (80-120 €/MWh) based on zonal energy prices would offer greater revenue predictability for RECs and prevent community projects from being overly affected by market fluctuations.

In addition, increasing the price of energy sales—for instance, by offering a higher grid sales price for excess renewable energy—could significantly boost the attractiveness of REC projects, spurring greater participation and yielding improved financial returns for members.

The technical integration of RECs into national energy systems requires targeted policy interventions. Policymakers should encourage the development of smart grids by prioritizing investments in smart grid technology and digital monitoring systems, which are essential for effective energy management and smooth grid interaction for RECs. Furthermore, promoting energy storage solutions through the introduction of incentives for battery storage systems and other energy storage technologies is key to increasing self-consumption rates and maintaining grid stability.

It is equally important to impose interoperability standards, establishing uniform technical criteria for REC EMS to ensure their seamless integration with national grids and other energy players. Public funding must also be directed towards investment in research and development to drive innovation in areas such as energy management platforms, blockchain-based energy trading and AI-based predictive analytics for RECs.

To conclude, ensuring there are robust grid strengthening plans in place is key to ensuring REC growth is supported by long-term grid infrastructure development, thus preventing increased local energy production from causing grid congestion or distribution inefficiencies.

The success of RECs depends on active local participation and solid collaboration of stakeholders. Politicians and local governments must increase public awareness and education by developing national campaigns and training programs to inform citizens, businesses and municipalities about the benefits of RECs. They should also encourage the participation of local businesses through financial incentives for SMEs, thus promoting local economic development and energy independence.

Furthermore, it is essential to strengthen local governance models; municipalities must be equipped with dedicated REC advisory bodies that can assist in structuring projects, ensure administrative compliance and support capacity-building initiatives. It is equally important to ensure fair and inclusive participation by introducing mechanisms that promote the involvement of marginalized communities, ensuring equitable access to the benefits of renewable energy.

Finally, policies should facilitate the expansion and scaling of RECs by supporting the gradual growth of REC models –allowing for the inclusion of additional members and an increase in installed renewable capacity– while structuring financial incentives to encourage progressive scaling rather than limiting them to small-scale installations.

The wider social and environmental impacts of RECs should be an integral part of policy planning. Policymakers and stakeholders need to align with national and EU climate objectives, ensuring that REC policies effectively contribute to achieving national decarbonisation goals and European Green Deal objectives. In doing so, they must also encourage circular economy principles by promoting energy efficiency measures, waste-to-energy initiatives and sustainable production-consumption cycles within RECs.

Furthermore, it is crucial to improve air quality and promote the protection of biodiversity by introducing regulations that prioritise REC projects in areas with high levels of pollution, thus mitigating environmental degradation and supporting biodiversity conservation. In addition to these measures, it is essential to establish key performance indicators to monitor social benefits, such as job creation, increased energy security and cost savings for households. Moreover, to promote energy security and independence, policymakers should promote self-sustaining REC models that reduce dependence on centralised energy markets and external energy suppliers, ultimately contributing to greater energy sovereignty at both local and national levels.

For RECs to become a long-term pillar of the energy transition, governments need to align REC policies with broader national and European energy transition plans. This means that governments should incorporate RECs into national energy strategies by formally integrating them into long-term planning frameworks, ensuring policy coherence everywhere. Furthermore, facilitating cross-border collaboration between RECs in different EU Member States can accelerate the adoption of best practices and technological innovation. Governments are also advised to legislate minimum renewable energy quotas for communities, requiring that a certain percentage of local energy consumption come from community-based renewable sources. As energy markets evolve, it is critical that REC policies remain adaptable, with periodic reassessments to incorporate emerging technologies and market developments.

Additionally, supporting multilevel governance by promoting collaboration between national, regional and local authorities is essential to harmonize REC policies and ensure effective implementation at various administrative levels.

RECs represent a transformative approach to energy production, decentralisation, and sustainability. However, their long-term success hinges on well-defined policies, financial incentives, technical infrastructure, and community engagement. The recommendations outlined in this section provide a roadmap for policymakers and local stakeholders to enhance REC adoption, ensuring their role as key contributors to the European energy transition. By implementing these strategies, national governments, municipalities, and energy regulators can create a thriving ecosystem where RECs play a central role in driving energy democracy, sustainability, and economic resilience.

6.2.2. Contribution of the thesis to academic knowledge and operational practices

This thesis provides a comprehensive analysis of RECs, bridging the gap between theoretical research and practical implementation. By integrating financial, regulatory, and organisational aspects, the study offers a structured framework to evaluate the effectiveness of RECs and their role in energy transition strategies. The findings of this research contribute to both academic discourse and the real-world operationalization of RECs, offering valuable insights for policymakers, industry stakeholders, and future scholars.

The study advances academic knowledge in multiple ways, addressing key gaps in the literature. First, it provides an in-depth analysis of the financial models applicable to RECs, offering a refined approach to assessing economic feasibility. Many existing studies focus on broad policy discussions or technical specifications, but this thesis delves into how financial mechanisms, incentive structures, and pricing models influence REC sustainability. By integrating concepts such as self-consumption optimisation, pricing strategies, and investment risk mitigation, the research offers a quantitative and qualitative assessment of financial sustainability (Adelekan et al., 2024).

Second, the study enhances the understanding of governance models and organisational structures within RECs. While previous research recognises the importance of collective decision-making, this thesis systematically explores how different governance frameworks impact financial performance, stakeholder engagement, and regulatory compliance. It also highlights the role of ESCOs in facilitating the formation and management of RECs, a topic that has received limited attention within existing work (Aggeli et al., 2022). Previous studies on governance structures have generally focused on aspects such as ownership models, participatory decision-making, and stakeholder influence, but have not combined these insights with financial evaluations in a holistic framework.

Third, the research contributes to the regulatory discourse on RECs by examining policy inconsistencies, barriers to entry, and areas for improvement within the legislative framework. Although European directives such as RED II have provided the basis for the development of RECs, their transposition into national policies has often led to complex regulatory environments that hinder widespread adoption. By analysing Italian legislation (D. Lgs. 199/2021) and related incentive structures, this thesis identifies practical recommendations to refine policies aimed at improving accessibility, financial feasibility, and long-term scalability (Trevisan et al., 2023).

Finally, this research offers an interdisciplinary perspective by combining elements of finance, law, economics, and organisational behaviour. Unlike purely technical or legal studies, this thesis provides a holistic approach, ensuring that the findings are applicable to both academic research and industrial implementation. The methodology applied in this research is particularly innovative as it combines both qualitative and quantitative approaches to assess the interplay between financial and governance aspects within RECs (Andoni et al., 2022).

Beyond its academic contributions, this thesis provides direct applications to professionals in the renewable energy sector, including REC developers, ESCOs, policymakers, and local authorities. The study's findings are directly applicable to financial planning and investment optimisation, as it examines various financial structures, incentive schemes, and pricing strategies, offering practical guidance for organisations looking to develop or invest in RECs. By focusing on NPV, IRR, and PBT, the research enables investors and stakeholders to make data-driven decisions and identifies optimal incentive allocation strategies that maximize both economic returns and social benefits (Affari di Borsa, n.d.).

Policymakers can use the findings to refine incentive mechanisms, pricing structures, and regulatory frameworks, addressing obstacles such as bureaucratic complexities, unclear policies, and inconsistent distribution of incentives. The structured analysis of how incentive policies influence REC growth serves as a benchmark for future regulatory improvements and policy adjustments (European Commission, 2023). In terms of operational efficiency and energy management, the thesis highlights the importance of efficient self-consumption and interaction with the grid, providing practical recommendations for REC operators and ESCOs. It highlights strategies to improve energy distribution, leverage digital tools for energy monitoring, and optimise demand response mechanisms while emphasizing the role of ESCOs in balancing financial and operational sustainability to ensure RECs remain economically viable in the long term (Di Silvestre et al., 2018).

The study also addresses stakeholder engagement and community participation, recognizing the challenge of ensuring active member involvement. It offers insights into how financial incentives, transparent governance structures, and effective communication strategies can improve stakeholder engagement, a finding particularly relevant to municipalities and community leaders seeking to establish socially inclusive REC models that benefit both businesses and citizens (Ahmed & Măgurean, 2024).

This thesis contributes to the broader energy transition debate by demonstrating how RECs serve as scalable and decentralised solutions to increase the adoption of renewable energy. The study reinforces the idea that RECs are not only financially sustainable but also play a crucial role in achieving European and national sustainability goals. Specifically, it aligns with key policy frameworks such as the European Green Deal and the United Nations SDGs, highlighting the importance of localised energy generation, community-led initiatives, and collaborative energy-sharing models (European Commission, 2021).

Furthermore, this research challenges existing assumptions about REC scalability and financial independence. While many policy discussions assume that RECs require substantial government intervention, this study explores how alternative financial mechanisms, the involvement of ESCOs, and market-driven models can reduce subsidy dependency and increase the autonomy of RECs (Cebekhulu et al., 2024). By providing an evidence-based framework for evaluating the financial and operational performance of RECs, this thesis offers practical tools to scale up community energy projects, improve financial planning, and enhance regulatory adaptability. The findings encourage policymakers to develop long-term support mechanisms, ensuring RECs remain a cornerstone of decentralised energy systems (IRENA, 2023).

The case study analysed in this research specifically examines the role of an ESCO (AESI) within a REC, focusing on its governance model and financial structure. Unlike previous studies that have analysed ESCOs as purely technical facilitators, this research demonstrates how AESI plays an active role in decision-making processes and financial planning, justifying its inclusion in the board of the REC. The findings suggest that the level of involvement of an ESCO should be proportional to its financial and operational contribution, and in this case, the AESI model aligns well with the governance and investment strategy of the REC (Bertoldi & Boza-Kiss, 2017).

Overall, this thesis offers a significant contribution by integrating financial and governance aspects into a unified analytical framework. This holistic and interdisciplinary approach provides a deeper understanding of the factors that drive REC success and sustainability, making it a valuable reference for future research, policy formulation, and practical implementation in the renewable energy sector.

By highlighting the financial viability, governance efficiency, and regulatory adaptability of RECs, this study offers a roadmap for scaling up community-driven energy models and ensuring their long-term sustainability within the global energy transition (OECD, 2020).

6.2.3. Limitations and Future Research Opportunities

The study of RECs remains a rapidly evolving field, with increasing attention from scholars, policymakers, and energy industry stakeholders. As these models play an increasingly vital role in energy decentralisation and sustainability strategies, future research must address critical gaps, explore new methodologies, and develop innovative frameworks to improve their effectiveness. This section outlines the limitations of the current study and the most pressing research prospects, highlighting key areas for doctoral studies and further academic investigation.

First, because this study is based on a single REC case, it is not possible to generalize the results and analysis to other RECs and contexts. Second, the financial empirical analysis rests on the assumption of different simulation scenarios, and it is not possible to follow up on the actual economic performance of the REC and, therefore, the interplay between governance structure, financial and incentive analysis, and the final performance of the REC since it has not been realised yet. Third, the qualitative analysis in terms of technological scenarios and the motivations to join the REC and the role of the ESCO is limited to some key technology and assumptions, and players and therefore not exhaustive.

However, these limitations represent a stimulus for future research that I will summarize below and further discuss in the next paragraphs:

- A deeper analysis of REC financing models, exploring how different capital structures, incentive mechanisms and revenue sharing models impact long-term sustainability.
- Comparative studies between different national REC frameworks, examining how regulatory environments shape REC performance, financial sustainability and community engagement.
- Technological advances in REC management, including the role of smart grids, AI-based energy forecasting and blockchain-based energy trading.

The role of ESCOs in emerging REC models, particularly in facilitating the scalability and investment attractiveness of community energy projects.

A complete understanding of RECs requires further research across multiple domains. Future studies should aim to gain deeper insight into financial models and economic sustainability, as RECs need to be financially sustainable in the long term to ensure continued participation of members and investors. However, existing financial models for RECs remain underdeveloped and further analysis of investment structures, revenue streams and risk management mechanisms are required.

Questions persist about the profitability of RECs, their ability to attract private capital and the most effective financing methods, be they green bonds, crowdfunding or institutional investments. Furthermore, research should focus on how to improve financial sustainability by optimising incentive structures, pricing mechanisms and fee allocation.

In terms of regulatory and policy frameworks, the landscape surrounding RECs is often unclear, fragmented or highly variable across jurisdictions. Future research should analyse the current policy context and propose improvements to improve the legal and regulatory conditions for the development of RECs. This includes examining how incentive structures, pricing models and market integration policies can be refined to encourage broader REC participation, as well as highlighting the role of ESCOs in navigating the regulatory landscape, acting as intermediaries and facilitating administrative compliance.

Governance structures and organisational frameworks also play a critical role in determining the success of a REC. Future research should explore which organisational structures, decision-making processes, and participatory mechanisms are most effective for improving REC performance. Furthermore, studies should analyse how ESCOs act as facilitators by providing expertise in energy management, financial structuring and legal compliance, while examining how community-led governance versus ESCO-led frameworks influence efficiency, scalability and financial sustainability.

The role of ESCOs in improving REC functionality is another key area of investigation. ESCOs serve as key players in technical design, financial structuring, legal compliance and operational management. Further research should investigate:

- How ESCOs facilitate the creation of RECs by aggregating different energy consumers.
- The extent to which ESCO involvement improves financial stability and reduces risks for individual participants.
- The challenges ESCOs face in balancing their business models with community-oriented objectives, particularly when managing fee structures and incentive allocation.

Social and behavioural dynamics in RECs also deserve closer scrutiny, as RECs depend on the active participation of consumers. Future research should explore what motivates consumers to join and remain in a REC, how collective decision-making impacts energy consumption patterns, and how behavioural incentives – such as differentiated tariff structures or reward systems – influence energy efficiency and self-consumption rates.

Finally, the widespread adoption of RECs is hampered by numerous obstacles and challenges that require further study. Future research should focus on identifying and proposing solutions for:

- Regulatory complexity: many REC policies remain unclear, leading to difficulties in legal structuring, access to incentives and long-term planning.
- Financial barriers: the high up-front costs associated with REC infrastructure discourage many potential participants. Research should explore alternative financing mechanisms to facilitate investment and reduce financial risk.
- Public awareness and participation: many potential participants are unaware of RECs or lack the knowledge needed to engage effectively. Research should explore communication strategies, educational campaigns and digital tools that can improve awareness and accessibility.

Given the multidisciplinary nature of RECs, future research should employ a variety of methodologies to build a more complete understanding of their function and impact. Although complex technical models should be avoided, some potential approaches include:

- Case studies: Comparative analysis of different RECs can provide insights into best practices, challenges and success factors.
- Economic Simulations: Model different financial structures and tariff allocations to evaluate their long-term sustainability and profitability.
- Policy Analysis: Evaluate the effectiveness of existing REC regulations and propose new incentive and governance frameworks.

These methodologies will allow researchers to bridge existing knowledge gaps while keeping the findings accessible to both academic and non-academic stakeholders.

For PhD students and researchers aiming to specialize in RECs, several key areas present opportunities for impactful studies. These include policy and regulation, which investigates how legal frameworks influence the scalability and efficiency of RECs, financial optimisation, focusing on alternative financing methods for RECs and their long-term economic viability, and ESCO integration, assessing the role of ESCOs in REC development and their impact on financial and operational performance. Some other relevant research areas are referred to tariff and incentive structures, examining how pricing mechanisms can be adjusted to maximize participation and profitability, and social behaviour and participation, exploring consumer engagement strategies and the factors that influence sustained involvement in RECs.

Future research should help refine REC policies by highlighting the need for simplified administrative processes, better incentive schemes and better market integration strategies. Specifically, the research should highlight the need for clearer guidelines on tariff structures, in particular value thresholds, incentive mechanisms, capital contributions and energy rating models.

It should also address the potential impact of dynamic pricing models that adjust tariffs based on self-consumption levels and energy market fluctuations, while underlining the need for greater collaboration between RECs, ESCOs and policymakers to create regulatory environments that support energy autonomy and local economic development.

As RECs continue to develop, future studies must ensure that their economic, regulatory, and social dimensions are fully explored. Research must focus not only on financial sustainability and governance, but also on overcoming key barriers such as unclear regulations, financing difficulties and consumer engagement. Furthermore, given the central role of ESCOs, it is essential to explore how their involvement can be optimised to maximize the economic and operational benefits of RECs while maintaining community control.

By addressing these areas of research, the academic community can contribute to the refinement and expansion of RECs, ensuring their long-term sustainability as a key component of the energy transition. Future doctoral research in this field will play a key role in shaping innovative policies, optimising financial models and strengthening the role of RECs in decentralised energy production.

Ultimately, this thesis positions RECs as a viable, scalable, and essential solution for driving forward a sustainable, decentralised, and community-led energy future. By bridging the gap between rigorous academic research and real-world implementation, the insights presented offer a clear and actionable contribution to the field, providing a solid foundation for policymakers, investors, and community leaders. Importantly, the research highlights the significant role ESCOs can play in facilitating REC's development. This foundation empowers stakeholders not only to accelerate the adoption of renewable energy solutions but also to foster greater community engagement, economic resilience, and environmental sustainability. As a result, moving forward, continued collaboration and strategic support from ESCOs and other key players will be crucial in overcoming existing barriers and maximising the potential of RECs to meaningfully transform global energy systems and achieve lasting change.

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APPENDICES

Appendix A: Laddering Questionnaire

The objective of this research is to analyse the motivations that drive respondents to participate in a Renewable Energy Community (REC). There are no right or wrong answers; furthermore, all responses are collected anonymously and aggregated to understand the most important themes that guide the decision to take part in this project.

Column 1	Column 2 – Why?	Column 3 – Why?
Reasons	**Why is this important to you?**	**Why is this important to you?**
Possibility for development/growth	It can lead to acquiring new customers and increasing business by building new plants.	As an entrepreneur, it is important for me to seize new opportunities that bring benefits to the company.
Contribution to CO2 emissions reduction (environmental impact)	Reputation and image. Gaining reliability and thus greater competitiveness in the market.	From a future perspective, this could add value to the company, for example by facilitating the acquisition of energy and environmental certifications.
Economic benefit	Even if small, there is a return from incentives which, in the case of large-scale projects, would be greater.	It could partly motivate/facilitate the company's participation in other initiatives if this project proves to be a success.

Column 1	Column 2 – Why?	Column 3 – Why?
Economic benefit	Possibility of saving money by amortizing the cost of building the plant.	It allows generating revenue from consumed energy without taking risks.
Contribution to the energy transition	Benefits for corporate image thanks to greater transparency.	I would be happy if this served as a driver motivating others to follow the example while also helping the company expand in the market.
Participation in sustainability goals	Positive environmental impact through energy savings and CO2 emission reductions.	In addition to contributing to biodiversity conservation, it could encourage public administrations to grant

		recognitions and certifications to the company.

Column 1	Column 2 – Why?	Column 3 – Why?
Social contribution	The initiative positions the company as more reliable and transparent, creating key drivers to convince others to adopt this model.	Benefit for the entire local community with the potential to involve more participants and expand with a positive social impact.
Environmental benefit	Opportunity to contribute to the development of an environmental improvement and protection project, aiming to achieve the SDGs of the 2030 Agenda.	It is important to me to help combat the climate crisis, also influencing local authorities and the broader community.
Absence of risk	This project allows participants to test this model with potential benefits and advantages without assuming risks (borne by the ESCO).	New opportunities and potential encouragement for participation in similar initiatives, enabling the wider dissemination of these projects and a stronger energy and environmental culture.

Appendix B: Glossary of Technical and Financial Terms Used

AESI = AXPO Energy Solutions Italia

AI = Artificial Intelligence

AMI = Advanced Metering Infrastructure

CBI = Climate Bonds Initiative

CBS = Climate Bond Standard

CEM = Clean Energy Ministerial

CSR = Corporate Social Responsibility

DCF = Discounted Cash Flow

DERs = Collective Energy Resources

DSO = Distribution System Operator

EMS = Energy Management Systems

EP = Electric Power

EPCs = Energy Performance Contracts

ESCOs = Energy Service Companies

ESG = Environmental, Social, Governance

EU = European Union

ETU = Energy Transformation Unit

EV = Electric Vehicle

GBP = Green Bond Principles

GCF = Green Climate Fund

GDP = Gros Domestic Product

GEF = Global Environment Facility

GHG = Greenhouse Gas

GME = Gestore Mercati Energetici

HVDC = High-Voltage Direct Current

ICMA = International Capital Market Association

IoT = Internet of Things

IRENA = International Renewable Energy Agency

IRR = Internal Rate of Return

ISA = International Solar Alliance

LCOE = Levelized Cost of Electricity

LMICs = Low- and Middle-Income Countries

MRV = Monitoring, Reporting and Verification

NPV = Net Present Value

P2P = peer-to-peer

PBT = Payback Time

PPA = Power Purchase Agreement

PPPs = Public-Private-Partnerships

PV = Photovoltaic

RE = Renewable Energy

RECs = Renewable Energy Communities

REDII = Renewable Energy Directive II

RES = Renewable Energy System

ROI = Return on Investment

RPS = Renewable Portfolio Standards

SA = Sensitivity Analysis

SDGs = Sustainable Development Goals

SFDR = Sustainable Financial Disclosure Regulation

SLL = Sustainability-Linked Loan

SMEs = Small and Medium-Sized Enterprises

TCFD = Task Force on Climate-Related Financial Disclosures

TIAD = Testo Integrato Autoconsumo Diffuso

TIP = Tariffa Incentivante Premio

TSO = Transmission System Operator

vPPAs = Virtual PPAs

WT = Wind Turbine

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