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Key Economic Drivers Enabling Municipal Renewable Energy Communities' Benefits in the Italian Context

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Abstract: Community energy is a buzzword that has historically included various type of experiences. In 2018, the Renewable Energy Directive (RED II) legally defined renewable energy communities (RECs). Based on the first pilot projects and on the Italian legal framework, a possible REC configuration of municipal initiative with a high replicability potential is one in which a photovoltaic system is installed in educational buildings and shares energy with neighbouring residential consumers. This analysis presents an economical evaluation of different possible scenarios depending on variables such as solar radiation, system capacity, fraction of self-consumption within the REC, installation costs and energy prices. All the scenarios identified and analysed show positive economic indexes, although the energy and economic results may significantly vary depending on the variables studied. In the analysed case studies, the Net Present Value (after 20 years) is between kEUR 51 and kEUR 478; the internal rate of return is between 9.5% and 88%; the payback time is between 13.6 years and 1.1 years. The results of this analysis are relevant as they allow us to better understand the critical factors that can enable REC in providing local economic and social benefits to have a real impact on energy poverty or on the provision of local social services.

Keywords: renewable energy community; public buildings; photovoltaic systems; profitability; municipal energy initiatives; society in energy transition; social benefits; Italy

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1. Introduction

Although community energy is a buzzword that has historically included various type of experiences, Energy Communities have only recently been introduced as a legal entity by the European Union (EU) legislation, with the Renewable Energy Directive 2001/2018 (RED II) part of the "Clean Energy for all Europeans Package". Some studies explored the prevalent approaches in designing Energy Communities before the introduction of RECs in the EU legislation [1–5]. These communities are analysed in terms of technology, structure, and organisation within a technical and policy context to maximize revenues for the community and its members. Typically, this type of analysis involves formulating a business model to define the community's goals and impacts and subsequently converting them into an optimisation problem. The literature employs both optimisation and heuristic simulation methods extensively in this regard [6]. On the contrary, Katsaprakakis et al. [7] conducted an in-depth analysis of the case of applications and licenses for projects of renewable energy plants that have been submitted in Greece without informing the local communities, resulting in very low probabilities of such plans being implemented. At the same time, Skiniti et al. [8] analysed the community acceptance factors for potential wind energy projects in Greece, concluding that the most important factors in public attitudes towards WPs are open and continuous briefing during the approval, design and operation processes (together with new job positions and reduction in greenhouse gas emissions), and indirectly suggesting a possible positive role for community projects. This alternative approach can deliver increased social and economic benefits for the insular populations, broad public acceptance, and minimum environmental impacts for the islands' natural ecosystems [7].

Lennon et al. [9] explored how local communities can be empowered to drive project development and engage in the low-carbon energy transition. While studying previous experiences, Tricarico [10] investigated how Community Energy Enterprises may innovate the governance of the current energy market. Lupi et al. [11] suggest that Collective Action Initiatives are intrinsically socially innovative models of implementation characterised by a strong level of citizen involvement and participation, and that they can contribute to the energy transition from technological and social perspectives. Social innovation and the energy transition was also thoroughly discussed by Hoppe and De Vries [12], who acted as editors of a Special Issue of *Sustainability*, and also by Hewitt et al. [13], who analysed community energy initiatives in eight European countries between 1970 and 2018. Nuñez-Jimenez et al. [14] simulated three policy options using data on 5000 buildings in a district of Zurich and found that a more permissive policy, allowing community solar with buildings within a 100 m radius, resulted in 21% more photovoltaic installed capacity in 2035 than for areas without community solar.

Kooij et al. [15] studied the possible interactions between grassroot initiatives and incumbent market actors, knowledge institutes, technology developers, and political parties. Rommel et al. [16] choose a different approach, investigating the relationship between the degrowth movement and community renewable energy projects in Germany. Barroco Fontes Cunha et al. [17] compared nine cases studied in Brasil and one in Italy, underlying the important role of specialised technical bodies and governmental institutions for the take-off and success of an energy community ecosystem and for tackling energy poverty.

A number of previous works focused on the Italian context. Candelise and Ruggieri [18–20] analysed community energy initiatives approaches concerning the dynamics of creation and organisational structures, type of activity and actual economic and non-economic outcomes. The challenges for a wider adoption and development of grassroots initiatives were addressed [21–23]. Magnani [24], Magnani et al. [25] and Bolognesi and Magnaghi [26] discussed how rural communities can play a role in the energy transition. New approaches such as community cooperation were suggested by Grignani et al. [27] to enhance the social capital for the development of renewable energy grassroot initiatives.

1.1. Renewable Energy Communities as Defined by the Renewable Energy Directive 2001/2018

In Article 21, the RED II introduces the configuration of "Self-consumers of Renewable Energy", and in Article 22, it introduces the "Renewable Energy Communities" (RECs), which represent the first common normative reference for all EU Member States. It is specified that RECs are allowed to "produce, consume, store and sell electricity, including through power purchase agreements from renewable sources"; that RECs members can share renewable energy; that end-customers have the right to join a REC without being subjected to unjustified or unfair conditions and that they maintain their rights and duties as end customers; and that the distribution system operator should cooperate with the communities.

In parallel, the European Directive 2019/944 (on common rules for the internal market for electricity) introduced Citizen Energy Communities (CECs). Differences between RECs and CECs have been widely discussed [28,29]. Here, we focus on RECs.

RECs bring together different actors, with different needs, yet with the shared aim of producing "environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits". A wide variety of actors can be involved in a REC, including public and private actors, citizens, and companies, and even associations. The objective of setting up a REC remains, however, to offer renewable energy at affordable prices to all its members, maximising self-consumption, both individually and collectively, from individual citizens to companies (except energy companies), from local authorities to research and education institutes, from non-profit to religious institutions.

The "prosumer" is a citizen, a customer of an electricity operator, who is not only a consumer of energy (consumer) but wants to be part of the energy production system itself. The prosumer is thus the owner of a power plant producing energy that is partially consumed onsite (possibly also using an electrical storage, e.g., a battery) and partially fed into the national grid. In the framework of different collective self-consumption systems (including RECs), this energy can be virtually exchanged with other customers.

Although the citizen prosumer is the owner of the production of energy, its feeding into the grid and its sale, the other members of the configuration that are consumers, citizens in the vicinity of his production plant, also have a relevant role. They are not simply energy consumers; in fact, they are entitled to participate in the RECs ruling body and to receive a part of the economic benefits that the REC collects, in accordance with the governance rules defined by the REC's members.

By governance of a Renewable Energy Community, we refer to the choice of the REC model, how decision-making processes take place within it, and what responsibilities citizens, entities, and companies participating in it have. To define the governance of the REC, it is necessary to establish it as a legal body. The RED II gives way for its members to decide on any form of entity for the energy community, as long as it can exercise certain rights and can be subject to other obligations. The statute and the internal regulation of the REC define the objectives of the communities, how to finance its activities and plants, and how to use the economic benefits generated (e.g., share them between members, rewarding prosumers adequately, or use them for collective purposes).

1.2. Renewable Energy Communities as Transposed in the Italian Legislation

The European Directives were transposed into Italian law through a series of pieces of legislation that started an experimental phase. Law No. 8 of 28 February 2020 transposes, in a premature and provisional manner, the European Directives 2018/2001 (RED II) and 2019/944 (on common rules for the internal market for electricity), immediately granting the possibility of implementing forms of collective self-consumers (located in the same building) and Renewable Energy Communities (RECs).

Those who can take part in an energy community are, as required by the RED II, natural persons, small and medium-sized enterprises, territorial authorities, or local authorities, including municipal authorities. Participation in an energy community cannot constitute the main business activity for the SMEs involved. Furthermore, the aim is to provide environmental, economic or social benefits to the members. In a REC, participants produce energy for self-consumption, which must come entirely from renewable sources. According to Law 8/2020, the REC participants must be connected to the same medium/low-voltage transformer substation in order to obtain the incentives for self-consumption. This provision is based on two rationales. On the one hand, all the electricity is shared in the local low-voltage grid and does not need to be transformed in the substation, thus decreasing the grid costs and the electricity losses. On the other hand, the RED II stresses the local perspective by stating that a REC "is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity".

Given these requirements, the benefits and obligations of each REC member are defined by the statute and the internal rules and are shared equally among the members. The REC can use existing distribution networks and use virtual self-consumption. Participants in the REC maintain their rights as final customers, notably to the right to choose their supplier and to withdraw from the community at any time.

On 16 September 2020, the Minister of Economic Development issued a Ministerial Decree identifying the incentive tariff for configurations of Collective Self-consumers and Renewable Energy Communities according to Law 8/2020. The incentive tariff will be granted for the energy shared in the first 20 years of activity for both forms of self-consumption. For RECs, an incentive tariff of EUR 110 was established for each MWh self-produced with a new renewable system (i.e., connected after 1 March 2020) and simultaneously shared between the community members.

The RED II Directive was conclusively transposed into Italian law by the Legislative Decree of 8 November 2021, No. 199, coming into effect on 15 December 2021. RECs can now include energy installation up to 1 MW and final customers connected to the same primary substation (HV/MV), while in the provisional phase only, plants up to 200 kW and customers connected to the same MV/LV substation could be included—meaning from hundreds of potential participants to tens of thousands of potential participants (in Italy, there is a total of around 2000 HV/MV substation for 60 million inhabitants). Finally, this decree stipulates that the regulations established for the transitional phase under Law 8/2020 will continue to apply until the date of entry into the force of the measures to be adopted by the Ministry of Environment and Energy Security and ARERA (the national regulatory authority), as provided for in Articles 8 and 32 of the aforementioned decree. At the time of writing, these measures are still awaiting approval by the European Union.

Regarding public subsidies, on 15 January 2021, the National Recovery and Resilience Plan (PNRR) was presented by the Italian Government, with ecological transition as the key point of the programme. The PNRR will provide EUR 2.2 billion for the development of energy communities projects in municipalities with a population of less than five thousand inhabitants. The call for proposals will be published only after the aforementioned measures have been defined. At the same time, several regional governments have approved regional laws in support of RECs, whose actual financial instruments will be defined when all the rules are finally published by the national government.

While the definitive normative framework is being completed, the first examples of RECs can be observed and studied [30–33]. As late as June 2023, there were approximately 54 active entities (17 RECs and 37 collective self-consumers) and almost 100 have requested accreditation from the GSE and the payment of incentives. The total installed power in the active entities is approximately 1.5 MW and is mainly located in northern Italy.

The REC of Magliano Alpi (Piedmont region) is considered to be the first Italian REC. The characteristics of the REC concern a 20 kWp photovoltaic (PV) system installed on the roof of the municipality, to which three domestic consumers, a carpentry business, and an electric car charging system are connected. An overview of its economic and energy performance was recently published [34], showing that the energy produced by the PV system allowed 35% of the energy demand to be met (of which 19% was physically self-consumed by the municipality and 16% of energy was shared with other energy community users).

In the following Section 2, the methodology adopted in this study is described, as well as its differences compared to previous works, the identification of variables of the base case hypothesis and the different scenarios that we will compare. Section 3 presents the economic and energy results for the base case and the sensitive analysis. Section 4 discusses the results and highlights the possible consequences of different decisions. Section 5 concludes the analysis, paving the way for further research.

2. Methodology

After the introduction of RECs in the national legislation, their possible role in the Italian energy transition was studied and two different guides were produced: one by AIEE and Federmanager [35], addressed to managers and decision makers, and one by Barroco et al. [36], addressed to citizens. Borchiellini et al. [37] analysed the constraints to the development of RECs in Italy during the pilot phase. Tricarico [38] explored the actions of project managers, communities, and local stakeholders in two Italian case studies at various engagement stages, aiming to emphasize the pivotal factors that contributed to enterprise development and the resulting perceived local value for investors. Magnani and

Cittati [39] studied two other RECs and tried to bridge the existing gap in informed analyses by integrating the multilevel perspective and the socio-technical imaginaries approach.

Bilardo et al. [40] developed and analysed a survey aimed at studying how people can be more involved in the energy market and how they could gain access to community energy. While Celesia et al. [41] explored the political and social dimensions of RECs, only a small number of studies assessed the technical–economic feasibility of a REC in the Italian context. In their study, Minuto and Lanzini [42] included a simulation of an energy community with 100 households and a 100 kWp photovoltaic system, and six scenarios were developed to explore how profits could be shared among various members. Cirone et al. [43] tested various energy community configurations by incorporating photovoltaic generators and electric batteries to optimize self-consumption for heat pump systems, for a REC located in a small town in Southern Italy. Viti et al. [44] compared the performance of an energy community with a configuration where customers act as single self-consumers and found that energy communities are able to accelerate renewable energy sources deployment, resulting in higher overall self-consumption rates. Mehta & Tiefenbeck [45] found that self-consumption ratio and PV capacity, but not community size, affect RECs projects' profitability. D'Adamo et al. [46] assessed the profitability of a PV plant by considering different political (tax deduction, subsidies) and market (purchase price, selling price) contexts and explored how benefits among renewable self-consumers can be divided, concluding that the share of self-consumption plays a key role, but soaring energy costs can spur final customer to engage in RECs or in other renewable energy projects.

2.1. RECs Performance: Variables and Indicators

Unlike most prior research, our study considers a range of energy and economic parameters relevant to energy communities' costs and benefits. We conduct a sensitivity analysis by varying individual conditions to assess their economic and financial impact on the analysed RECs. This study ultimately aids in making informed decisions regarding the establishment of a REC and presents an optimal scenario to the stakeholders involved.

The principal technical and economic determinants for a REC encompass:

- Solar radiation availability: this parameter depends on the location and determines the overall energy production potential.
- Installed photovoltaic size (in peak kilowatts): the installed peak power determines the electrical production and must be chosen according to the number and type of a REC's members.
- Capital expenditure (CAPEX) represents the initial investment costs of the RES power system.
- Operational expenditure (OPEX), including the RES power plant maintenance costs and insurance, as well as the REC management annual costs.
- Electricity purchase price: since the operational lifetime of the system is normally above 25 years, it is very difficult to estimate this variable for such a long time span, given the wide fluctuations witnessed in recent periods influenced by external factors and events.
- The public incentives granted to the REC, i.e., subsidised loan and/or a premium tariff on shared energy in the REC that applies in the Italian legislation.
- The interest rate, in case of a loan.

The individual variation is observed to impact the overall feasibility of the REC in terms of traditional economic metrics:

- Net Present Value (NPV): The NPV measures the investment's profitability by calculating the sum of annual cash outflows (C_t) generated by the REC over its 20-year operational span (N = 20), discounted to the present day (depending by the discount rate i). From the perspective of one REC, any bank loan (if available) is deducted from the initial investment (C_0), and the loan repayment is included as a cost in the subsequent cash flows until it has been fully repaid.

$$NPV = \Sigma_{t=0}^{N} \frac{C_t}{(1+i)^t} \quad (1)$$

- Internal Rate of Return (IRR): The IRR is determined by finding the interest rate at which the NPV becomes zero, indicating the rate of return achieved by the investment, and can be compared to the market interest rate to verify the profitability.

$$\Sigma_{t=0}^{N} \frac{C_t}{(1+IRR)^t} = 0 \quad (2)$$

- Payback Period: The payback period, often referred to as the payback time, denotes the number of years required for the investment to recoup its initial cost and commence generating positive returns. It is calculated by solving Equation (1) with respect to time for a predefined value of i.

When analysing the performance of a single PV system included in a REC, the relevant energy variables are (all in kWh):

- Photovoltaic (PV) System Production: this is influenced by geographical position, tilt, orientation and obstacles.
- Physical Self-Consumed Energy: i.e., the energy directly utilised by the devices connected to the Renewable Energy System (RES) before the electric meter that connects it with the grid (e.g., in a residential system all the energy utilised by the appliances and lighting system in the household).
- Energy fed into the grid: this is the surplus energy obtained by subtracting the physical self-consumed energy from the PV plant production, which is then injected into the electrical grid.
- Shared energy: as defined by ARERA (the Italian energy authority), shared energy represents the minimum energy, on an hourly basis, resulting from the net difference between the electrical energy fed into the system and the electrical energy drawn from the connection points relevant to a group of renewable energy self-consumers or a renewable energy community (i.e., it is the energy that is put into the grid by a prosumer and is simultaneously utilised by the other members of the REC).
- Surplus production: i.e., the energy fed into the grid, minus the shared energy, resulting in the net surplus energy put into the grid.

According to Ciocia et al. [47], the Total Self-Consumption Index (SC) is determined by the ratio between the energy locally generated and consumed (E_{lgc}) within a specified time interval, and the total energy produced by the photovoltaic system during the same time frame (E_{gen}).

$$SC = \frac{E_{lgc}}{E_{gen}} \quad (3)$$

Conversely, the Energetic Self-Sufficiency Index (SS) is calculated as the ratio of the consumption amount supplied by local generation (E_{lgc} the same numerator of the SC) with respect to the total consumption (E_{load}) during the same time frame.

$$SC = \frac{E_{lgc}}{E_{load}} \quad (4)$$

A final issue to be explored concerns the division of income deriving from participating in a REC. This division also depends on the type of legal entity that is chosen for the energy community. Some communities provide for an equal distribution of all profits among members, while others decide to reinvest the proceeds in new renewable energy initiatives or socially responsible actions. In this study, we consider two scenarios of revenues redistribution among the members of the REC, i.e., in the former, revenues are equally divided among the REC members, while in the latter, vulnerable families take priority and 50% of the economic benefits are reserved for the 20% most vulnerable families.

2.2. Base Case Scenario Description

While municipalities are not the exclusive promoters behind an Energy Community, they can undeniably assume a pivotal role during the initial activation phase. In particular, when municipalities align with the objectives and acknowledge the public interest of RECs, they can offer areas or rooftops for the installation of PV plants and collaborate with other prosumers in energy production. Municipal buildings, such as town halls, schools, gymnasiums, libraries, or municipal warehouses, are well suited for initiating RECs initiatives.

The case study examined concerns the economic feasibility of establishing a REC with the installation of a photovoltaic system on the roof of a school. The school's demand for electricity during the summer months is very low, generating an overproduction that can meet part of the demand of the residential members. RECs typically encompass diverse consumer types, both in the public and private sectors. However, for the purpose of this research, our focus is (in addition to the municipal school) exclusively on households, primarily in consideration of the potential for replication.

In our Base Case scenario, the Renewable Energy Community is situated in Rome and is designed to incorporate a renewable energy production facility connected to the low-voltage grid, in compliance with the regulatory constraints defined in the Italian Law 8/2020, which prescribes a maximum size of 200 kWp for each plant. The PV plant installed in the school serves primarily for physical self-consumption. To model electrical consumption of the school, we have elaborated monthly data gathered from a real educational facility, as reported by Zanon [48]. These data encompass actual electricity consumption values from the bill and information from the "peak time" F1 time slot, which in Italy applies from Monday to Friday, spanning from 8:00 a.m. to 7:00 p.m., excluding holidays.

The residential units included in the REC have been categorised into clusters characterised by similarities in terms of the number of occupants, occupancy patterns, and building attributes such as surface area and energy efficiency. Within each cluster, the data provided pertain to a single representative dwelling, referred to as the "typical dwelling".

The analysed RECs consist of 100 households, with differences in the quality of their building envelope that influences heating and cooling demand. In particular, homes are divided into two clusters. The first includes 30 homes with good envelope quality, while the latter includes 70 households with poor envelope quality. For all houses, the heated floor area is assumed to be equal to 75 m^2, while the cooled floor area is smaller (35 m^2), since we have assumed that space cooling is present in a few rooms. Regarding the heating and cooling systems, heating is provided by a natural gas boiler and the electrical demand for heating purposes is neglected (only auxiliaries and control system), while cooling is provided by means of a local air conditioner and the corresponding electrical demand has been considered in the simulations.

The base case REC is located in Rome, and it has a 100 kWp PV system, i.e., 1 kWp per household. Although this proportion is not sufficient to cover the total energy demand of an average Italian household, it is aligned with some existing REC pilots in Italy and, as a first approximation, covers the residential consumption that is simultaneous to PV production. The initial costs of the PV system are assumed to be 1400 EUR/kWp and the electricity price is assumed to be 0.30 EUR/kWh.

2.3. REC Variants

Four sensitivity analyses are formulated, each addressing one of the key determinants previously identified. The simulated REC variants are summarised in Table 1.

Table 1. Simulated REC variants. Differences with respect to the base case are in italics.

ID	Location	PV Size [kWp]	PV Initial Cost [EUR/kWp]	Electricity Purchase Price [EUR/kWh]
BASE	Rome	100	1400	0.30
1a	*Milan*	100	1400	0.30
1b	*Palermo*	100	1400	0.30
2a	Rome	*50*	1400	0.30
2b	Rome	*200*	1400	0.30
3a	Rome	100	*1200*	0.30
3b	Rome	100	*1600*	0.30
4a	Rome	100	1400	*0.25*
4b	Rome	100	1400	*0.40*

"Location" includes three representative cities for northern, central, and southern Italy: Milan (45° N latitude, solar irradiation 1457 kWh/m^2 year on the horizontal plane), Rome (42° N latitude, solar irradiation 1643 kWh/m^2 year on the horizontal plane), and Palermo (38° N latitude, solar irradiation 1731 kWh/m^2 year on the horizontal plane).

The installed size of the PV system ranges from 50 kWp to 200 kWp, with the intermediate and base case configurations set at 100 kWp (Table 2). The PV system losses (14%) are based on the PVGIS database [49,50], while effects due to angle of incidence, temperature, and low irradiance depend on the location. Total losses are therefore between 22.0% and 22.9%. A conservative value of 1% for the average annual yield loss is considered.

Table 2. Description of the photovoltaic system considered in this study.

Installed power	50–100–200 kWp
Cells technology	Crystalline silicon
Type of installation	Rooftop integrated
Tilt	35°
Orientation	0°
System loss	14.0%
Total loss	22.0–22.9%
Extraordinary maintenance periodicity	12 years
Average annual yield loss	1%

PV investment costs, including design, installation, components, labor, taxes, and all relevant expenses, range from 1200 EUR/kWp to 1600 EUR/kWp. The purchase electricity price varies from 0.25 EUR/kWh to 0.4 EUR/kWp, while the electricity sale price is outlined in Table 3.

Table 3. Economic parameters used in the simulations.

CAPEX and OPEX	
Initial unit PV cost	1200–1400–1600 EUR/kWp
Annual O and M costs	4400 EUR/year
Average Electricity Prices	
Purchase price	0.25–0.30–0.40 EUR/kWh
Sell price	0.12–0.15–0.22 EUR/kWh
Financial Parameters	
Discount rate	4%
Inflation	2%
Loan	2/3 of the initial investment
Annual loan interest rate	3%
Loan duration	10 years
Number of annual loan instalments	1

Regarding the form of financing, we have assumed that two-thirds of the initial investment are financed through a ten-year bank loan with a 3% annual interest rate.

2.4. The Simulation Tool

Simulations have been carried out with RECON (Renewable Energy Community economic simulator), a web application developed by ENEA [51]. RECON is aimed at supporting REC promoters and citizens in performing preliminary energy, economic, and financial assessments of RECs and collective renewable self-consumption initiatives, in accordance with the current legislative framework in force in Italy, i.e., Law nr. 8/2020 and subsequent implementation provisions.

RECON relies on a limited set of inputs, including data related to the building and electrical equipment, electricity consumption data derived from the bill, characteristics of the PV plant, and some economic–financial parameters. It conducts an energy and economics analysis and calculates the typical key performance indicators (KPIs) for investment evaluation. It considers some financing options, including tax deductions, and calculates the available incentives in the Italian context.

The current release of RECON (version 1.2.3) focuses on residential end-users that can be aggregated into clusters, each of them collecting users with the same characteristics. Regarding the RES power plant, RECON considers a PV system, and PV production is obtained by means of an API from the PVGIS tool of the Joint Research Centre of the European Commission [49,50].

The main outputs of RECON include the energy production of the PV system, the physical self-consumption and the shared energy in the configuration, the energy self-sufficiency, the environmental impact (i.e., CO_2 emissions reduction), economic savings from self-consumption, revenues (energy sold to the grid and incentives) and costs, discounted cash flows, and the main financial indicators (i.e., NPV, IRR, payback time).

Some of RECON's strengths are its ease of use—the input data are simple; users are guided by tooltips during the compiling process—and the ability to simultaneously analyse clusters of dwellings with different levels of knowledge of the information. If the electricity consumption from the bill is not available, the simulator estimates it based on algorithms that consider the contribution of the single electrical end-use (i.e., appliances and lighting, space heating, space cooling, domestic hot water production). The simulator was validated on an extensive dataset of real consumption and production data recorded with a time step of fifteen minutes.

RECON is organised into four sections:

- General Data: the user is prompted to assign a name to the project and select the location (province and municipality). Additionally, the configuration must be specified as either renewable energy community or collective self-consumption (i.e., all members and the PV plant are in the same building). Furthermore, the grid connection for the PV plant needs to be selected.
- Consumption Units: this section includes the input data related to electricity consumption and corresponding members: prosumer (the school in our case) and the consumers, which are organised into clusters (the households). Each cluster is characterised by specific information related to the building (thermal envelope quality), equipment (heating, cooling, domestic hot water), electrical consumption (data availability and values), and the occupants' profile.
- Production Plant: this section collects the technical information on the PV plant.
- Economic and Financial Parameters: this section includes the economic parameters, such as average purchase and sale prices of electricity, initial operating costs, annual operating costs (including the plant maintenance and REC operational costs), and financial parameters such as the discount rate, inflation rate, and information related to the bank loan.

3. Results

3.1. Base Case

This section analyses the output that the RECON software version 1.2.3 returns, and all results related to the base case are listed in Table 4.

Table 4. Results for the base case.

Annual Electricity Consumption and Production (at Year 1)	
Total electricity consumption	343,540 kWh
Daytime electricity consumption	175,372 kWh
PV plant production	137,624 kWh
Energy self-consumed	19,175 kWh
Shared Energy	81,892 kWh
Energy fed into the grid	118,449 kWh
Surplus production	36,557 kWh
Energy and Environmental Indicators	
Physical self-consumption index	13.93%
Virtual self-consumption index (shared energy)	59.50%
Total self-consumption index	73.44%
Self-sufficiency index	29.42%
Annual avoided CO_2 emissions	45.40 t CO_2
Analysis of the Investment Costs (at Year 1)	
Total area of the PV modules	670 m^2
Initial plant cost	140,000 EUR
Equity	46,700 EUR
Loan	93,300 EUR
Fiscal deductions	0 EUR
Annual Savings, Revenues and OPEX (at Year 1)	
Savings from physical self-consumption	5753 EUR/year
Revenues from electricity fed into the grid	17,767 EUR/year
Total savings and revenues	23,520 EUR/year
OPEX	4400 EUR/year
Annual loan payment (for first 10 years)	16,076 EUR/year
Incentives and Reimbursement of Tariff Components (at Year 1)	
Incentive on shared energy	9008 EUR/year
Reimbursement of network charges	673 EUR/year
Financial Indicators	
Net present value (after 20 years)	EUR 274,617
Internal rate of return (IRR)	39.4%
Payback time	2.7 years

The school annual electric consumption in the first year amounts to approximately 39 MWh, with approximately half of this consumption occurring during daytime. The PV modules occupy a roof area of 670 m^2 and generate nearly 140 MWh per year. As anticipated, the self-consumed energy is relatively low, around 20 MWh, accounting for only 14% of the total production. The shared energy in the REC amounts to 82 MWh, i.e., 60% of the production, while the REC's self-sufficiency index is approximately 30%, leading to an annual reduction of about 45 tons of CO_2 emissions.

From an economic point of view, the PV plant generates annual revenues of roughly EUR 18,000 from electricity fed into the grid and the REC can benefit of nearly EUR 10,000 in ministerial incentives on shared energy. Savings associated with physical self-consumption amount to around EUR 5,750. Considering a Capital Expenditure (CAPEX) of the PV plant of EUR 140,000 (2/3 collected as a bank loan and 1/3 anticipated by RECs members) and an Operational Expenditure (OPEX) of EUR 4400 per year, the payback period is 2.7 years, with an Internal Rate of Return (IRR) of 39% and a Net Present Value (NPV) of EUR 275,000 after 20 years.

3.2. Sensitivity Analysis

3.2.1. Location

The graph presented in Figure 1 shows how the payback time and IRR vary depending on the geographical location of the Renewable Energy Community. The base case is situated in Rome (latitude 41.91°), while the two comparative reference locations are Milan (latitude 45.47°) and Palermo (latitude 38.12°).

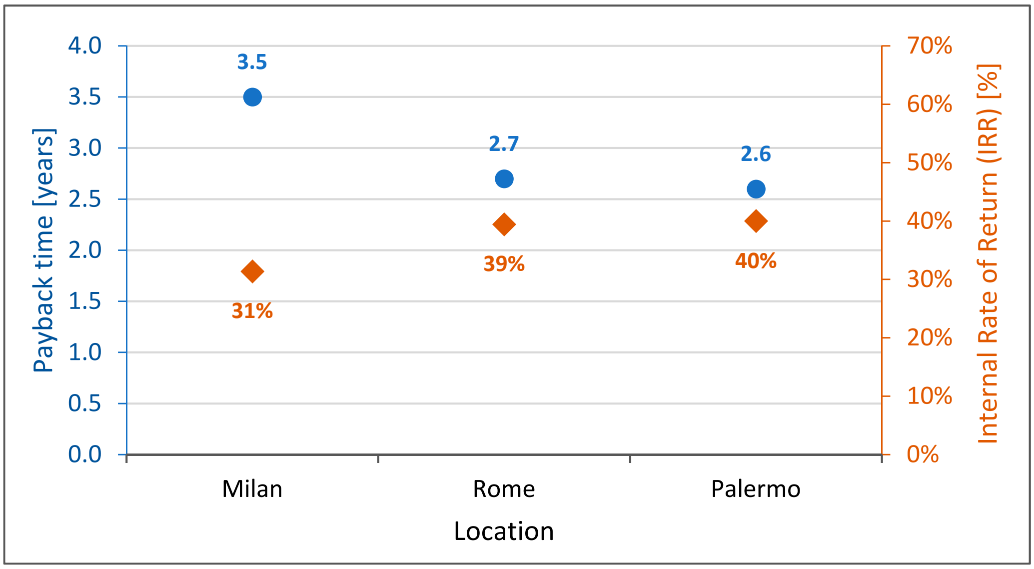

Figure 1. Financial indicators by varying the location of the REC.

The solar energy potential, which increases moving southward, shows a higher impact on the financial indicators for northern locations, i.e., while the difference between Rome and Palermo is relatively modest, comparing Milan with Palermo results in a 13% increase in the PV production, and a reduction in the payback time from 3.5 to 2.6 years. The IRR is 31% for Milan, 40% for Palermo, and 39% for Rome.

3.2.2. PV Size

By increasing the PV size while keeping the households equal to 100, the virtual self-consumption index decreases. Therefore, in the analysed base case, the PV plant with a size of 50 kWp shows a better economic performance, with a 26% reduction in the payback time compared to the case with a higher power capacity (200 kWp); moreover, the IRR decreases from 42% to 33%. However, as depicted in Figure 2, a 200 kWp PV plant increases the payback time to just 3.4 years, a value not significantly dissimilar to the base case, which remains interesting from an investment point of view.

Figure 3 shows self-sufficiency and total (physical plus virtual) self-consumption indexes in the three aforementioned configurations.

Their differences may also be interpreted as an adjustment in the ratio between the number of households and the PV size. Shifting from 2 households per kWp to 0.5 households per kWp results in a reduction in total self-consumption (including physical and virtual) from 88% to 49%, while self-sufficiency increases from 18% to 39%.

In the aforementioned configurations, by increasing from 50 kWp to 200 kWp, the cumulative annual revenues of the REC increase from EUR 18,000 to 58,000, and the NPV after 20 years rises from EUR 146,000 to 548,000. Although in our cases study, larger PV plants exhibit a lower IRR and a higher payback time, they lead to higher overall economic benefits. Given a constant number and type of REC members, each household can obtain higher benefits. For instance, if we consider both ministerial incentives and the revenues from energy sold to the market and an equal redistribution among the members, the annual pro-quota for each family increases from EUR 42 to 228 (net of operational expenses and loan repayments).

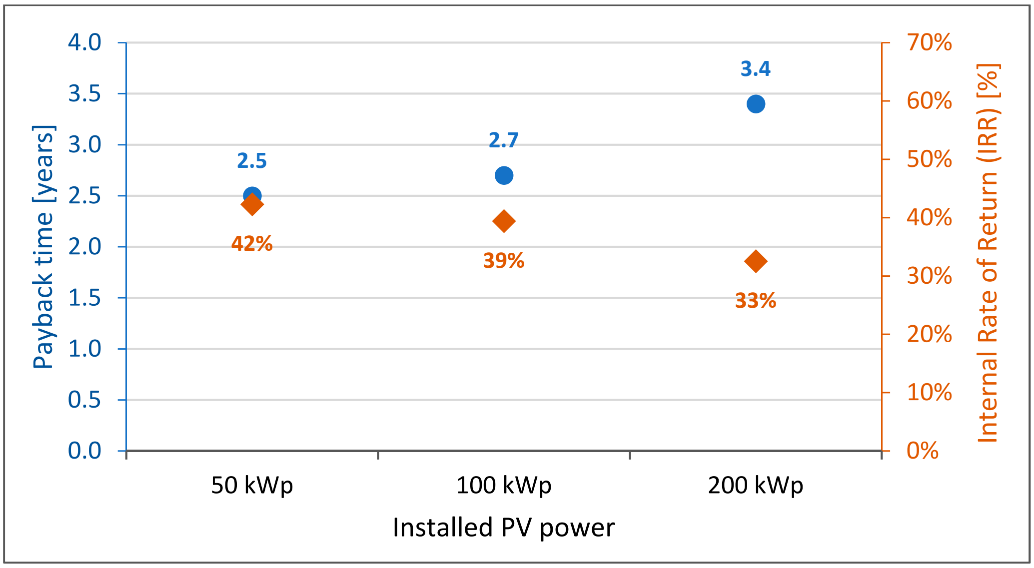

Figure 2. Sensitivity analysis—influence of PV size on the financial indicators.

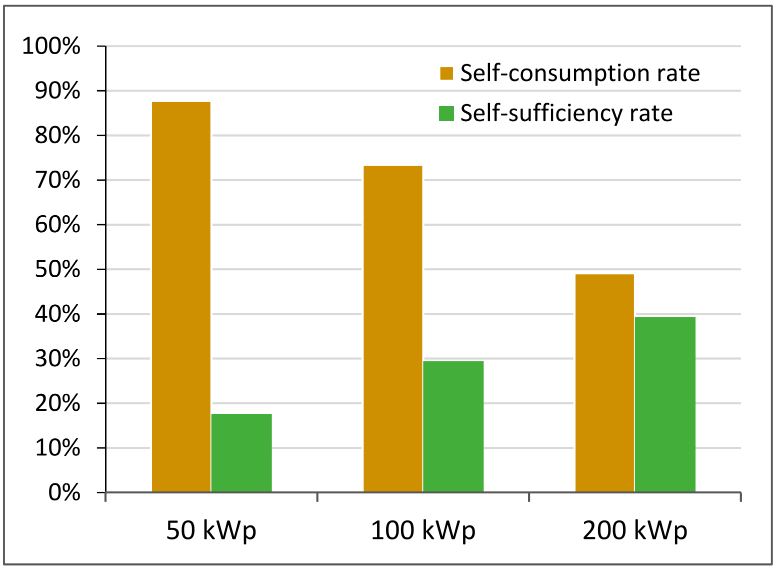

Figure 3. Sensitivity analysis—influence of PV size on self-sufficiency and total self-consumption rates.

3.2.3. Investment Costs

The initial costs for the turnkey PV plant may vary depending on fluctuations in the prices of components and labour, a situation that has occurred in recent years due to different economic and geopolitical circumstances. Local governments, particularly if they are participants or investors in a REC, face significant challenges when it comes to maintaining the stability of costs for engineering, procurement, and construction of the RES power plants. To account for potentially increasing costs, we have compared three different turnkey-specific costs for the PV plants that are representative of the price variations in Italy in recent years for the PV plant sizes analyses in this work, i.e., 1200 EUR/kWp, 1400 EUR/kWp, and 1600 EUR/kWp.

As illustrated in Figure 4, an increase of 200 EUR/kWp in initial costs of the PV plant results in a 7–10% decrease in the IRR and in an increase in the PBT by more than six months. Still, the three scenarios are largely cost-effective.

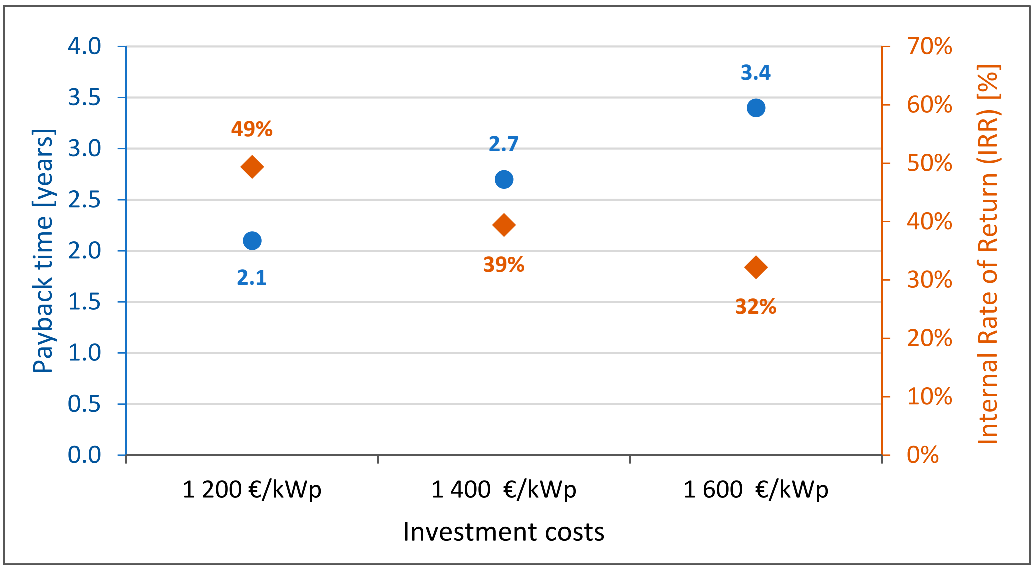

Figure 4. Sensitivity analysis—influence of the PV plant turnkey costs on the financial indicators.

3.2.4. Energy Prices

Energy prices, both for the purchase and sales of electricity, strongly impact the economic performance of the REC prosumers. Before 2019, the wholesales market price of electricity in Italy varied in a small range, between 50 EUR/MWh and 80 EUR/MWh. Nevertheless, in recent years, extreme price fluctuations have characterised the electricity market due to the COVID pandemic, the conflict in Ukraine, and other events that have characterised the energy supply chain. In this context, Figure 5 shows the trend of Italian quarterly electricity prices in the regulated market for domestic users, which include the cost of energy, network charges, system charges, and taxes. The assumption that future electricity prices would align with historical data has yet to be proven and may lead to significant deviations between calculated and actual economic performance. Therefore, realistic assumptions about future energy prices are a challenging task.

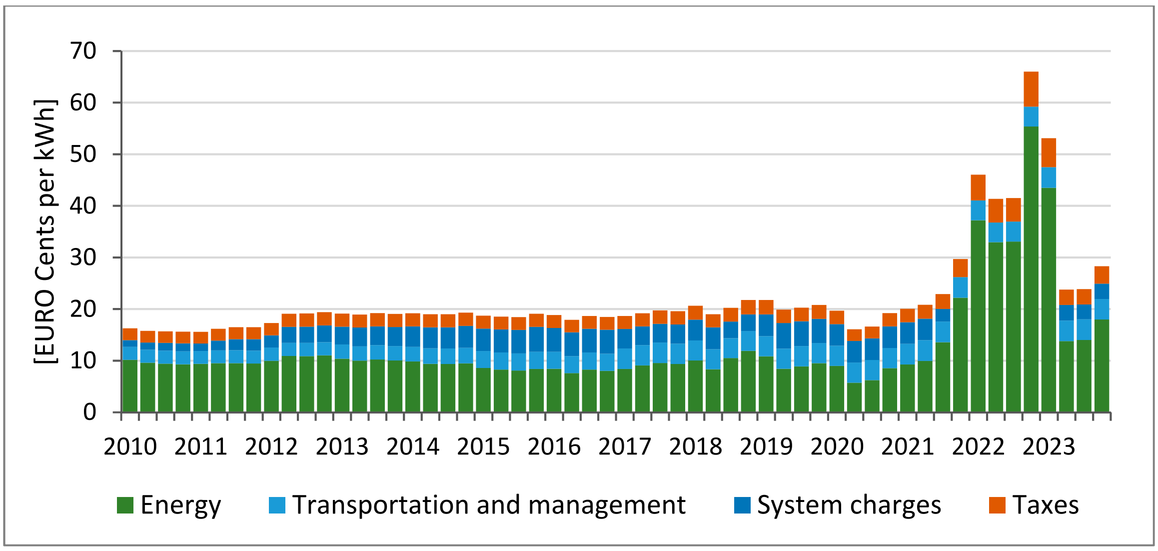

Figure 5. Trend of Italian quarterly electricity prices for regulated domestic users (Source: ARERA).

The increase in the costs of energy results in substantial savings and revenues from self-consumption for prosumers in a REC. Prosumers can also benefit from an increase in the revenues from the energy they sell to the grid. When considering the REC as an entire entity, an increase in the wholesale electricity price from 0.12 EUR/kWh to 0.22 EUR/kWh and of the purchase price from 0.25 EUR/kWh to 0.40 EUR/kWh results in a doubling of the IRR, from 30% to 60%. Similarly, PBT decreases from 3.7 to 1.7 years (Figure 6).

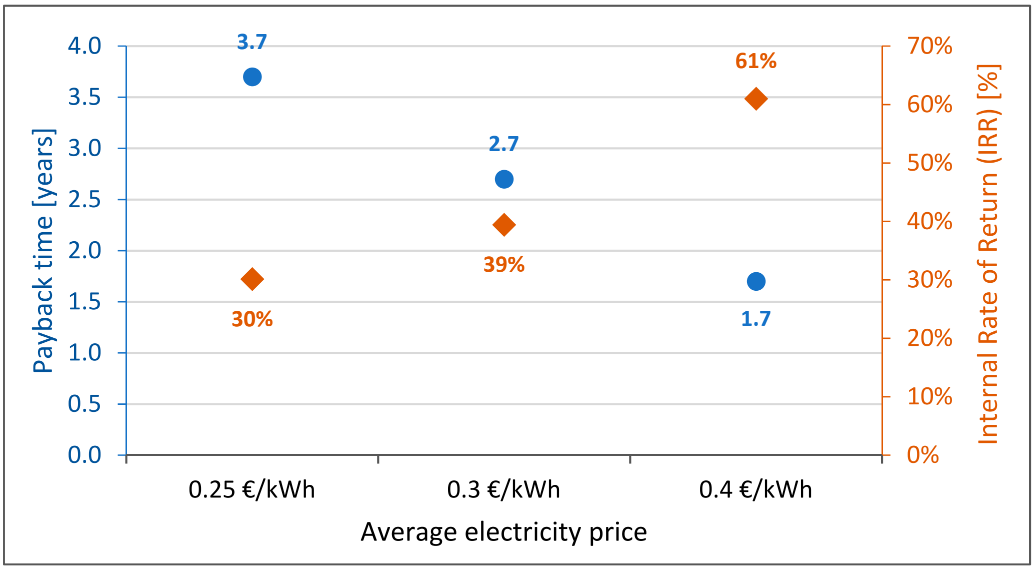

Figure 6. Sensitivity analysis—influence of average electricity prices on financial indicators.

4. Discussion

All the scenarios identified and analysed show positive economic indexes, although the energy and economic results may significantly vary depending on the variables studied.

At present, only a specific real case can be considered as a reference, namely the first Italian REC of Magliano Alpi, for which the first year of monitored data is accessible [34]. Although it is a small-scale REC (with 20 kW installed and involving five members), when scaled to a larger plant size, its cash flows show minimal deviation compared to those obtained in this study. This real case is more oriented on the physical self-consumption, with a relatively small number of connected consumers; however, the total annual gains are 20% lower than those obtained for our closely aligned scenario.

This comparison suggests that the results of this analysis are relevant, as they help us to better understand which are the critical factors that can enable REC in providing local economic and social benefits so as to have a real impact on energy poverty or on the provision of local social services. To offer further insights into the potential social impact, the best- and worst-case scenarios are extensively compared in the next section.

4.1. Best-Case and Worst-Case Scenarios

In the previous sensitivity analyses, we evaluated the influence of individual input variables by adjusting parameters one at a time while keeping other inputs constant. The following scenario analysis, on the other hand, aims to assess the project's feasibility by examining the combined effects of multiple parameters that are varied simultaneously. In this instance, we have created a best/worst-case scenario, based on input assumptions derived ex post from previous simulations:

- In the worst-case scenario, we assume that all variables are set in order to decrease the benefits (or increase the costs) for the REC members as much as possible. The REC is located in Milan (with the lowest PV production among those evaluated), with an installed capacity of 100 kWp and 50 consumers connected (worst combination). The turnkey unit cost of the PV plant is set at the highest value within the range

(1600 EUR/kWp), and the average purchase price of electricity corresponds to the lowest value (0.25 EUR/kWh). Moreover, the operational costs are increased to 7500 EUR/year (respect the 4400 EUR of the best case), while the loan is maintained to two-thirds of the CAPEX with an interest rate of 3% (as for the base case).
- In the best-case scenario, we assume that all variables are set to increase the benefits (or decrease the costs) for the REC members as much as possible. The REC is in Palermo (with the highest PV production), with an installed capacity of 100 kWp and 100 consumers connected. The unitary turnkey cost of the PV plant is set at the lowest value within the range (1200 EUR/kWp), and the average purchase price of electricity is the maximum value (0.40 EUR/kWh). Additionally, a loan with a 0% interest rate is evaluated (i.e., from a public loan) to once again cover two-thirds of the CAPEX.

Table 5 reveals that the best-case scenario—i.e., REC in Palermo featuring high energy prices, a moderate level of debt, and a zero interest rate applied—achieves a self-consumption rate of 73% and self-sufficiency of approximately 30%. This combination results in an IRR of nearly 90%, confirming the overall attractiveness of the investment, which is paid off in just over a year.

Table 5. Technical and financial indicators under the best- and worst-case scenarios.

Output	Worst Case	Best Case
Physical self-consumption	15.8%	13.8%
Virtual self-consumption	43.0%	59.5%
Total self-consumption	58.7%	73.3%
Energy self-sufficiency	37.1%	29.6%
Net present value (after 20 years)	EUR 51,713	EUR 478,021
Internal rate of return (IRR)	9.5%	88%
Payback time	13.6 years	1.1 years

The worst-case scenario—i.e., REC established in Milan with higher initial and ongoing operational costs, standard interest rates, and average energy prices—results in a self-consumption rate of 60% and self-sufficiency of approximately 37%, and it requires 13 years to pay back the initial investment. The IRR in this scenario is slightly below 10%, which can be still considered an interesting value for a profitable investment.

4.2. *Benefits: For Whom?*

All the economic analyses carried out evaluate total economic benefits, regardless of how these benefits could be used, e.g., for community initiatives or redistributed among REC members. Due to the public nature of the initiative under investigation, there is an opportunity to underscore the social value that the REC intends to realize. For instance, the municipality (as the school owner) might be satisfied by keeping bill savings generated from physical self-consumption and agree to redistribute revenues from electricity sold to the grid and the incentive on shared energy among other REC members (the households). This allocation is subject to deductions for OPEX and bank loan instalments, and we do not consider tax implications, which depend on many features (e.g., the legal model) that are outside the scope of the present paper.

The REC may adopt an equal redistribution of profits among its members, or it can prioritize vulnerable people by reserving, for example, 50% of the income for the most vulnerable 20% of its members. The annual gains for the REC members in both cases are presented in Table 6. They are indeed noteworthy and, in the best-case scenario, likely adequate to alleviate energy poverty situations.

Table 6. Maximum annual gains that can be distributed to the residential members, under the 3 scenarios and 2 distribution approaches.

Distribution Approach		Worst Case	Base Case	Best Case
Equal		68 EUR/year	121 EUR/year	244 EUR/year
Differentiated	50% to 20%	171 EUR/year	303 EUR/year	609 EUR/year
	50% to 80%	43 EUR/year	76 EUR/year	152 EUR/year

5. Conclusions

As Italian institutions work toward finalising the definitive regulatory framework for establishing RECs in Italy, the current landscape of actual operative RECs remains limited, characterised by small-scale installations typically below 100 kW and with less than 100 members. In this context, we explored the critical determinants that have a substantial impact on the business model of a REC. Our analysis focused on a public configuration with a high potential for replication, in which a photovoltaic system is installed on the premises of an educational institution, and the energy generated is shared with nearby residential consumers.

In our investigation, RECs serve as a catalyst for the enhancement of energy self-sufficiency and for the realisation of economic savings for the participants. These savings may be achieved through reductions in energy bills, driven by the sharing of incentives. What is noteworthy is that this benefit extends to consumers, leading to a reduction in their energy expenditures, when the earnings are shared, or the earnings can be used to finance community initiatives. Furthermore, the REC model generates a 'short supply chain' for energy provision, thereby positively influencing local environmental conditions and sustainability indicators.

All the scenarios identified and analysed show positive economic indexes that may vary considerably, depending on certain variables. Specifically, variables such as geographical location, system capacity (or the ratio of connected households to capacity), installation costs, and energy prices exert significant influence on the energy balances within the REC. This, in turn, affects the economic performance of the community. These types of assessments are instrumental in shaping the governance mechanisms of the REC and in determining its social impact.

Considering these insights, the sensitivity and scenario analyses that we have presented serve as support tools for decision-makers, municipalities, and other stakeholders engaged in the promotion and implementation of RECs. These analyses provide a means to thoroughly assess the feasibility of establishing and operating a REC, making informed decisions that align with broader sustainability and energy self-sufficiency goals.

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Conflicts of Interest: The authors declare no conflict of interest.

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