

Technical-economic evaluation for maximizing the self-consumption contribution in an energy community: The case study of Pattada in Sardinia

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Abstract. Ministerial Decree 414/2023 implements Legislative Decree 199 which defines the conditions and methods under which producers, consumers, and prosumers have the right to organize themselves into Renewable Energy Communities (REC), promoting the production and sharing of electricity from renewable sources. The economic feasibility of an energy community is largely influenced by its investment options: public capital only, third-party co-financing, or direct investment by interested households. A common issue in these cases is the allocation of costs among local community members to ensure cost recovery. To evaluate the feasibility of an Energy Community, an economic analysis with different technical and economical options is conducted, considering various cost allocation methods. The analysis is carried out in the case study of Pattada, a small municipality in northern Sardinia, and is focused on the availability of hourly consumption of public buildings and of two energy-intensive utilities in the tertiary sector. Residential consumption has been modelled based on the indications provided by the GSE and validated for some practical cases through targeted experimental measurements. Different scenarios were analysed by varying the size of the plants intended for self-production, the percentage of capital financing, the types of users and the number of residents adhering to the REC. The results confirm that the most favourable incentive tariff is obtainable minimizing the amount of energy fed into the grid. From an economic point of view, the participation of residents in energy generation is always favourable to the improvement of the NPV for all the prosumers. The higher profits are obtained without capital contributions, obviously due to the higher amount of the corresponding premium rate. On the other hand, capital contributions play an important role in the entry of new prosumers, especially in the residential sector, contributing to broadening the community pool. The interplay between distributed generation, energy storage and active participation in grid flexibility not only improves overall energy efficiency but also helps to reduce environmental impacts and promote greater energy independence.



1. Introduction

The energy transition can be achieved by utilizing Renewable Energy Communities (RECs), which are one of the most promising solutions to achieve the EU's decarbonization objectives. Starting from the RED II Directive [1] and its subsequent national transpositions [2], [3] RECs have progressively emerged as models capable of combining environmental sustainability, social inclusion, and technological innovation. The regulatory evolution in Italy is still under discussion today and shows a constantly changing framework, especially at an operational and legal level. [4]

Different studies revealed that insularity, rurality, and territorial proximity are favourable starting points for the development of RECs. Sardinia presents itself as a favourable context for the implementation of RECs, given the abundance of resources, Renewable Energy Sources (RES), the high social capital and the public policies. The Greek experience, largely explained by Yfanti et al. [5], presents a fascinating comparative perspective: low-density territories, deeply tied to local identity and with high solar potential, naturally lend themselves to collective energy production and sharing models.

However, the development of RECs goes beyond mere technological aspects. As various contributions have demonstrated [6, 7] the success of such initiatives also depends on inclusive governance, active citizen participation, and the ability to integrate environmental, social, and economic objectives.

Alongside these socio-institutional dimensions, a broad investigation has explored the technical potential of RECs, both in urban and rural contexts. In metropolitan areas such as Milan [8], simulations highlight the flexibility of configurations in terms of installed capacity, energy storage, and revenues. At the same time, projects like ComER [9] and studies such as that of Shi et al. [10] on rural contexts confirm that decentralized and peripheral areas can also benefit from technologically advanced approaches, through load forecasting tools, predictive control algorithms, and intelligent management of shared energy.

Experiences collected in the "Comunità Intraprendenti" report [7] and in the exemplary case of Assisi [11] also show how RECs can become tools for social inclusion and civic regeneration. Integration with public buildings, schools, vulnerable individuals' home allows environmental goals to be combined with concrete actions against energy poverty.

As previously mentioned, a certain degree of inconsistency remains in the field of regulation [12, 13]: legal uncertainty, fragmented responsibilities, and authorization barriers still hinder the widespread diffusion of RECs. The Italian framework, in comparison with the ones of Germany, Spain or the Netherlands, needs to be clearer, stable and coherent.

This study aims to assess technical and economic feasibility with reference to the described context, in the municipality of Pattada, Sardinia. The analysis is based on the simulation of different scenarios, varying the number of prosumers and consumers, as well as the installed capacity of the photovoltaic system, to estimate potential benefits in terms of self-consumption, energy balance, and collective savings. Pattada—a small inland municipality with good solar resources and a strong territorial identity—represents an ideal testing ground for the replication of REC models in rural and insular contexts.

Moreover, this study aims to contribute to the literature on RECs through an integrated approach, combining technical-economic analysis, regulatory references, and a territorial reading of the phenomenon. Assessing the potential of an REC in a municipality with fewer than 3,000 inhabitants allows for reflection on the concrete possibility of building a new energy model for small towns—one based on collaboration, sustainability, and the effective enhancement of local resources.

2. Case Study

The case study concerns the Municipality of Pattada, located in the province of Sassari, Sardinia, at an altitude of approximately 850 meters above sea level. With a population of around 2,800 inhabitants and an area of over 160 km², Pattada exhibits the typical characteristics of rural Italian contexts, including low population density, a dispersed urban fabric, and a strong artisan and agri-food vocation.

The municipal territory hosts numerous renewable energy production plants, primarily photovoltaic systems—118 installations in total—amounting to approximately 957 kW of capacity from private solar systems, along with 270 kW from wind power across six installations.

The Municipality itself owns two photovoltaic plants, one of which supplies an electric vehicle charging station. This scenario demonstrates a strong local inclination toward sustainable approaches, making Pattada a favourable setting for piloting a REC. This is further reinforced by the municipal administration's willingness to take on a leadership role in the initiative.

3. Methodology.

3.1. Simulations

The assessment of the feasibility of establishing a REC in Pattada was carried out through the definition of various technical-energy configurations and the simulation of their effects in terms of energy production, consumption, and economic benefits. The types of users considered for inclusion in the REC include: 22 municipal users, two small and medium-sized enterprises (an artisanal cheese factory and a hospitality facility), and a variable number of residential users.

Hourly consumption data for the municipal users were obtained through a formal request to the local electricity distributor. For residential users and Small and Medium-sized Enterprise (SMEs), consumption data were derived from monthly billing information and from typical residential load profiles available in the literature [14], [15]:

Two scenarios were simulated:

- Scenario 1: The municipality acts as a prosumer with three increasing levels of installed photovoltaic capacity (85, 142, and 227 kW). Residents (50 users) and commercial entities participate as consumers.
- Scenario 2: The municipality remains a prosumer with the same photovoltaic configurations as in Scenario 1. Commercial entities continue to act as consumers, while the residential sector is split between 50 consumers and 50 prosumers, the latter equipped with 3 kW systems each, totalling 150 kW of installed residential capacity.

The evaluations were aggregated monthly to facilitate comparison with available billing data. Hourly electricity production was simulated using dedicated software calibrated to reflect the local climatic conditions and the technical specifications of the selected photovoltaic panels.

In Scenario 1, the Municipality is the only electricity producer and the direct self-consumer of the produced energy, while residents and SMEs act as virtual consumers. Figure 1 shows the average monthly consumption of the different users. Specifically, the total annual electricity consumption of municipal users amounts to approximately 117,000 kWh; the consumption of the dairy, concentrated in the summer months and in periods near the Christmas holidays, is 33,642 kWh; the consumption of the hotel, which operates from May to September, is about 85,000 kWh.

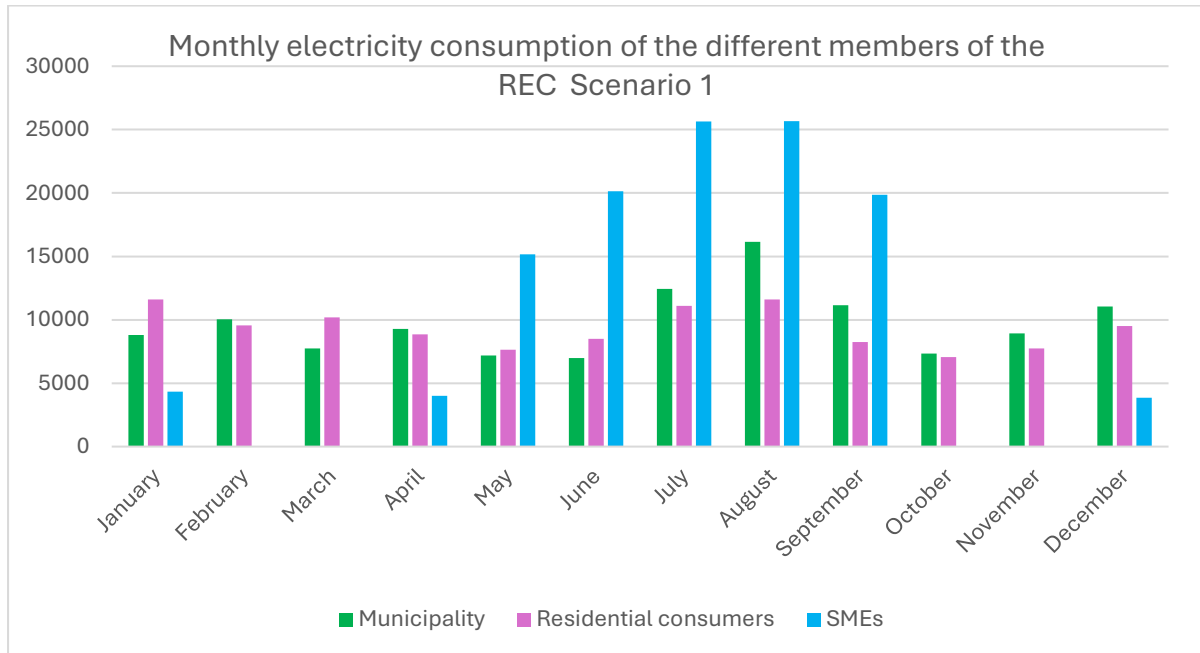


Figure 1. Monthly electricity consumption of the different members of the REC-Scenario 1.

In scenario 2, the only difference in consumption is due to the presence of the 50 prosumer residents (Figure 2).

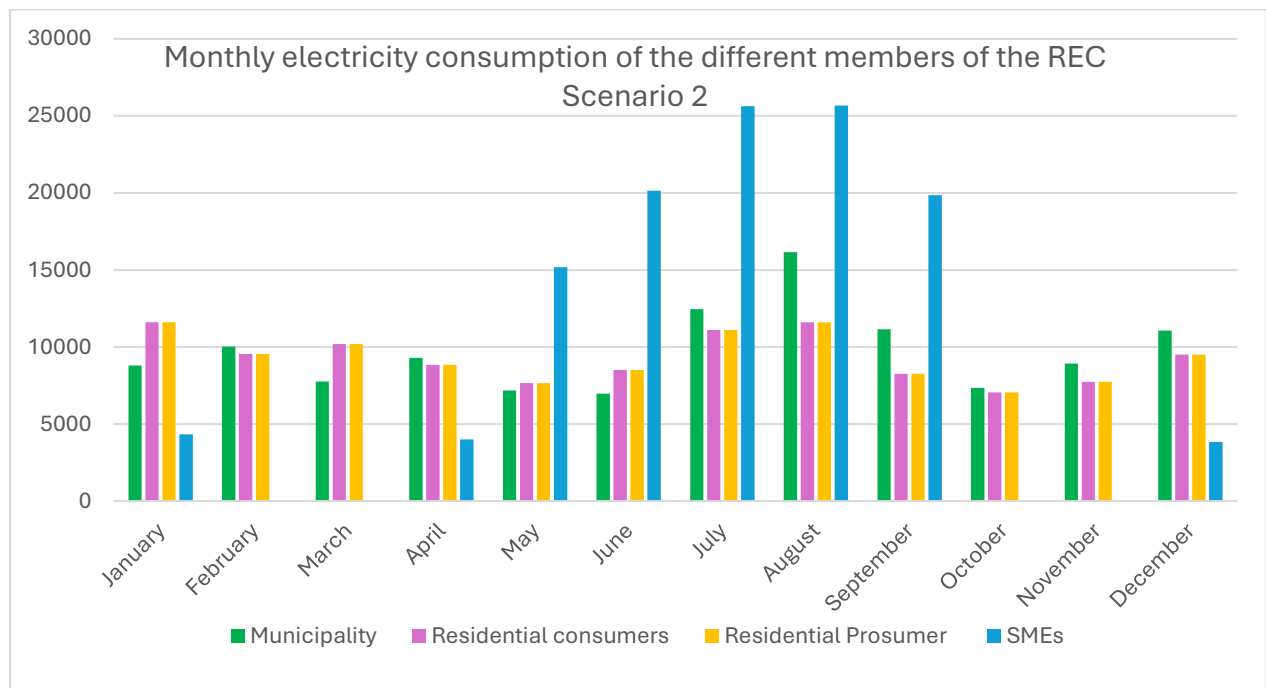


Figure 2. Monthly electricity consumption of the different members of the REC-Scenario 2.

3.2 Key Performance Indicators

To evaluate the different scenarios from an economic, energy, and environmental perspective, specific Key Performance Indicators (KPIs) were adopted. (1)

$$NPV = \sum_{k=0}^n \frac{C_k}{(1+C)^k} \quad (1)$$

The costs directly related to the installation (CAPEX) and operation (OPEX) of the systems are borne solely by the Municipality in Scenario 1, and by both the Municipality and the residential prosumers in Scenario 2.

The main difference lies in the Municipality's inability to benefit from physical self-consumption, as it does not have any loads directly connected to the POD of the PV system installed for the REC. For the economic assessment, the Net Present Value (NPV) was used:

- K = time horizon (20 years)
- C_k = cash flow at time K (including both CAPEX and OPEX)
- C = weighted average cost of capital (WACC), set at 4%

For the energy assessment, the KPIs used include:

- Self-Consumption Index (SCI) (or percentage of self-consumption): the ratio between shared energy and total production (2)
- Self-Sufficiency Index (SSI) (or percentage of self-sufficiency): the ratio between shared energy and total consumption (3)

$$SCI_{Tot} = \frac{E_{PSc,Tot} + E_{VSc,Tot}}{E_{P,Tot}} * 100 \quad (2)$$

$$SSI_{Tot} = \frac{E_{PSc,Tot} + E_{VSc,Tot}}{E_{C,Tot}} * 100 \quad (3)$$

Where:

- $E_{PSc,Tot}$: Total physical self-consumption energy;
- $E_{VSc,Tot}$: Total virtual self-consumption energy;
- $E_{P,Tot}$: Total energy produced;
- $E_{C,Tot}$: Total energy consumed.

From an environmental perspective, the amount of carbon dioxide emitted into the atmosphere was calculated both in the presence (P_{REC, CO_2}) and in the absence (P_{CO_2}) of the REC. To compute this indicator, it is appropriate to also consider the amount of CO_2 generated during the production of photovoltaic panels; the P_{REC, CO_2} value therefore accounts for this component.

As a result, the I_{CO_2} index (4) was calculated, which measures the percentage reduction in carbon dioxide emissions due to the establishment of the Renewable Energy Community.

$$I_{CO_2} = \frac{P_{CO_2} - P_{REC, CO_2}}{P_{CO_2}} * 100 \quad (4)$$

4. Results and discussion.

The incentives considered for which an REC may be eligible can be divided into:

- capital grants [3];
- premium tariffs [3];
- dedicated withdrawal [16];
- compensation for the valorisation of self-consumed energy [17].

4.1 Energy Production and Self-Consumption

Figure 2 shows the annual electricity production of the municipal photovoltaic systems, which increases progressively across the three configurations: from 89,729 kWh in Configuration A, to 149,548 kWh in Configuration B, and up to 239,277 kWh in Configuration C.

Figure 3 presents the monthly electricity production attributed to the residential prosumers. The total annual production from these systems amounts to approximately 164,500 kWh, with the majority concentrated in the summer months, in line with the typical solar irradiation profile of the area.

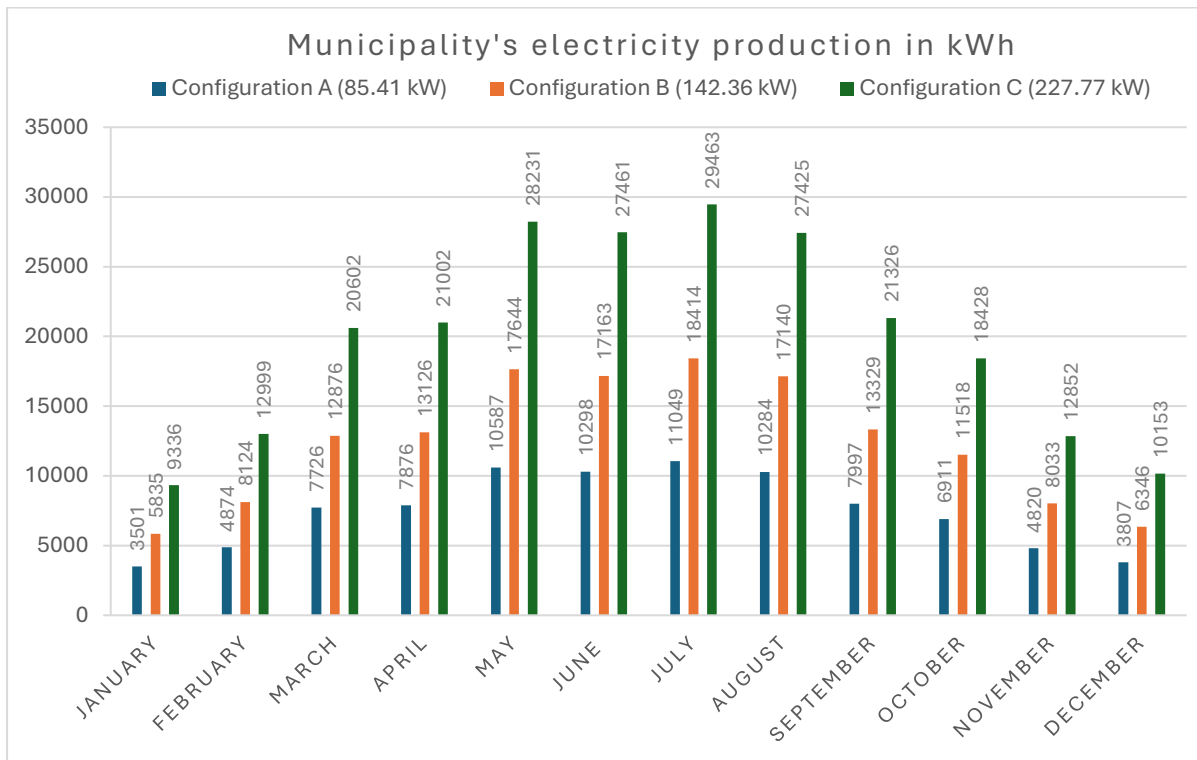


Figure 3. Monthly electricity production (kWh) from municipal PV systems under the three different configurations

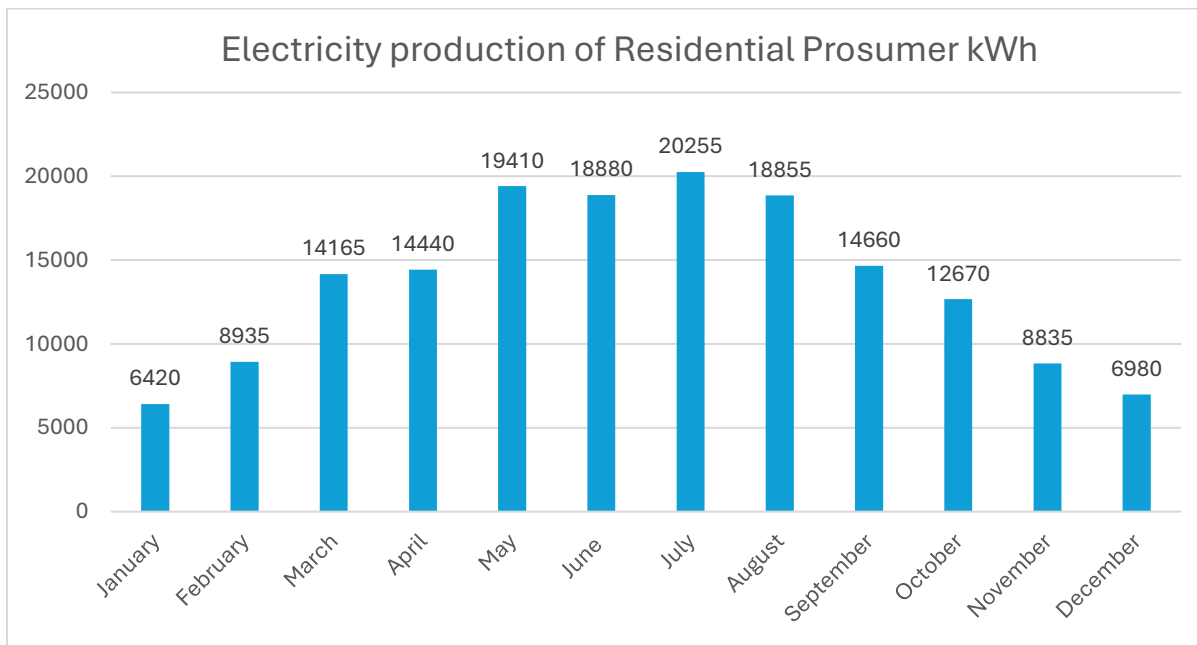


Figure 4. Monthly electricity production (kWh) from residential prosumer PV systems

4.2 Energy Exchanges

Figure 4 illustrates the percentage distribution of energy flows for the different simulated scenarios. Specifically, the following shares are represented:

- the portion of energy produced by the Municipality and injected into the grid (orange).
- the portion of energy virtually self-consumed by the Municipality (green).
- the portion of energy virtually self-consumed by commercial users (purple).
- the portion of energy virtually self-consumed by residential consumers (cyan).
- the portion of energy directly and virtually self-consumed by residential prosumers (grey);
- the energy injected into the grid by residential prosumers (yellow).

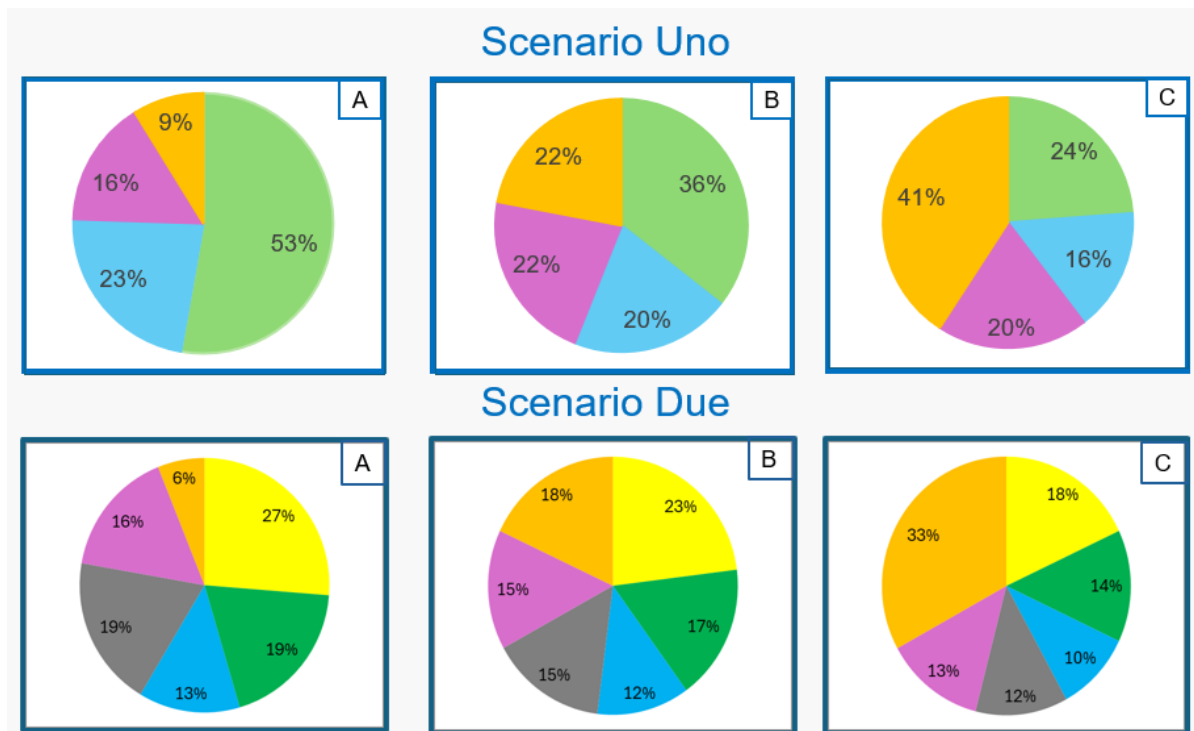


Figure 5. Energy exchanges within the REC as a function of the scenario and system configuration

In Scenario 1, increasing the installed capacity of the municipal Photovoltaic (PV) systems leads to a general rise in all self-consumption shares, though not proportionally. When the installed power is doubled and tripled:

- The municipal users, which represent the lowest share of overall consumption, show only a 15% and 23% increase in virtual self-consumption.
- The residential users demonstrate a more substantial increase, with virtual self-consumption rising by 45% and 86%.
- Commercial users experience an increase in self-consumption roughly proportional to the growth in installed capacity, effectively doubling and tripling their self-consumed energy.

However, a significant rise in surplus energy (i.e., produced but not self-consumed) is observed, increasing by 307% and 1100% in Configuration C. This leads to a reduction in the SCI, which drops from 91% to 78% and 59%.

Conversely, the SSI increases from 24% to 34% and 41%, indicating a more efficient use of the generated energy (including both direct and virtual self-consumption).

In Scenario 2, while the installed capacity of the municipal systems is again doubled and tripled, the installed capacity for residential users remains constant. In this case, all self-consumption shares show a general decrease:

- Municipal users experience a decrease of 11% and 26%,
- Residential users show a reduction of 16% and 31%,
- Commercial users exhibit a smaller drop of 6% and 19%.

The expenditure item considered therefore concerns the purchase of electricity: consequently, prosumer residents have a 43% lower expenditure than consumer residents, despite both groups being made up of fifty households with identical electricity consumption. The increase in surplus energy is less significant compared to Scenario 1, amounting to 28% and 59% in Configuration C. As a result, the SCI decreases from 68% to 59% and 49%. Nonetheless, the SSI increases from 38% to 40% and 43%, following a trend like that observed in Scenario 1.

The amount of shared energy—i.e., that which is instantly self-consumed among REC members—depends heavily on the overlap between production and consumption profiles. Scenario 2, due to the distributed generation among multiple participants and the diversification of loads, enables a better balance and higher instantaneous self-consumption compared to Scenario 1.

4.3 Distribution of incentives, NVP, PBP

One of the most complex aspects in the establishment phase of an REC concerns the drafting of the agreement between the parties, particularly regarding the distribution of the Premium tariff and incentives among the various members of the community.

Several solutions can be adopted; however, for the purposes of this study, the following assumptions were made:

- The Premium tariff and dedicated withdrawal revenues are equally shared among all residential members and SMEs of the REC.
- The Municipality receives economic returns only from the physical self-consumption of the loads directly connected to the PV system.
- Residential prosumers benefit additionally from the physical self-consumption of the energy produced by their individual systems.

For the calculation of the NPV, three different configurations of capital grant access were considered: 0%, 20%, and 40%. Currently, in Sardinia, capital grants are not available for residential users, and thus this type of funding is only accessible to public entities, businesses, and the Municipality.

The revenues related to the Premium tariff and dedicated withdrawal are included as cash inflows in the NPV calculation over a 20-year period. A positive NPV does not imply the complete elimination of monthly energy expenses but rather their reduction through physical self-consumption. Therefore, it is assumed that such revenues contribute to recovering the capital invested by the system owners and provide lower electricity bills for regular consumers.

Table 1 presents, for the three different scenarios (A, B, and C) and for the three levels of capital grant received by the Municipality (0%, 20%, 40%), the Payback Period (PBP) in years and

the NPV at year 20, for both the Municipality and the 50 residential prosumers. The table also reports the total annual savings for the 50 consumers and the two SMEs.

Table 1. Scenario 2: NPV and PBP for Municipality and Prosumer, Distribution of incentives in the REC

		A			B			C		
		0%	20%	40%	0%	20%	40%	0%	20%	40%
Municipality	PBP	9	7	5	15	11	8	20	15	11
	NPV [€]	95k	118k	140k	46k	84k	121k	0	50k	100k
Prosumer	PBP	12	13	13	11	11	11	9	10	10
	NPV [€]	99k	92k	85k	154k	141k	128k	215k	173k	167k
Consumer+ SMEs	[€/anno]	8.8k	8.3k	7.8k	12.8k	11.9k	10.9k	17.4k	14.2k	13.8k

The table reveals some significant trends:

Municipality: In all three configurations (A, B, and C), increasing the capital incentive (from 0% to 40%) leads to a reduction in the PBP and an increase in the NPV. However, as the size of the facility increases (from A to C), the PBP lengthens, especially in the absence of an incentive. For example:

- In configuration A, the PBP varies from 9 to 5 years.
- In B, from 15 to 8 years.
- In C, from 20 to 11 years. Specifically, with zero incentive (0%), the payback period only occurs in the twentieth year.

Prosumer: Due to the reduction in the available incentive share, the NPV behavior is the opposite of that of the Municipality: it decreases as the capital contribution increases, in all configurations. The PBP for prosumers remains nearly stable within each configuration and is minimal (about 10 years) for Case C.

For Consumers and the two SMEs, due to the reduction in redistributed amounts, the annual economic benefits (€/year) increase with the size of the system and decrease with the increase in capital contribution, ranging from an annual amount of €169/user to €334/user.

Scenario 2, which includes 50 residential users equipped with photovoltaic systems (total installed capacity of 156 kW), demonstrated significantly better performance. The distribution of generation among multiple users and the temporal diversification of demand resulted in increased overlap between generation and consumption, thus improving both self-consumption and self-production. In the configuration C, the share of shared energy exceeded 70%, while the total energy demand coverage of the REC reached 60%, leading to a substantial increase in incentives and bill savings.

From an environmental perspective, the benefits are measurable in terms of avoided emissions. Using an average emission factor of 0.406 kg CO₂/kWh, it is estimated that under the optimal configuration of Scenario 2, the REC can avoid the release of over 160 tonnes of carbon dioxide into the atmosphere annually.

For Scenario 1, a ten-year PBP is assumed for the Municipality to recoup its initial investment; this is possible provided that the Municipality can benefit from a portion of the Premium Tariff and the dedicated withdrawal. Table 2 shows the distribution percentages required for economic recovery within this timeframe.

The table also shows the cumulative earnings of the Municipality in the twentieth year following the establishment of the REC. These earnings, which reach €171,000 in the C configuration without incentives, suggest the possibility of reinvestment in the expansion of the photovoltaic park or for further interventions in the area.

Table 2 also describes the redistribution of incentives to consumers and SMEs; this distribution increases the larger the size of the system and the lower the incentive requested by the Municipality: it varies from a minimum of €129/user (Configuration A) to a maximum of €375/user (Configuration C).

Table 2. Scenario 1: NPV and PBP for Municipality and Prosumer, Distribution of incentives in the REC

		A			B			C		
		0%	20%	40%	0%	20%	40%	0%	20%	40%
Municipality	%	0%(4*)	0% (6*)	0% (8*)	40%	20%	0% (7*)	50%	30%	5%
	NPV [€]	141k	118k	96k	133k	121k	121k	171k	143k	114k
Consumer+ SMEs	[€/anno]	5.7k	6.7k	7.7k	9.5k	11.2k	12.1k	12.6k	16k	19.5k

* Year of PBP

As shown in the table, the Municipality is always included in the investment: the most critical cases arise when access to the capital account is zero (0%), the distribution percentage required to cover the investment within the pre-established time frame is 40% (configuration B) and 50% (configuration C); conversely, this high percentage leads, in the twentieth year, to a higher profit for the Municipality and a reduction in the profit obtained by consumers.

An appropriate design of installed capacity in relation to actual consumption is essential to maximize both energy and economic benefits. The results clearly indicate that the active participation of citizens (as prosumers) is a key element in optimizing the energy and economic performance of a REC. The aggregation of multiple small-scale photovoltaic systems distributed across various buildings enhances the synergy between energy supply and demand.

5. Conclusions.

The study conducted in the Municipality of Pattada demonstrates the concrete technical, economic, and environmental feasibility of establishing a REC in a rural context. The adoption of flexible scenarios and the use of real data make the results applicable to other small Italian municipalities.

The main benefits identified include reduction of energy costs for participants, mitigation of climate-changing emissions, increased energy resilience of the territory, and active citizen engagement.

From an economic point of view, configurations with greater prosumer participation are more sustainable even in the absence of large centralized systems. This makes the model replicable in other rural contexts with similar characteristics to those of Pattada, especially given

the incentives provided by the Italian REC Decree and PNRR funding dedicated to municipalities with fewer than 5,000 inhabitants.

Scenario 2, under Configuration C, proves to be the most effective in all indicators: self-consumption exceeds 70%, and self-production covers more than 60% of the community's electricity demand. Avoided emissions reach nearly 160 tonnes of CO₂ per year.

To maximize the impact of REC in rural areas, it is essential to:

- promote citizen participation also as prosumers,
- ensure adequate local energy planning,
- support municipalities with appropriate technical and financial tools.

The energy transition also—and above all—passes through small municipalities: the Pattada Renewable Energy Community is a concrete example of this.

7. Acknowledgments

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