



# Techno-Economic Assessment of a Renewable Energy Community in the Municipality of Pattada: Energy Balance Analysis of Municipal Photovoltaic Integration

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**Abstract:** This study addresses the growing role of Renewable Energy Communities (RECs) in supporting decentralized renewable energy integration and improving local energy self-sufficiency within the European energy transition framework. The work aimed to evaluate the technical and economic feasibility of a municipal REC in Pattada, a small municipality located in Sardinia, Italy, through an energy balance analysis based on distributed photovoltaic generation and shared electricity consumption. A techno-economic assessment framework was developed by combining the estimated electricity production of municipally owned photovoltaic systems with the load profiles of municipal, commercial, and residential users participating in the REC. The photovoltaic energy production was estimated using the Photovoltaic Geographical Information System (PVGIS) simulation platform, while the shared energy within the REC was evaluated by considering the simultaneity between electricity generation and demand under different residential participation scenarios. The results showed that the municipal photovoltaic systems achieved an annual electricity production of approximately 506.41 MWh, while direct physical self-consumption remained limited to 3.10 MWh/year due to the mismatch between municipal demand and photovoltaic generation profiles. The analysis further showed that the REC reached an energy equilibrium condition with the participation of 285 residential users, corresponding to nearly 23% of the households within the municipality, allowing virtually shared energy to reach 425.92 MWh/year. The economic evaluation demonstrated that the municipal administration obtained the highest share of the overall economic return, mainly driven by electricity exported to the grid and incentive revenues associated with shared energy. The results indicate that the integration of municipally owned photovoltaic systems within REC configurations provides an effective approach for improving local energy sharing and enhancing the economic viability of distributed renewable energy systems in small municipalities. The proposed framework offers practical support for local administrations in planning renewable energy investments and optimizing REC configurations under real operating conditions.

**Keywords:** Renewable energy communities; Distributed photovoltaic systems; Energy balance analysis; Shared electricity; Techno-economic assessment; Local energy systems

## 1 Introduction

Renewable Energy Communities (RECs) represent one of the main innovations introduced by the new national and European regulatory framework on energy transition, with the aim of promoting collective self-consumption, active participation of citizens and local stakeholders in the management of the energy system, and distributed generation from renewable sources.

Within the framework of the European Green Deal and in implementation of Directive (EU) 2018/2001 (RED II) [1], the Italian legislator has introduced regulatory tools and incentives aimed at fostering the creation of local energy communities, defined as autonomous legal entities capable of producing, sharing, managing, and self-consuming energy from renewable sources [2–4].

In this work, after analyzing the territorial context of Pattada, a small municipality located in north-central Sardinia, the main results of the energy and economic analysis are presented. In particular, starting from the assessment of the potential production of new Renewable Energy Sources plants on available municipal properties, the number and type of consumers participating in the REC were analyzed in order to identify the optimal energy and economic configuration. The study is completed with a benefit analysis of the investment that the municipal administration intends to undertake.

This study aims to support small municipal administrations in identifying the best possible configuration of a local energy system based on shared self-consumption and renewable energy production, with the general objective of promoting energy self-sufficiency and environmental sustainability within the territory, as a further development of the work of Piga et al. [5].

Although several studies have addressed the energy and economic analysis of RECs [6–8], this work differs in terms of its methodological framework. Specifically, it starts from the assessment of the electricity generation potential of municipally owned photovoltaic plants, based on a study previously conducted by the municipal administration. On the basis of this generation potential, a parametric analysis of shared energy is then carried out, assuming the number of residential users participating in the REC through the municipal administration as the variable. This framework allows for a direct evaluation of the conditions under which the REC achieves energy balance.

## 2 Baseline Analysis

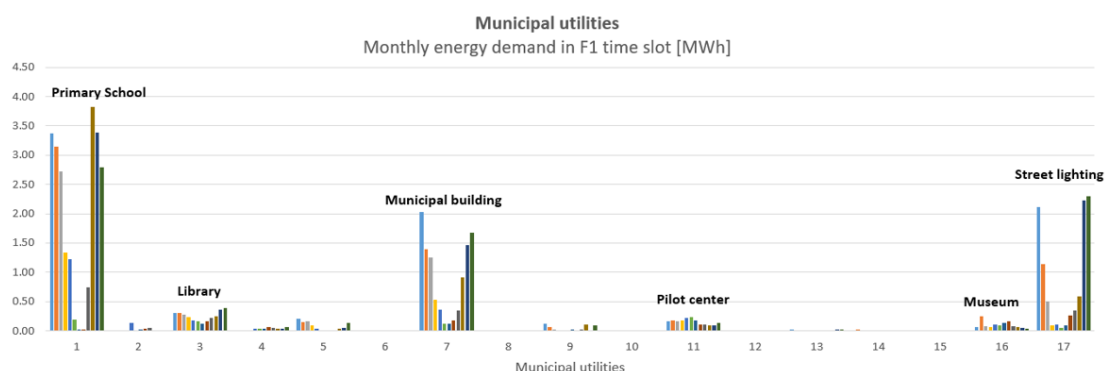
The first step of the study consisted in identifying the types of consumers participating in the REC and collecting data on their energy demand. Subsequently, in agreement with the municipal administration, a specific electrical capacity that could be installed as an investment by the municipal administration was identified.

### 2.1 Energy Demand of Consumers

In order to identify the share of energy potentially self-consumable within the REC, the energy demand of both municipal and private users was analyzed, particularly with reference to the F1 time slot, which includes weekdays from Monday to Friday between 8:00 and 19:00.

The hourly consumption data of municipal users were obtained through a formal request submitted to the local electricity distribution system operator. Commercial users' energy consumption data were derived from information reported in monthly electricity bills, while residential consumption data were estimated based on typical load profiles [9, 10].

The graph in Figure 1 refers to supply points owned by the public administration. For each user, numbered sequentially, the electricity consumption values in the F1 time slot for each month are reported. Three municipal facilities identified as hosting photovoltaic systems (sports field, playroom, and sports hall) were excluded, as they will directly self-consume the produced energy. Supply points from number 1 to number 16 refer to civil buildings, while number 17 represents the total demand of all public lighting supply points.



**Figure 1.** Monthly energy demand of municipal supply points during F1 time slot

From the qualitative analysis of the graphs, it is evident that the municipal supply points with the highest probability of energy sharing are the municipal building, primary schools, and public lighting; to a lesser extent, the library and the pilot center.

Moreover, a higher energy demand is observed during winter months compared to summer, increasing the temporal mismatch between photovoltaic production and shared self-consumption for municipal supply points.

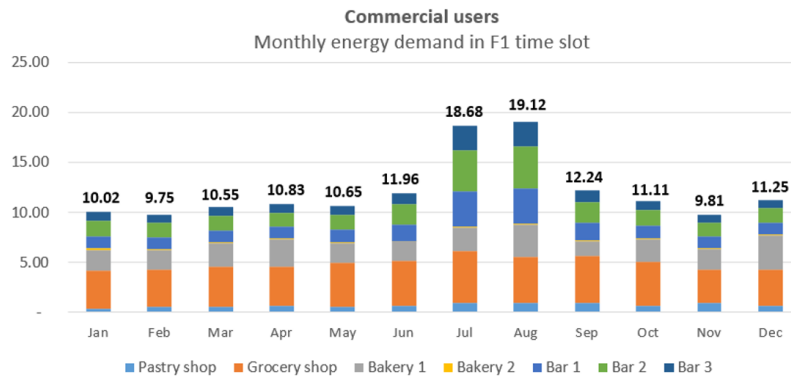
As regards the other consumers, reference is made to the base configuration selected for the municipal administration establishes a new association, foundation, or cooperative for the implementation of the REC of the municipality of Pattada, acting as the main promoter.

Based on a territorial survey, a potential participation of commercial users has been hypothesized, using rather conservative assumptions, along with a variable number of residential users, with the aim of identifying the optimal REC structure in terms of energy, social, and economic maximization. The commercial users considered as reference are:

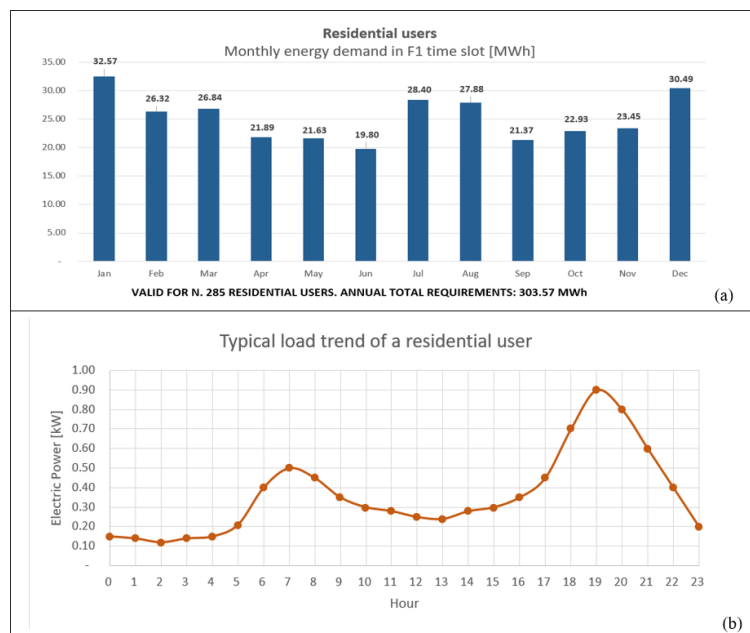
- 3 bars
- 2 bakeries
- 1 pastry shop
- 1 grocery shop

For these users, consumption data were obtained directly from the owners or estimated on the basis of load profiles available in the literature.

Figure 2 shows the cumulative monthly energy consumption in the F1 time slot of the commercial users considered. On average, the energy demand during the hours of greatest simultaneity with photovoltaic energy production amounts to 30.2% of total consumption. The most energy-intensive user is the grocery store, which also makes the largest contribution to the energy demand in the F1 time slot, whereas bakery number 2 is characterized by a lower energy demand.



**Figure 2.** Monthly energy demand of potentially commercial users associated with Pattada’s REC during F1 time slot



**Figure 3.** (a) Monthly energy demand of 285 residential users associated with Pattada’s Renewable Energy Communities (RECs) during F1 time slot; (b) typical electrical load trend of a residential user

The number of users represents the main variable for the energy and economic analysis of the REC configurations examined. Figure 3 presents the graph of monthly consumption in the F1 time slot for 285 residential users, developed on the basis of a typical electrical load profile of a residential user and provided for indicative purposes. As will be further highlighted below, the number of residential users considered represents a break-even point for the analyzed REC configuration.

## 2.2 Municipal Photovoltaic Systems: Energy Production Estimate

Regarding the estimate of the energy produced by photovoltaic systems, this study was based on a defined nominal electrical power of the photovoltaic systems to be built in the municipality of Pattada, evaluating the available spaces.

Four photovoltaic plants were identified, with the capacities reported in Table 1. The first three systems will be partially integrated on existing rooftops, while the fourth system, located in a former quarry, will be ground-mounted.

**Table 1.** Location of the municipal photovoltaic systems to be built and expected nominal power

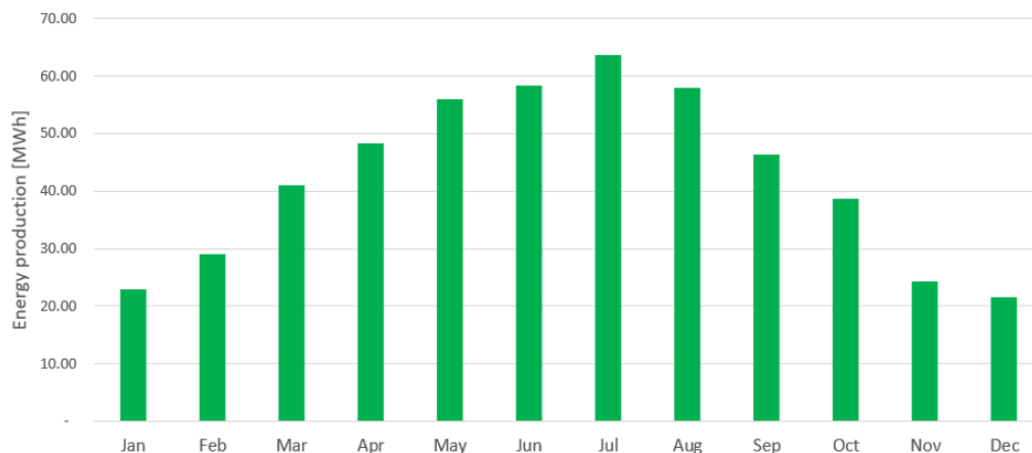
Number Plant	Location	Address	Nominal Power (kWp)
1	Sports ground	Località Proiana	100
2	Sports hall	Viale Europa	70
3	Playroom	Viale Europa	10
4	Abandoned quarry	SS 128bis Centrale Sarda	200

The production estimate was carried out using the “Photovoltaic Geographical Information System (PVGIS)” [11] simulator developed by the Joint Research Centre (JRC), by setting location, tilt, orientation, and system parameters.

Input data included:

- Geographic location (latitude and longitude);
- Solar radiation database (SARAH);
- Nominal power;
- Module technology (monocrystalline silicon);
- Azimuth and tilt;
- System losses (14%); and
- Mounting system.

Table 2 reports the expected values of specific yield and the estimates of direct on-site physical self-consumption for the supply points at which the photovoltaic systems are planned to be installed, whereas Figure 4 presents the aggregated monthly energy yields of the four photovoltaic plants.



**Figure 4.** Estimated cumulative monthly energy production of 4 municipal photovoltaic systems

By cross-referencing the production profiles of the photovoltaic systems with the load profiles of the supply points where the installations are planned (football field, sports hall, and recreation center), the share of directly self-consumed energy was estimated; the corresponding annual values are reported in the last column of Table 1.

It is noteworthy that, despite a total annual energy yield of 506.41 MWh, direct self-consumption amounts to 3.10 MWh/year, corresponding to a very low percentage of 0.61%. The remaining share of the generated energy therefore represents energy shared within the REC.

**Table 2.** Estimated specific energy production and physical self-consumption for municipal photovoltaic systems

Number Plant	Location	Estimated Specific Energy Producibility (MWh/kWp-year)	Estimated Annual Physical Self-Consumption (MWh/year)	Yearly Self-Consumption (%)
1	Sports ground	1.220	1.67	1.37
2	Sports hall	1.163	1.16	1.42
3	Playroom	1.300	0.27	2.08
4	Abandoned quarry	1.450	0.00	0.00

### 2.3 Economic Benefits of Renewable Energy Communities

The first step of the study consisted in identifying the types of consumers participating in the REC and collecting data on their energy demand. Subsequently, the maximum electrical capacity installable through photovoltaic systems by the municipal administration was determined.

The Ministerial Decree of December 7, 2023 (CER Decree), in force since January 24, 2024, defines the incentive mechanisms for RECs [4, 12].

The incentives are granted for 20 years and are calculated on the electricity that is virtually shared within the REC.

The economic contributions are of two types:

- Incentive Rate (IR) for shared electricity; and
- Valorization Fee (VF), which returns avoided grid costs.

The IR varies approximately between 60 €/MWh and 120 €/MWh depending on:

- plant size
- electricity price
- geographical location

To these benefits, revenues from the sale of electricity injected into the grid and not physically self-consumed must also be added, regardless of whether the energy is virtually shared within the REC or not. In the case of a contract under the dedicated withdrawal mechanism (Feed-in Tariff, FIT), the selling price recognized by the national energy service management (Italian acronym, GSE Gestore dei Servizi Energetici) is based on the hourly zonal market price, with electricity valued on an hourly basis according to the market zone in which the primary substation of the REC is located [13]. For the area under investigation, the average prices recorded in Sardinia for the year 2025 were considered. These prices were calculated as a weighted average based on the amount of shared energy across the three time slots (with F1 having the greatest impact, as the majority of the energy is injected into the grid during this time slot). The resulting value amounts to slightly over 90 €/MWh.

It should be noted that access to the FIT mechanism is subject to administrative management fees retained by the GSE on the revenues from electricity sales, equal to 0.65 €/kWp for photovoltaic systems with nominal power greater than 3 kW and  $\leq 200$  kW, and 0.60 €/kWp for photovoltaic systems with nominal power exceeding 200 kW, up to a maximum of 10,000 €/year.

In addition to these economic incentives, direct savings on electricity bills resulting from the energy produced by photovoltaic systems and physically self-consumed on-site must also be accounted for. The economic value of this contribution corresponds to the unit cost of electricity purchased from the grid, i.e., the charges paid on the electricity bill.

With regard to the economic assessment, the present study adopts the economic parameters reported in Table 3.

It is further appropriate to clarify that the allocation of the economic shares deriving from the IR and the VF applied to shared electricity among the members of the REC is delegated to the participating entities and is defined by the internal regulations of the legal entity managing the energy community.

Without prejudice to the fact that the allocation rules within the REC may be reviewed and defined at the time of its formal establishment, and acknowledging that the municipal administration may independently decide how to allocate the revenues generated from electricity sales under the FIT scheme, for the sake of consistency and clarity of analysis, a predefined and fixed allocation scheme has been adopted in this study, as follows:

- 40% of the IR + VF revenues allocated to prosumers, according to their respective shares of shared energy;
- 40% of the IR + VF revenues allocated to consumers, proportionally to their contribution to shared energy; and
- 20% allocated to the association, to support management and promotional activities of the REC.

**Table 3.** Reference values considered for the energy produced by photovoltaic systems

<b>Reference Values Considered for the Economic Analysis</b>	
Value of physical self-consumption energy	250 €/MWh
Energy exported to the grid (FIT contract)	90 €/MWh
<b>Virtually Shared Energy within the Renewable Energy Community (REC)</b>	
Incentive rate (IR)	120 €/MWh
Valorization fee (VF)	10.57 €/MWh

Note: FIT = Feed-in Tariff.

### 3 Results

Before presenting the main energy and economic results, the scope and validity limits of the present study are clarified.

#### 3.1 Limitations of the Study

Although the analyses are conducted on a real case study, the results are subject to several assumptions, which are detailed below:

1) The energy demand of residential users is aggregated assuming a common standard load profile, developed on the basis of previous studies [9, 10]. This choice was made in order to provide a sufficiently general reference for residential energy demand that can be replicated in other studies, as this type of user is characterized by a high degree of load profile replicability. However, these profiles are not derived from real billing data, unlike the energy demand of commercial users included in this study.

2) The case study is based on the assumption of limited participation of commercial users in the REC. This assumption is motivated by the widespread presence of existing private photovoltaic systems in the area, which already serve these types of users. As a result, this study is highly context-specific and may not be easily transferable to scenarios where significant participation of commercial users is expected, given the substantial heterogeneity of their load profiles.

3) Given the high electricity generation potential expected from municipally owned photovoltaic plants, the participation of residential users as prosumers was not considered within the REC. It should be noted, however, that RECs are inherently open and flexible structures, and the inclusion of residential or private prosumers is fully feasible both at the time of establishment and at later stages.

4) The economic analyses are constrained by the incentive schemes for RECs defined by Italian national regulations and by national zonal electricity prices. Consequently, the results obtained may vary under different regulatory frameworks or economic conditions.

#### 3.2 Energy Analysis

With reference to the baseline scenario described in section 2, the amount of electricity shared within the REC was analyzed by assuming the number of residential users participating in the energy community as the main variable. The objective of the analysis is to identify a range of possible configurations and, in particular, the one capable of optimizing energy sharing.

The results of the analysis are illustrated in the following chart (Figure 5).

The green histogram represents the amount of energy generated by the municipally owned photovoltaic plants and injected into the REC. This value remains constant, as the installable peak capacity was fixed based on the available surfaces and the investment capacity of the municipal administration. This choice was deliberately made in order to limit the number of variables affecting the subsequent energy and economic analyses.

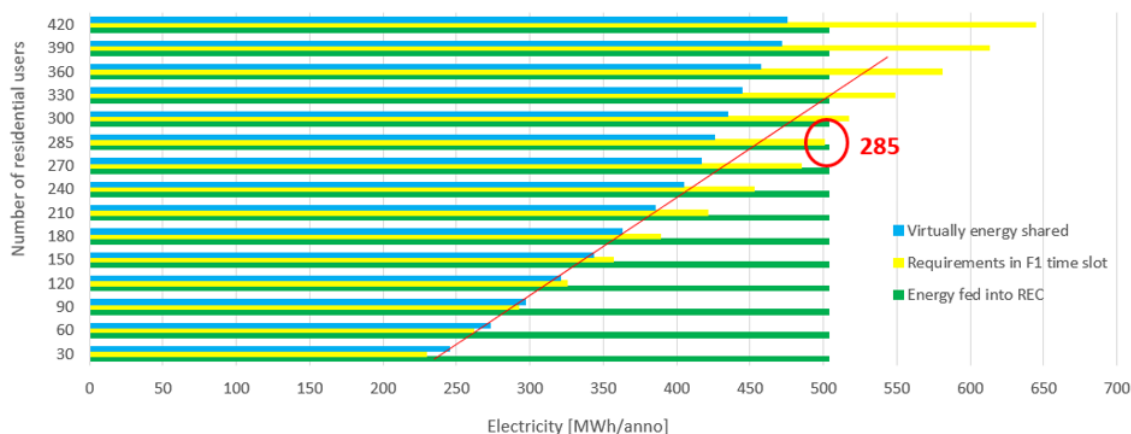
The yellow histogram represents the energy demand of consumers during the hours included in the F1 time slot: this demand increases in a substantially linear manner as the number of participating residential users increases.

However, the non-linear—specifically logarithmic—trend of virtually shared energy should be emphasized: as the overall energy demand of the REC increases, there is no directly proportional increase in the amount of virtually shared energy within the REC (see red curve), due to the constraints imposed by the temporal coincidence between generation and demand. This aspect will be further investigated through the subsequent analysis of the economic impacts associated with the different configurations.

When green and yellow histograms reach the same magnitude, an energy balance condition between the energy injected into the REC and the total demand of the REC is achieved. This occurs for 285 residential users, corresponding to approximately 23% of the households residing within the municipality. Under this condition, the amount of virtually shared energy equals 425.92 MWh/year (light blue bar).

It is worth noting that these values are strictly linked to the peak installed capacity of the municipally owned photovoltaic plants and, consequently, to the amount of energy injected into the REC, equal to 503.78 MWh/year. Furthermore, the volume of shared energy also depends on the number of commercial users participating in the REC, which, in the present analysis, was kept constant and deliberately limited in order to adopt a conservative approach.

Finally, it should be noted that when the number of residential users is relatively low (below 60 users), the amount of shared energy exceeds the energy demand in the F1 time slot. This occurs because, given the substantial amount of electricity made available within the REC, consumers are able to virtually absorb energy not only by saturating the F1 time slot, but also during other time bands (typically F2 on Saturdays and F3 on Sundays).



**Figure 5.** Energy fed into Renewable Energy Communities (REC), requirements in F1 time slot of REC and virtually shared energy within the REC

### 3.3 Economic Analysis Results

Based on the energy analysis, the total incentive amount accruing to the REC for shared electricity was calculated, considering both the IR and the VF components, using the reference economic values reported in Table 3.

The total incentive exhibits the same trend as the virtually shared energy within the REC; consequently, a non-linear behavior is observed as the number of participating residential users increases (light-blue bars in Figure 5).

At the same time, a growing economic benefit emerges not only for the municipal administration, but also for the residential sector and for the association, to the detriment of the incentive share allocated to commercial users, whose proportion of shared energy decreases as the share of residential users increases (Figure 6).

The economic benefit accruing to the municipal administration from its share of the incentives exceeds that obtained by the other actors participating in the REC and varies within a range from 61 k€ (for 30 residential users) to 72.5 k€ (for 450 residential users).

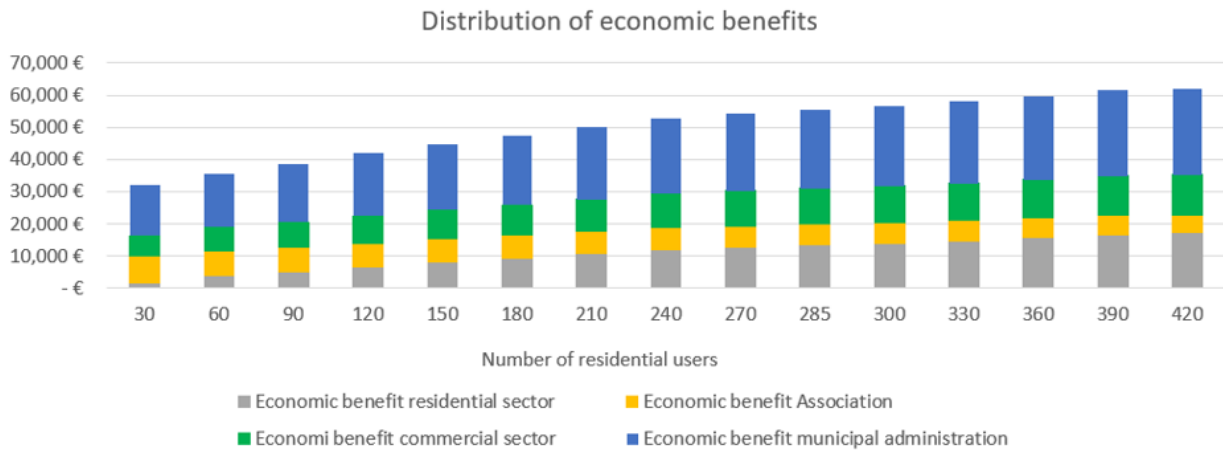
This benefit should not be interpreted as a profit-oriented investment, but rather as a collective advantage for the community, insofar as the revenues generated by the Energy Community can be used to support projects and initiatives aimed at territorial enhancement, in line with the social objectives envisaged by the legislator for this type of measure [14–16], in particular as a tool to counteract the progressive depopulation affecting inland and rural areas [17–19].

With regard to the allocation of the incentive tariff among the different actors participating in the REC and deriving from shared energy (IR and VF components), the corresponding shares are illustrated in the pie chart in Figure 7 and refer to the REC energy balance condition (285 residential users).

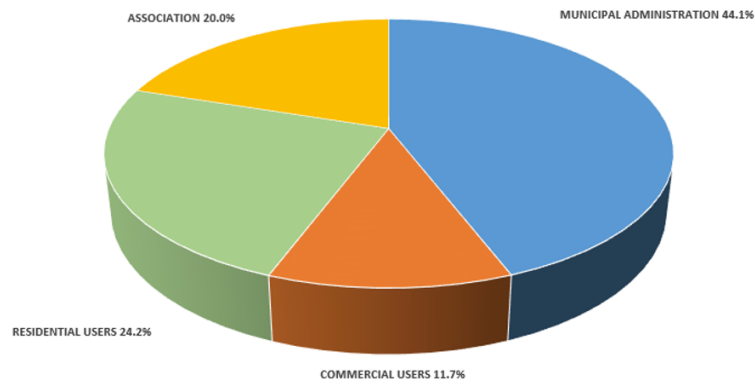
Figure 8 illustrates the quantification of the overall economic benefit achievable by the municipal administration under the REC energy balance condition, broken down into the individual components contributing to the total value: IR + VF revenues derived from the prosumer component, IR revenues associated with the consumer component, revenues obtained through the FIT scheme, and savings resulting from direct physical self-consumption.

It can be observed that the largest contribution arises from the electricity sold to the GSE under the FIT contract. The second most relevant contribution, in terms of magnitude, derives from the allocation of the incentives (IR and VF) associated with shared energy within the REC in the role of prosumer.

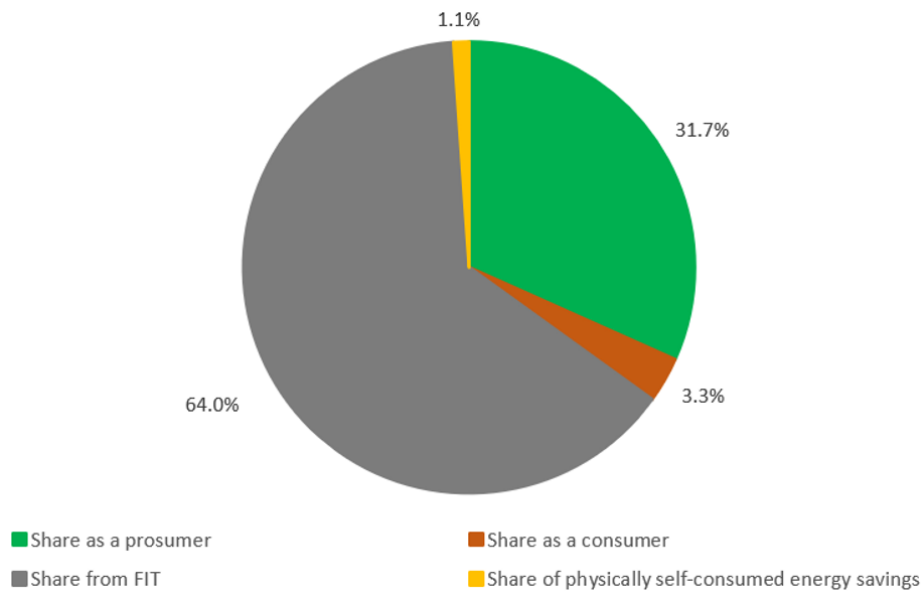
Conversely, the revenues linked to the allocation of incentives for shared energy consumed by municipal facilities and buildings in the role of consumer, as well as the savings on electricity bills resulting from avoided electricity purchases due to direct physical self-consumption, appear to be negligible.



**Figure 6.** Share of total economic incentive achievable to the Renewable Energy Communities (REC) actors



**Figure 7.** Distribution of economic incentives—the Incentive Rate (IR) and the Valorization Fee (VF)—provided for Renewable Energy Communities (REC) in energy equilibrium conditions with 285 residential users



**Figure 8.** Economic benefits achievable by the municipal administration divided according to the 4 contributive items

Note: FIT = Feed-in Tariff.

## 4 Conclusions

The present feasibility study conducted within the territory of the Municipality of Pattada clearly and systematically demonstrates the full technical, economic, and territorial feasibility of establishing a Renewable Energy Community (REC).

The analysis highlights the following key elements:

- the availability of suitable surfaces for the installation of municipally owned photovoltaic systems;
- the assessment of local energy demand and the identification of configurations capable of achieving energy balance conditions between generation and consumption; and
- significant economic outcomes, closely related to the configuration structure and the attainable energy balance within the REC.

The analysis of municipal energy demand shows that the Municipality of Pattada exhibits limited electricity consumption during the hours of simultaneity with photovoltaic generation. Consequently, the involvement of private users is essential for the successful development of the REC. In particular, considering the characteristics of the territory and the presence of several photovoltaic systems owned by commercial users that cannot be leveraged for REC development, it becomes crucial to focus primarily on residential users.

Based on the available energy data—both with respect to the expected production of installable municipal photovoltaic systems and the energy demand of the users potentially participating in the REC—the optimal configuration is achieved with the participation of 285 residential users, corresponding to approximately 23% of the total households in the municipality, together with a limited number of commercial users (seven, with varying energy demands).

Under these conditions, the investment undertaken by the municipal administration yields highly robust economic results, while the overall performance enables the legal entity established for REC management to achieve a well-defined level of operational autonomy.

It is important to consider the political and social implications of the obtained results. The involvement of a significant number of residential users and/or other private users requires that issues related to energy transition and energy independence be placed at the core of the municipal administration's political agenda. This condition is also emphasized by the legislator, who assigns local administrations a crucial role as promoters, facilitators, and active members of RECs.

It should also be emphasized that the economic benefit estimated for the municipal administration should not be interpreted as a profit-driven investment, but rather as a collective advantage for the community. The revenues generated by the Energy Community can be deployed to support projects and initiatives aimed at enhancing the local territory, in alignment with the social objectives envisaged by the legislator for such schemes.

Beyond economic aspects, it is also important to highlight that the REC generates social and environmental value, contributing to:

- the reduction of greenhouse gas emissions
- the strengthening of territorial cohesion
- the enhancement of local value chains

### Author Contributions

Conceptualization, R.P. and A.F.; methodology, R.P. and C.C.M.; investigation, R.P., R.B., and M.P.; data research and analysis R.P., M.P., and M.Z.; writing—original draft preparation R.P.; writing—review and editing, R.P., A.F., R.B., C.C.M., M.P., and M.Z.; supervision, A.F. and R.B. All authors have read and agreed to the published version of the manuscript.

### Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

### Conflicts of Interest

The authors declare that they have no conflicts of interest.

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## **Nomenclature**

F1, F2, F3	Time slots
FIT	Feed-In Tariff
GSE	National Energy Service Manager (Italian acronym)
IR	Incentive Rate
JRC	Joint Research Centre
PVGIS	Photovoltaic Geographical Information System
REC	Renewable Energy Community
SARAH	Solar radiation database
VF	Valorization Fee