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Evaluation of a Renewable Energy Community for enhancing renewable energy use: An Italian case study

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Abstract. Renewable Energy Community (REC) offers a strategic opportunity to increase local renewable energy adoption and maximise energy self-consumption. This study evaluates the realisation of a REC within a municipality in the Marche region, Center of Italy, by analysing two different scenarios based on both Small-Medium Enterprise (SME) and residential energy consumption. The first scenario focuses on evaluating the size of a Photovoltaic (PV) system that maximises the energy self-consumption along with economic feed-in tariffs. The second scenario expands on this concept by integrating a second-life battery energy storage system (BESS), which allows excess energy to be stored for later use during peak demand hours, increasing the REC's virtual self-consumption. In the PV-only installation scenario, the PV production covers 39.00% of on-site energy consumption, with 465.82 MWh of exports and 465.17 MWh of imports. Adding a 0.30 MWh-BESS, it increases the on-site energy self-consumption rate up to 50.00%, reduces exports by 21.35%, and imports by 17.26%. The BESS shifts 80.30 MWh of surplus PV to energy self-consumption. However, the introduction of a second-life BESS, economically speaking, is not cost-effective. To have a positive Net Present Value (NPV), the CAPital and EXpenditure (CAPEX) cost of the second-life BESS must be decreased to 75 €/kWh.

Nomenclature

ARERA Regulatory Authority for Energy, Networks and Environment

BESS Battery Energy Storage System

CAPEX Capital Expenditure

DoD Depth Of Discharge

DW Dedicated Withdrawal

GHG GreenHouse Gas

KPI Key Performance Indicator

LCOS Levelised Cost Of Storage

LEC Local Energy Community

NORC North Centre

NPV Net Present Value

O&M Operation and maintenance

PBP PayBack Period

PV Photovoltaic

PZO Energy market price

REC Renewable Energy Community

RES Renewable Energy Source

SCI Self Consumption Improvement

SCR Self Consumption Ratio

SLSQP Sequential Least Squares Programming

SME Small-Medium Enterprise

SOC State Of Charge

1 Introduction

The transition toward a sustainable and resilient energy system is one of the key challenges of our time. This transformation is crucial not only for climate change mitigation but also for reducing dependence on fossil fuels, increasing energy security, and ensuring a fairer distribution of energy resources. At the heart of this transition lies the integration of distributed Renewable Energy Sources (RESs), which promote decarbonisation and decentralisation of energy systems.

In this context, Renewable Energy Communities (RECs) emerged as an innovative and socially inclusive model for locally integrating renewable energy. RECs enable citizens, small businesses, and public institutions to come together to produce, share, and consume clean energy at a local level [1]. By fostering proximity-based, energy self-consumption, and community ownership, RECs contribute to lowering GreenHouse Gas (GHG) emissions, reducing energy costs, enhancing energy awareness, and alleviating energy poverty [2]. Furthermore, these communities strengthen social cohesion and empower individuals to play an active role in the energy transition.

Among RES technologies, Photovoltaic (PV) systems are the most applied due to their technology readiness, ease of installation, capital costs, and modularity. According to [3], the continuous decrease in the price of PV modules has made this technology increasingly accessible, enabling widespread adoption across both residential and industrial sectors. Recent studies explored the use of PV capacities within RECs. In this regard, Minuto et al. [4] used Monte Carlo simulations to examine the impact of rooftop orientation, demonstrating that east- and west-facing panels can offer performance comparable to south-facing ones while reducing injection peaks into the grid. The study showed that within a REC, south-facing orientation, commonly considered optimal, has a shared energy index of 18.7%. Meanwhile, east- and west-facing orientations, despite their suboptimal energy generation capabilities, have higher shared energy values of 21.6% and 22.6%, respectively. Similarly, Belloni et al. [5] proposed a tool to determine the optimal PV size for each prosumer to enhance overall energy balance. The study showed that the optimal size of a PV system for a prosumer company is approximately 300 kWp in Northern and Central Italy, while it decreased by 17% in the Southern Italy. Sassone et al. [6] introduced an optimisation model that jointly determines the number of prosumers and their respective capacities to maximise the economic returns of a REC. The results of simulations conducted on a REC in Potenza (Southern Italy) showed that the optimal configuration consists of 45 prosumers, each with a 1.25 kWp PV system, and 55 consumers. To further improve the benefits of RECs, Colarullo et al. [7] studied the use of end-of-life electric vehicle batteries as stationary storage systems within Local Energy Communities (LECs). The study demonstrated an increase in energy self-consumption of renewable energy up to 30%, a reduction in energy costs for community members down to 20%, and an improvement in the overall efficiency of the local energy system. Along the same line, Terkes et al. [8] analysed the technical and economic feasibility of using second-life Battery Energy Storage Systems (BESSs) in shared residential settings by determining their optimal size. The implementation of second-life BESSs, with sizes ranging from 5 to 10 kWh per housing unit, led to a maximum of 25% reduction in energy costs for prosumers.

While these contributions provide valuable insights into the PV system design, the integration of second-life BESSs into RECs to support PV plants remains a key question. BESS can store surplus solar energy and shift it to times of either higher demand or higher electricity prices, potentially increasing energy self-consumption and economic returns. However, given the non-negligible costs and degradation characteristics of batteries, the economic feasibility of such integration requires a detailed, case-specific assessment.

This study addresses this gap by proposing a comprehensive tool that evaluates both the technical performance and economic viability of integrating a second-life BESS into a REC built around an optimally sized PV system. The tool models energy flows, BESS charge/discharge dynamics, long-term degradation, and financial metrics across two configurations: PV-only and PV + BESS installations. Key Performance Indicators (KPIs) such as energy Self-Consumption Ratio (SCR), energy import/export flows, and net economic benefits are evaluated.

To validate the proposed approach, a real-world case study is carried out in a potential REC located in the Center of Italy, comprising one Small-Medium Enterprise (SME) and 111 residential users. Hourly energy consumption profiles, PV generation data, energy market prices, and BESS characteristics are used to simulate the energy flows and assess the economic outcome over a 20-year horizon.

The remainder of this paper is structured as follows: Section 2 details the methodological framework, including data pre-processing, PV sizing, BESS modeling, and economic evaluation. Section 3 presents the case study together with the simulation setup and used parameters. Section 4 reports the results coming from the analysis of the two different configurations. Conclusions and recommendations are then discussed in Section 5.

2 Materials & Methods

This study introduces a comprehensive tool to evaluate both the economic feasibility and technical performance of integrating a BESS within a REC. Specifically, the tool determines the optimal PV capacity and assesses whether it is more economically beneficial to install a BESS or to sell surplus energy under the prevailing energy market price regime.

The primary objective of including the BESS is to increase the share of energy that is virtually self consumed within the REC. By storing PV surplus that would otherwise be exported, the BESS enables its later use by community members, thereby avoiding the sale of excess energy at the Energy market price (PZO) bases, which is typically less favorable than the internal valorization achievable through self consumption. The used approach is shown in Figure 1, which presents a five-step workflow outlining the methodology adopted in this study.

1. *Data Ingestion:* Importing hourly energy consumption and generation from PV system time series.
2. *Load Aggregation:* Combining generic SME and residential load profiles into a single REC's aggregated energy demand. The tool is designed to process arbitrary consumption profiles, allowing for broad applicability beyond the specific case study presented.
3. *PV Sizing:* Determining the optimal PV capacity that minimises the net annual energy imbalance.
4. *BESS Simulation and Sizing:* Modeling the hourly charge/discharge dynamics and long-term aging of the BESS.
5. *Economic Analysis:* Computing cash flows, feed-in tariffs, Net Present Value (NPV), PayBack Period (PBP), and Levelised Cost Of Storage (LCOS) for two different configurations (PV-only vs. PV + BESS installations).

The implementation was was carried out in Python language using `pandas` for data management, `scipy.optimize.minimize` for PV capacity optimisation, and custom functions for storage modeling.

2.1 Input Data and Pre-processing

The numerical simulation is based on a four-hour time series: industrial and residential electricity consumption, PV generation, and energy market prices. The SME data represent the hourly energy consumption of a mineral water plant, which directly contributes to the REC's energy demand. Residential energy consumption is derived from "Autorità di Regolazione per Energia Reti e Ambiente" (ARERA)'s open source hourly profiles [9]. PV energy generation is modeled using normalised hourly data (1 kW$_mathrmpeak$) from Renewables.ninja [10] database, based on weather conditions and local solar irradiance. After determining the PV system size, the profile is scaled to obtain the energy output. Energy market data includes PZO, corresponding to the end-user-selected Italian price zone, and are used

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Figure 1: Algorithmic Workflow for PV-BESS Integration Assessment

to calculate grid transaction costs and the feed-in tariff coming from the virtual energy self-consumption. All datasets are preprocessed to ensure consistency of timestamps, completeness, and correctness of units of measure. They are then merged into a single time-indexed data frame, allowing accurate hour-by-hour simulation of energy and economic flows.

2.2 Method for Aggregating Loads in RECs

The REC's energy demand is obtained by combining industrial and residential demands with an hourly resolution.

$$C_{\text{res}}^{\text{tot}}(t) = C_{\text{res}}(t) \times N_{\text{res}}, \tag{1}$$

$$C_{\text{REC}}(t) = C_{\text{SME}}(t) + C_{\text{res}}^{\text{tot}}(t), \tag{2}$$

where $C_{\text{res}}(t)$ and $C_{\text{SME}}(t)$ are the energy demand profiles and N_{res} is the number of residential end-users. This aggregation reflects the total energy consumption by the REC. It is worth noting that the PV + BESS system must serve or compensate for each hour.

2.3 PV Sizing Procedure

To match the PV energy production with the REC's energy consumption and minimise grid exchanges, the tool solves:

$$\min_{P_{\text{peak}}} \mathcal{L}(P_{\text{peak}}) = \left| \sum_{t=1}^{T} C_{\text{REC}}(t) - \sum_{t=1}^{T} G(t)\, P_{\text{peak}} \right|, \tag{3}$$

$$\text{s.t.} \quad \sum_{t=1}^{T} G(t)\, P_{\text{peak}} \leq \sum_{t=1}^{T} C_{\text{REC}}(t), \tag{4}$$

where T is the number of hours and $G(t)$ is the PV energy production profile. The absolute difference in the objective quantifies total annual mismatch (surplus + deficit). The inequality constraint prevents PV energy surplus generation. To determine the optimal peak power capacity for the PV system, a constrained optimisation problem is formulated and solved. The key components of the optimisation procedure are summarised as follows:

- Initial guess: $P_{\text{peak},0} = 1\,\text{kW}$.
- Bounds: $(0, \infty)$ to enforce non-negative values.
- Constraint function: $f(P) = \sum G(t)P - \sum C_{\text{REC}}(t) \leq 0$.
- Optimiser: `scipy.optimize.minimize` with method 'Sequential Least Squares Programming - SLSQP' for handling inequality constraints.

Upon convergence, the algorithm yields the optimal peak capacity P_{peak}^*, rounded to the nearest integer. This value represents the best trade-off between energy generation and demand, maximising energy self-consumption while minimising economic exposure to market prices.

2.4 BESS Simulation and Aging Model

Using the optimised peak capacity P_{peak}^*, the net hourly energy surplus is calculated as the difference between the energy generated by the PV system and the energy consumed by the REC at each time step. This energy surplus is the PV electricity production that exceeds the REC's energy demand, which can be either stored in a BESS, if installed, or injected into the grid. That said, using P_{peak}^*, the net hourly energy surplus is:

$$\Delta E(t) = G(t)\, P_{\text{peak}}^* - C_{\text{REC}}(t). \tag{5}$$

The BESS model tracks the State of Charge (SOC) with the following parameters: nominal capacity (C_{BESS}), round-trip efficiency (η), and Depth of Discharge (DoD) per each hour:

- *Charge*: if $\Delta E(t) > 0$ and available capacity exists:

$$E_{\text{charge}}(t) = \min\{\eta\, \Delta E(t),\, C_{\text{BESS}}\, \text{DoD} - \text{SOC}(t)\}. \tag{6}$$

- *Discharge*: if $\Delta E(t) < 0$ and SOC is positive:

$$E_{\text{discharge}}(t) = \min\{|\Delta E(t)|/\eta,\, \text{SOC}(t)\}. \tag{7}$$

The SOC is clamped to $[0,\, C_{\text{BESS}}\, \text{DoD}]$ and evolves via:

$$\text{SOC}(t+1) = \text{SOC}(t) + E_{\text{charge}}(t) - E_{\text{discharge}}(t), \tag{8}$$

To account for both calendar and cycle aging over a 20-year time horizon, as the decree provides, the tool applies a rotating cycling pattern across three BESS units, reducing average DoD per battery and distributing cycle counts. The annual capacity fade is computed using empirical degradation models [11, 12, 13], and C_{BESS} is adjusted yearly to reflect the energy loss capacity of the BESS.

2.5 Economic Analysis and Feed-in Tariff

To assess the techno-economic performance of the REC, two distinct scenarios are evaluated, each representing a different energy management strategy:

- PV-only Installation (Scenario A): The energy produced by the PV system that is not self-consumed by the REC is sold at the PZO, and all the energy grid deficits are purchased according to the energy contractor's price.
- PV + BESS Installation (Scenario B): The energy surplus from the PV system is sold at the PZO, and the unmet energy demand is covered either by BESS discharge or grid purchases.

The hourly financial flows are computed to evaluate the economic performance of each scenario over the analysis period. These flows are referred to the PV energy production, end-users' energy consumption, storage, and exchange with the grid calculated as follows:

$$E_{\text{import}}(t) = \max\{C_{\text{REC}}(t) - [G(t)P^*_{\text{peak}} + E_{\text{discharge}}(t)], 0\}, \tag{9}$$

$$E_{\text{export}}(t) = \max\{[G(t)P^*_{\text{peak}} + E_{\text{charge}}(t)] - C_{\text{REC}}(t), 0\}, \tag{10}$$

$$E_{\text{virt}}(t) = \min\{G(t)P^*_{\text{peak}} + E_{\text{discharge}}(t), C_{\text{REC}}(t)\}, \tag{11}$$

$$I_{\text{virt}}(t) = \min\{E_{\text{virt}}(t) \times PZO(t), \text{Max Tariff}\}. \tag{12}$$

Where $E_{\text{import}}(t)$ and $E_{\text{export}}(t)$ are, respectively, the hourly imported and exported energy, and $E_{\text{virt}}(t)$ represents the value of the virtually self-consumed energy within the REC. The incentive $I_{\text{virt}}(t)$ is calculated as the product of the energy shared among REC members (i.e., the minimum between locally available generation and consumption) and the hourly zonal market price $PZO(t)$, in line with the Italian regulation on virtual net metering for energy communities.

According to the current national regulation for energy communities, the incentive tariff for shared energy is composed of:

- a fixed component, depending on the nominal power of the PV system and including a geographical bonus for PV systems;
- a variable component, which varies between 0 and 40 €/MWh depending on the hourly zonal price (PZO).

The table 1, adapted from Annex 1 of the CER Decree [14], reports the fixed component and the maximum total achievable tariff:

Table 1: Fixed tariff component and maximum incentive (CER Decree, Annex 1)

PV Size [kW]	Fixed Tariff [€/MWh]	Max Tariff (Non-PV) [€]	Max Tariff (PV) [€]
$P \leq 200$	80 (+ geo. comp.)	120	124 (Center) / 130 (North)
$200 < P \leq 600$	70 (+ geo. comp.)	110	114 (Center) / 120 (North)
$P > 600$	60 (+ geo. comp.)	100	104 (Center) / 110 (North)

Geographical bonus for PV systems:

- +4 €/MWh for Central Italy
- +10 €/MWh for Northern Italy

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2.6 Key Performance Indicators
To enable a comprehensive comparison between the PV-only and PV + BESS configurations, the following KPIs are computed. These indicators capture both technical and economic aspects of REC's performance and provide insight into the REC's energy behaviour and financial viability of each scenario:

- SCR: Fraction of the REC's energy consumption served directly by PV generation and/or BESS discharge:

$$SCR = \frac{\sum_{t=1}^{T} E_{\text{self}}(t)}{\sum_{t=1}^{T} C_{\text{REC}}(t)}, \tag{13}$$

  where $E_{\text{self}}(t) = \min\{G(t)P^{*}_{\text{peak}} + E_{\text{dis}}(t),\, C_{\text{REC}}(t)\}$.

- Exported Energy: Total energy sold to the grid at the PZO:

$$E_{\text{export}} = \sum_{t=1}^{T} E_{\text{export}}(t). \tag{14}$$

- Imported Energy: Total energy purchased from the grid:

$$E_{\text{import}} = \sum_{t=1}^{T} E_{\text{import}}(t). \tag{15}$$

- Net Benefit (B_{net}): Net cash flow considering both economic incomes and outcomes of the REC calculated at the end of the set time horizon:

$$B_{\text{net}} = \sum_{n=1}^{N} \left\{ \sum_{t=1}^{T} \Big[E^{(n)}_{\text{export}}(t) \cdot PZO(t) - E^{(n)}_{\text{import}}(t) \cdot EP_{\text{avg}} + I^{(n)}_{\text{virt}}(t) + E^{(n)}_{\text{self-consumed}}(t) \cdot EP_{\text{avg}} \Big] \right\} - BESS_{\text{cost}} - PV_{\text{cost}} \tag{16}$$

  where N indicates the number of years considered in the analisys, T indicates the number of time intervals within each year. EP_{avg} is the average Energy Price stipulated with the energy contractor. The term $I^{(n)}_{\text{virt}}(t)$ refers to the incentive attributed annually to the REC. The quantity $E^{(n)}_{\text{self-consumed}}(t) \cdot EP_{\text{avg}}$ represents the monetary savings achieved through self-consumption, as this energy is produced and consumed locally, avoiding purchase from the grid.

  The term $BESS_{\text{cost}}$ accounts for all costs associated with the battery energy storage system over the analysis period, including installation, maintenance, and any scheduled replacements. Similarly, PV_{cost} covers the total investment and maintenance costs related to the PV system throughout the considered timeframe.

  Self Consumption Improvement (SCI) (ΔSCR): difference between the PV + BESS and PV-only installations in term of SCR.

3 Case Study
To validate the proposed methodology, a case study is analysed and it regards a potential REC located in Castelsantangelo sul Nera, Macerata, Italy. The REC consists of an industrial consumer and 111 residential users. The primary goal is to assess the economic benefit and technical performance of a REC based on the scenarios reported in the previous section. Fig. 2 shows the configuration of the REC and the energy flows involved in the system.

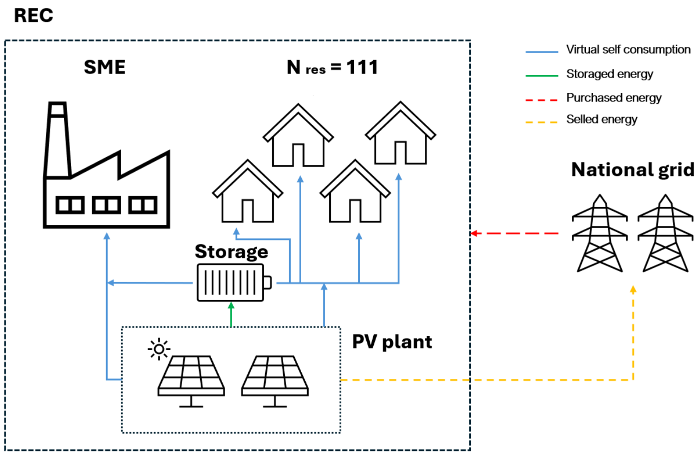

Figure 2: Graphical representation of the REC scheme and the involved energy flows

3.1 Energy Demand Profiles

The REC's energy demand profile consists of the hourly electricity consumption of all participating members over the analysis period. Specifically, the demand profile includes:

- Industrial Energy Consumption: Hourly energy consumption profile from an SME provided for the year 2024 [15].
- Residential Energy Consumption: Hourly, standard energy consumption profile for 1.5–3 kW residential customers from ARERA [9], scaled by $N_{\text{res}} = 111$.

3.2 PV Energy Generation

The hourly PV energy output per unit peak power (1 kW_{peak}) is retrieved from Renewables.ninja [10] for the coordinates of the case study under investigation. The current energy production profile is computed as:

$$G(t) = g_{\text{norm}}(t) \cdot P_{\text{peak}},$$

where $g_{\text{norm}}(t)$ is the normalised hourly generation.

3.3 Simulation Parameters and Scenarios

The simulation is carried out for the year 2024 with hourly time resolution. The REC consists of 111 residential users and an SME. Table 2 shows the parameters of the BESS used in the simulation. Annual capacity degradation is modeled using empirical laws based on calendar and cycle aging from relevant scientific literature [11, 12]. The economic model considers a PV CAPital EXpenditure (CAPEX) of

Table 2: BESS parameters

Parameters	Value
Round-trip efficiency	95%
DoD	90%
Lifetime	10 years

€1200 per installed kW_{peak} [16], and a BESS CAPEX of €120 per kWh of capacity [17]. Operation & maintenance (O&M) costs are €20/kW_{peak}/year for PV [16] and €15/kWh/year for BESS [18]. A discount rate of 5% is used, and the investment horizon is fixed at 20 years [19].

Electricity market prices are represented by PZO, corresponding to the Center-North zone in Italy, used both for energy import/export and as the basis for computing the feed-in tariff coming from the virtual energy self-consumption incentives. PV system sizing is obtained by selecting the peak power P_{peak} that minimises the annual net energy imbalance with the grid. BESS sizing is performed via an iterative simulation of the Net Benefit over a discrete range of storage capacities, from 0 to 300 kWh, in 1 kWh increments.

Two main scenarios are considered:

- Scenario A (PV-only installation), where the REC self-consumes PV energy when available, sells any surplus to the grid at the PZO, and purchases deficits at the energy contractor's price.
- Scenario B (PV + BESS installation), a BESS allows time-shifting of PV surplus to better match the load, maximising both virtual self consumption and revenue.

Simulation outputs include the optimal PV size and BESS capacity, if applicable, time series of hourly REC's energy demand, PV energy production, BESS SOC, and import/export flows with the grid. Virtual energy self-consumed is tracked. Results are aggregated into annual summaries and visualised through comparative bar plots of KPIs. The simulation concludes by reporting the BESS size, the net economic benefit of adding BESS relative to the PV-only installation scenario, and a final recommendation on whether or not to invest in BESS.

This simulation framework provides a reproducible benchmark for assessing the techno-economic impact of integrating BESS storage in rural RECs, under current Italian energy market regulations.

4 Results & Comments

The simulation is carried out for the Center-North market zone over the full year 2024, using the actual hourly consumption profile of an SME and the residential load of 111 end-users. Two scenarios are analysed: Scenario A and B, previously explained.

In the PV-only installation, the tool identified an optimal PV peak power of $P^*_{\text{peak}} = 497$ kW, corresponding to the value that minimises the annual net exchange with the grid. When the BESS is introduced, the optimal capacity is found to be $C^*_{\text{BESS}} = 0.30$ MWh, of which 0.27 MWh are usable after accounting for the DoD constraint. This value emerged from an exhaustive simulation sweep between 0 and 0.30 MWh and represents the capacity that delivers the least negative net economic outcome.

From an energy balance perspective, both scenarios share the same total PV energy generation, amounting to 767.66 MWh over the year. However, the share of energy that is directly self-consumed changes significantly with the addition of storage. In the PV-only case, virtual self consumed energy reaches 301.85 MWh, covering about 39.00% of the total energy production, while 465.81 MWh are exported and 465.17 MWh are imported from the grid. With the BESS, self-consumed energy increases up to 382.14 MWh, boosting the SCR to 50.00%, and leading to a notable reduction in both exported and imported energy, dropping down to 366.38 MWh and 384.87 MWh, respectively. Overall, the BESS enables an additional 80, 297.83 kWh of PV surplus to be shifted into self-consumption, which highlights its impact on internal energy balancing. These effects are visually evident in Figure 3, which show a representative week for each season where midday PV energy peaks are used to charge the BESS and evening load peaks are met via BESS discharge.

Key observations:

- *PV-only installation:* 39.00% of PV energy is used on site, with high exports (465.81 MWh) and imports (465.17 MWh).
- *PV + BESS installation:* The BESS increases SCR up to 50.00%, reduces exports by 21.35% and imports by 17.26%. However, the 0.30 MWh-BESS still yields a negative net economic benefit.
- The BESS shifts 80.30 MWh of PV energy surplus into self-consumption.

While the energy metrics demonstrate an improvement in energy self-consumption and a reduction in external grid interaction, the economic results reveal that the integration of BESS under current cost assumptions is not yet viable. The 20-year cumulative net benefit with storage remains negative, namely at −13, 516.46 €. This outcome is largely driven by the relatively high capital cost of storage, which in the baseline scenario is assumed to be 120 €/kWh. Interestingly, the optimisation algorithm does not enforce a non-negative constraint on B_{net}, meaning that even when all solutions are unprofitable, it still returns the capacity with the least economic loss, in this case 0.30 MWh.

To assess under which conditions the BESS could become economically feasible, the break-even point is evaluated by redistributing the total economic loss across the installed capacity. Subtracting the specific loss per kWh from the original assumed cost, the CAPEX would need to drop from 120 €/kWh to approximately 75 €/kWh.This value is in line with projections for BESS costs in future years [20].

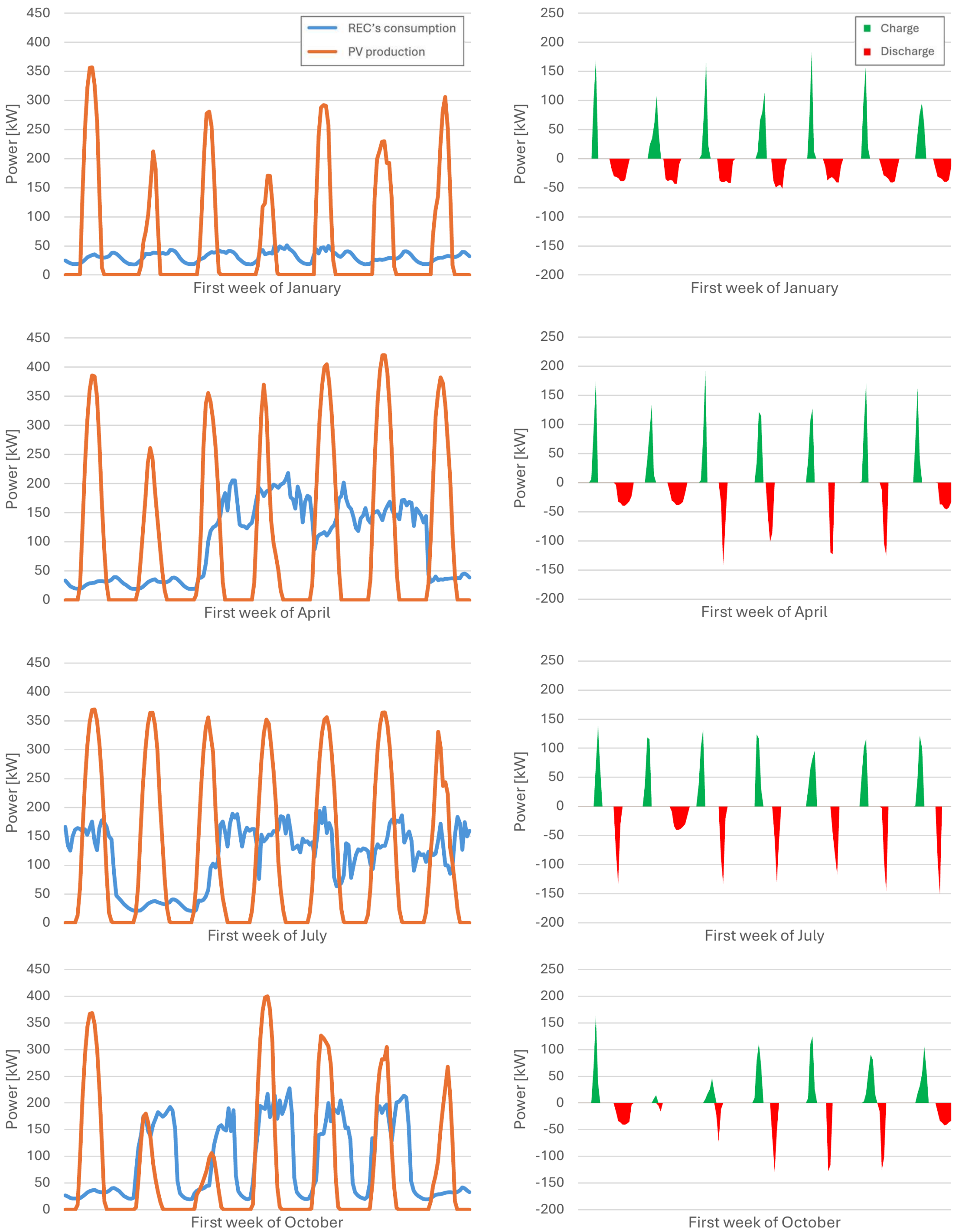

Figure 3: Hourly PV energy production vs REC's energy consumption over a representative week for each season. Charging periods vs discharging periods

Table 3: Annual Energy Flows in 2024: Comparison Between PV-Only and PV + BESS Configurations

	PV-only	PV + BESS
Total PV generation [MWh]	767.66	767.66
Self-consumed energy E_{self} [MWh]	301.85	382.14
Exported energy E_{export} [MWh]	465.81	366.38
Imported energy E_{import} [MWh]	465.17	384.87
Self-Consumption Ratio (SCR)	0.39	0.50
Net Benefit B_{net} [€]	–	–13,516.46

Overall, these results suggest that, although technically beneficial in terms of grid independence and increased energy self-consumption, the economic viability of BESS in rural RECs still depends heavily on future cost reductions. Improvements in BESS technology, the introduction of specific feed-in tariffs, or the adoption of innovative business models (e.g., shared or distributed storage) could shift this balance. Additionally, future developments of the work will explore alternative configurations, such as multi-user distributed storage, integration of additional RESs, and sensitivity analyses on key parameters like CAPEX, market prices, and BESS aging dynamics. Such extensions will provide a broader picture of the role of storage in enhancing RECs' performance under various future energy system scenarios.

5 Conclusions

This study proposed a tool for the techno-economic analysis of the integration of BESS within RECs equipped with optimised PV systems. Through the application to a real case located in Castelsantangelo sul Nera, Macerata, Center of Italy, with an SME and 111 residential users, two scenarios are analysed: PV-only and PV + BESS installations.

Results show that integration of the BESS allows to achieve a significant increase in energy self-consumption (from 39% to 50%) and a reduction in both energy exported to the grid and energy imported, thanks to the possibility of storing excess energy and using it at times of higher demand. However, despite the obvious technical benefits, economic analysis over a 20-year horizon showed negative profitability for the system with BESS, mainly due to the high investment and operating costs associated with BESS.

These results underscore the importance of careful case-specific evaluation for the adoption of storage systems in RECs, considering not only the potential energy and environmental benefits but also the economic implications in the context of the current Italian electricity market. The tool proved to be effective in determining the optimal size of the PV system and BESS, providing a reproducible and flexible tool to support strategic decisions.

Looking forward, improvements in the costs of storage technologies, the introduction of specific incentives, or innovative business models could change the economic balance in favour of integrating BESS into RECs. In addition, future extensions of the model could include simulation of multi-user scenarios with distributed storage systems, integration of other RESs or flexibility technologies, and assessment of overall environmental impacts.

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