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Original
Techno-Economic Assessment of Real-World REC Configurations in Southern Italy via Co-Simulation / Schiera, D.S., De Vizia, C., Rando Mazzarino, P., Villa, E., Ferrari, M., Amendola, A., Bottaccioli, L., Patti, E.. - (2026). (26th IEEE EEEIC International Conference on Environment and Electrical Engineering (EEEIC) Lisbon, Portugal 29 June – 02 July 2026).

Availability:
This version is available at: 11583/3018456 since: 2026-11-26T12:59:34Z

Publisher:
IEEE

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28 November 2026

Techno-Economic Assessment of Real-World REC Configurations in Southern Italy via Co-Simulation

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***Abstract*—Renewable Energy Communities (RECs) are emerging as an effective vehicle for the energy transition. Yet, their techno-economic viability depends on the interplay of community composition, generation capacity, and the regulatory framework. This paper presents a comprehensive assessment of real-world REC configurations in Southern Italy, conducted using the OMITTED co-simulation platform. The platform was extended with two new modules: (i) a detailed economic module encompassing diverse economic indicators under the full Italian incentive structure; and (ii) a bifacial PV production model with single-axis horizontal trackers for a 346.5 kW agrivoltaic installation. Four REC configurations of increasing complexity are compared, i.e., from a non-residential baseline to mixed communities with varying residential participation and prosumer scenarios, under conditions with and without non-repayable grants. The load profiles of the community members are obtained from measured data and typical load profiles representative of each actor category. Results show that non-repayable grants substantially improve economic performance, although a saturation effect limits the benefits of adding residential consumers beyond a certain threshold, and consequently, the most effective strategy under the current generation capacity is to include municipal buildings and public schools rather than expanding residential membership.**

***Index Terms*—Renewable Energy Communities, co-simulation, techno-economic assessment, bifacial photovoltaics, Italian incentive framework**

I. Introduction

Renewable Energy Communities (RECs) are increasingly studied as a means to integrate distributed generation, local consumption, and novel organizational models for the energy transition [1]. In this context, the OMITTED co-simulation platform [2], [3] provides a modular environment for representing the diverse actors involved in community-scale energy scenarios and assessing the REC through the evaluation of different key performance indicators.

This work is partially supported by COMET - Co-simulation of Multi-energy systems for Energy Transition, Italian National funded project under PNRR M4C2, Investimento 1.4 - Avviso n. 3138 del 16/12/2021 - CN00000013 National Centre for HPC, Big Data and Quantum Computing (HPC).

Simulating real-world RECs requires representative consumption data for all participants. Depending on the actor type, different strategies are adopted: real metered data, typical load profiles from the literature, or building energy archetypes [4]–[6], or agent-based synthetic profiles calibrated on census data. Combining these heterogeneous sources allows the platform to reconstruct a complete and realistic picture of community-level energy flows. Building on prototypical scenarios previously discussed in [7], the present work extends that prior contribution along two main novel directions, which are the introduced novel contributions:

1) A **comprehensive economic module** for Italian RECs, covering Net Present Value (NPV), Payback Time (PBT), Internal Rate of Return (IRR), and Return on Investment (ROI), together with the Italian incentive structure: the Incentive Premium Tariff (TIP, *Tariffa Incentivante Premio* in italian), the contribution for avoided system charges (REF), the Dedicated Withdrawal (RID, *Ritiro Dedicato* in italian), non-repayable grants (NRG), corporate income tax (IRES, *Imposta sul Reddito delle Società* in italian), regional tax on productive activities (IRAP, *Imposta Regionale sulle Attività Produttive* in italian), PV system costs and degradation, and French amortization financing.

2) A **bifacial PV production model** with single-axis horizontal trackers, implemented via `pvlib` and `pvfactors`, representing an agrivoltaic installation of 346.5 kW.

The case study involves industrial actors, public administration buildings, schools, and residential consumers. Four REC configurations are compared, with and without NRG, to identify the most effective community composition under the current generation capacity.

The remainder of this paper is organized as follows. Section II describes the simulation modules, with particular attention to the new economic and bifacial PV components. Section III presents the case study and scenario definitions. Section IV discusses the energy and economic results, and Section V summarizes the main findings.

II. Methodology

The analysis relies on the OMITTED co-simulation platform [2], [3], which was extended to support the assessment of Renewable Energy Community configurations. From a simulation perspective, the actors of an energy community can be represented as combinations of modules. A residential prosumer, for example, is obtained by coupling a model of end-user consumption with a PV simulator; more complex communities are then created by replicating and parameterizing these building blocks according to the characteristics of the participants. At the core of the platform lies the orchestrator, which synchronizes the exchange of information between the simulation modules. The platform accommodates different software tools, programming languages, and external data services through dedicated interfaces, exploiting in particular the Functional Mock-up Interface (FMI) [8] and structured scenario configuration files.

The modules considered in this work belong to four categories — *Third parties*, *Physical entities*, *Social entities*, and *Scenario analysis* — following the taxonomy established in [7]. Previously available components such as the weather file, Electric Heat Pump, building envelope, smart meter, KPI, agent-based residential demand model, and monofacial PV simulator are used here as supporting modules; their detailed description is available in [7], [9]. The following subsections focus on the two novel modules that are central to the present contribution.

A. Economic Module

The economic module evaluates the financial performance of REC configurations through four main indicators: NPV, PBT, IRR, and ROI. It is self-contained and models the complete Italian regulatory and economic framework for RECs, from investment costs and financing to incentives and taxation. The default parameter values used throughout this section are collected in Table I; scenario-specific overrides for the real-world case study are described in Section III-A.

1) Investment, Degradation, and Financing: The energy balance for each prosumer considers the total PV production E_{PV}, which is divided into self-consumed energy E_{self} and energy injected into the grid E_{inj}:

$$E_{\text{PV}} = E_{\text{self}} + E_{\text{inj}} \tag{1}$$

PV system costs are assumed following the Italian Market Report from International Energy Agency Photovoltaic Power Systems Programme (IEA-PVPS). The default cost adopted is 1.8 €/W, corresponding to the upper bound of the residential building-applied photovoltaics (BAPV) category; this conservative value accounts for the heterogeneous mix of system types present in the case study and avoids underestimating investment costs.

PV production is subject to annual degradation at a rate of $\delta = 0.5\%$/yr, so that the production in year t is $E_{\text{PV}}(t) = E_{\text{PV}}(0) \cdot (1-\delta)^t$. The Italian framework also provides NRG up to a maximum of 40% of the eligible investment cost; the grant amount per unit of installed capacity is 1500 €/kW for systems below 20 kW, 1200 €/kW for 20–200 kW, and 1050 €/kW for 200–1000 kW. The remaining investment cost (after NRG deduction, if applicable) is financed through a bank loan modeled with French amortization, assuming monthly payments. Given an annual interest rate r_a, the monthly rate is $r = r_a/12$ and the total number of payments over the loan duration of n years is $m = 12n$. Each constant monthly installment R is:

$$R = C_0 \cdot \frac{r(1+r)^m}{(1+r)^m - 1} \tag{2}$$

where C_0 is the initial debt.

TABLE I: Default parameters of the economic module.

Parameter	Symbol	Default
Analysis horizon	N	25 years
PV system cost	c_{PV}	1.8 €/W
PV degradation rate	δ	0.5%/yr
Non-refundable grants share	—	20%
Loan interest rate	r	4%
Loan duration	n	10 years
Debt share	$D/(D+E)$	20%
IRES rate	—	24%
IRAP rate	—	8.5%
Depreciation (year 1)	—	2%
Depreciation (subsequent)	—	4%
Insurance	—	0.25%/yr
O&M	—	14 €/kW/yr
REC management	—	500 €/yr
Cost of electricity	—	260 €/MWh
REF	—	9 €/MWh
RID	—	100 €/MWh
Cost of equity definition	K_e	CAPM-based
Cost of debt	K_d	4%
Expected return of other assets	—	0%/yr
Risk-free return	R_f	0%/yr
Beta levered	β_l	1

2) Taxation, Operating Costs, and Incentives: The module considers Italian corporate taxation through IRES at 24% and IRAP at 8.5%, for a combined tax rate $\tau = 32.5\%$. Fiscal depreciation of the PV asset follows the Italian schedule of 2% in the first year and 4% in subsequent years over the asset's useful life. Annual operating expenditures (OPEX) comprise insurance at 0.25% of the investment per year, operation and maintenance at 14 €/kW/yr, and REC management costs of 500 €/yr.

The Italian REC incentive framework comprises three components. The TIP is a premium tariff applied to shared energy that depends on the installed power P and the zonal electricity price P_z:

$$\text{TIP}(P, P_z) = \begin{cases} 80 + \max(0,\, 180 - P_z) & \text{if } P \le 200\,\text{kW} \\ 70 + \max(0,\, 180 - P_z) & \text{if } 200 < P \le 600\,\text{kW} \\ 60 + \max(0,\, 180 - P_z) & \text{if } P > 600\,\text{kW} \end{cases} \tag{3}$$

expressed in €/MWh, ranging between 60 and 120 €/MWh depending on the power tier and zonal price. When a capital contribution (such as NRG) has been received, the TIP is reduced by a factor F proportional to the grant share, i.e. $\text{TIP}_{\text{adj}} = \text{TIP} \cdot (1 - F)$, where F varies between 0 (no grant) and 0.50 (maximum grant share). This reduction does not apply to shared energy from withdrawal points owned by local authorities, religious entities, third-sector organizations, and

environmental protection entities. The second component is REF, a fixed amount of approximately 9 €/MWh applied to shared energy. The third is the RID, which compensates all energy injected into the grid at a price based on the hourly zonal price obtained from the electricity market manager.

3) NPV, WACC, and Summary of Parameters: The NPV over a time horizon of N years is computed as:

$$\text{NPV} = \sum_{t=0}^{N} \frac{CF_t}{(1+\text{WACC})^t} \tag{4}$$

where CF_t is the net cash flow in year t, accounting for revenues (TIP, REF, RID, self-consumption savings), operating costs, loan payments, taxes, and fiscal depreciation benefits. The Weighted Average Cost of Capital (WACC) is:

$$\text{WACC} = K_e \cdot \frac{E}{D+E} + K_d \cdot \frac{D}{D+E} \cdot (1-\tau) \tag{5}$$

where K_e is the cost of equity, K_d the cost of debt, E and D the equity and debt components, and τ the tax rate. The cost of debt is assumed equal to the loan interest rate, while K_e is defined through the Capital Asset Pricing Model (CAPM). With the default parameters in Table I, the risk-free return and expected market return are both set to zero (net of inflation), yielding $K_e = 0\%$. Combined with a debt share of 20% at a cost of debt of 4% and a combined tax rate of 32.5%, the resulting WACC is approximately 0.54%. This conservative discount rate reflects the assumed low opportunity cost of capital for community-driven investments. The PBT is defined as the year at which the cumulative discounted cash flows become positive, the IRR is the discount rate that sets the NPV to zero, and the annualized ROI is computed as the ratio of the average annual net benefit to the total investment.

B. Bifacial PV Model

The bifacial PV model represents an agrivoltaic installation implemented using `pvlib` [10] and `pvfactors` [11] for rear-side irradiance simulation, with TMY weather data from PVGIS. The system employs single-axis horizontal trackers (GCR = 0.35, azimuth 7.3° east of north, backtracking enabled) with Trina Solar Vertex N 720 Wp bifacial panels (bifaciality factor 0.80) and 80 kW inverters at 98% efficiency. The total installed capacity is:

$$P_{\text{plant}} = 5 \times 6 \times 16 \times 720\,\text{W} = 345{,}600\,\text{W} \approx 346.5\,\text{kW} \tag{6}$$

A derating factor of 0.84 accounts for mismatch (5%), DC wiring (2%), and other losses (9%). The simulation covers the full conversion chain from TMY irradiance — including bifacial rear-side contribution via `pvfactors` — through tracker geometry, cell temperature (PVSyst model), and DC-to-AC conversion (PVWatts), as shown in Figure 1.

III. Case Study

The case study is an heterogeneous REC in Southern Italy. The municipality comprises 1,367 families totaling 3,284 individuals, according to the 2021 Italian permanent census

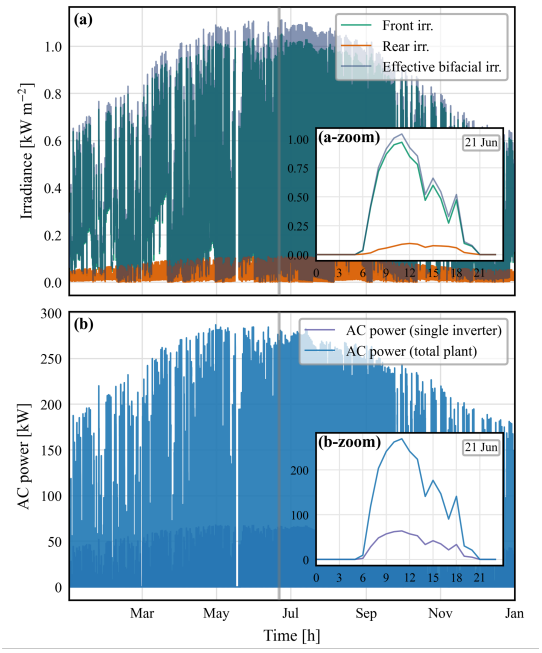

Fig. 1: Bifacial PV simulation results: (a) front and rear irradiance, (b) AC power output, with one-day zoom picture-in-picture

published by the Italian National Institute of Statistics (ISTAT) [12]. The potential REC participants include administrative offices with standard consumption patterns, an industrial research and development laboratory, an Agri 4.0 laboratory that combines agricultural production with PV generation and battery storage, the residential population characterized through census data, and public buildings comprising municipal offices and schools.

A. Data Collection and Business Model

For each actor, the data acquisition strategy combined real metered data, when available, with typical load profiles representative of each actor category when metering was unavailable. Table II summarizes the data collection strategy for each actor.

The REC follows an ESCo-based business model in which the municipality acts as the REC promoter, utilizing the PNRR funding mechanism that provides a 40% non-repayable grant. The remaining 60% of the investment is financed through a bank loan with French amortization (Section II-A). The ESCo manages the REC operations and receives annual revenues until the financing is fully repaid: revenues from energy sold to the grid via RID are retained by the ESCo, while the incentive revenues (TIP on shared energy and REF) are distributed among the community members.

B. Scenario Definitions

Four REC configurations of increasing complexity are analyzed, each designed to isolate the effect of a specific design choice — adding public buildings, varying residential participation, or extending generation capacity to the residential sector.

TABLE II: Summary of data collection strategy for each actor.

Actor / Load	Real Data	Alternative	Source
Offices	Real metered data	—	Direct use
Industrial lab	Real metered data	—	Direct use
Agri 4.0 lab (control center)	Measured annual consumption	Constant load	Measured data
Agri 4.0 lab (office)	—	Typical office profile	Literature [5]
Agri 4.0 lab (agrivoltaic)	—	Typical agricultural profile	Literature [13]
Schools	—	School archetype profile	Literature [6], [14]
Residential households	Census data [12]	Agent-based simulation	Co-simulation platform

a) CS1 — Non-Residential REC: The baseline configuration considers a REC composed exclusively of non-residential actors: three real metered loads from the offices and industrial laboratory, one constant-load profile for the Agri 4.0 control center, one typical office profile for the Agri 4.0 office building, and one typical agricultural profile for the agrivoltaic system. The agrivoltaic system consumes local renewable generation and includes battery storage without exporting surplus energy to the grid; the relevant quantity for REC assessment is therefore the withdrawal from the grid. Because detailed empirical data for agricultural electricity demand are limited, most of the consumption is assumed to be concentrated during daylight hours, consistently with the operating schedule of the underlying activities and with the literature on agrivoltaic systems [13]. The PV generation for CS1 is provided by the bifacial agrivoltaic plant described in Section II-B.

b) $CS1_{pub}$ — Non-Residential REC with Public Administration: This configuration extends $CS1$ by adding public schools as community members. Seven schools of varying sizes are located in the study area; however, given the lack of specific data on school sizes and student numbers, only four are included: two classified as "large" according to the archetype data and two smaller ones derived by scaling the existing consumption profile. The school consumption profiles were constructed using Italian school archetype data from [6] and energy audit reports [14].

c) CS2 — Mixed REC: The $CS2$ configuration extends $CS1_{pub}$ by adding residential consumers from the municipality. The residential demand was simulated for 1,367 families (3,284 individuals) using ISTAT census data [12] and the agent-based model. Five participation levels — 20%, 40%, 60%, 80%, and 100% of the municipal population — define the sub-scenarios $CS2_{20\%}$ through $CS2_{100\%}$, making it possible to observe how increasing community participation affects the shared-energy outcome under a fixed generation capacity.

d) CS3 — Innovative Mixed REC: The $CS3$ configuration considers the residential population as prosumers rather than consumers, assuming rooftop PV installation for the participating households. The rooftop potential is estimated through the GIS-based methodology presented in [15], which identified 1,098 roofs as suitable for PV installation. This configuration assesses whether extending generation capacity to the residential sector improves the economic performance of the REC.

IV. Results and Discussion

All scenarios are evaluated under two distinct macro-conditions: *with NRG* (w/NRG) and *without NRG* (wo/NRG), to quantify the impact of non-repayable grants on the economic performance. The $CS3$ scenario is reserved for separate analysis due to its fundamentally different structure.

A. Energy Performance

Figure 2 presents the evolution of shared energy (SE) across the considered scenarios, together with its relative contribution (%SE), the incentivized fraction (%SE exploited), and the excess share not eligible for incentives (%SE excess), for both configurations with and without NRG.

In the baseline scenarios ($CS1$ and $CS1_{pub}$), the SE values are relatively limited, although the %SE already reaches moderate levels, indicating a good alignment between local generation and consumption. The inclusion of public users in $CS1_{pub}$ slightly improves SE, due to a better temporal matching with PV production.

As the share of residential users increases (CS2 scenarios), SE grows significantly from CS1 up to $CS2_{40\%}$, after which it stabilizes, showing a clear saturation effect. This is further confirmed by the %SE curve, which approaches 100% in the higher-penetration scenarios, indicating that nearly all locally generated energy is being shared within the community.

However, this increase in shared energy does not translate into proportional economic benefits. The incentivized fraction (%SE exploited) rapidly reaches its maximum limit and remains constant across all CS2 scenarios. Conversely, the excess shared energy (%SE excess), i.e., the portion not eligible for incentives, increases steadily with the number of residential users. This highlights that the incentive mechanism becomes saturated already at relatively small community sizes, and additional users primarily contribute to non-remunerated shared energy.

A similar trend is observed in the configuration with NRG, where SE values are slightly higher, but the overall behavior remains unchanged: the incentive cap is reached early, and further increases in community size lead only to marginal gains in SE and to a larger share of non-incentivized energy.

In the $CS3$ scenario ($CS3_{20\%}$), the yearly energy withdrawal is comparable to $CS2_{20\%}$, while the yearly injection increases significantly due to the additional rooftop PV capacity of the residential prosumers. However, the SE does not show a substantial increase, indicating that this configuration does not yield proportional shared-energy benefits for the

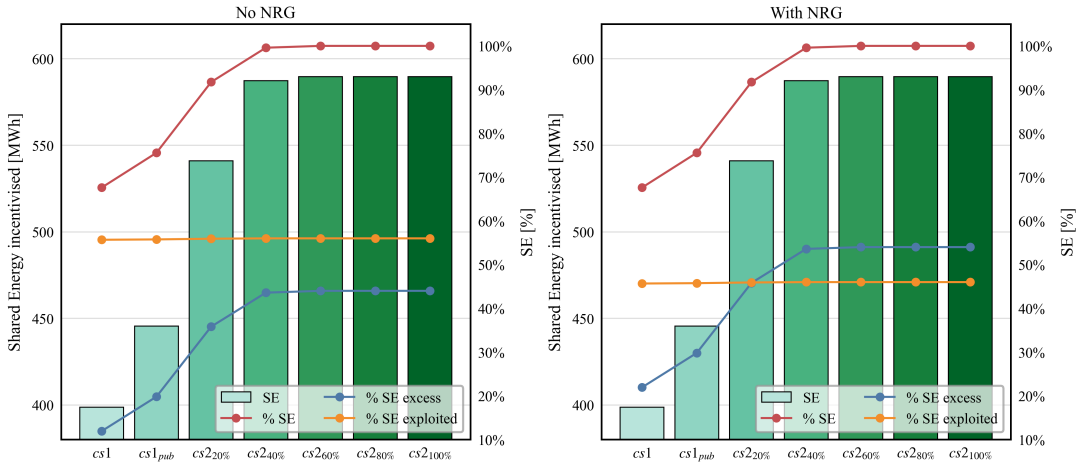

Fig. 2: Shared Energy (SE): wo/NRG (left) and w/NRG (right).

community despite the higher generation. Overall, beyond a certain community size, both energy and economic benefits exhibit saturation effects. While larger communities improve the degree of energy sharing, they do not provide proportional financial returns due to the binding constraint imposed by the incentive cap.

B. Economic Performance

1) Mean Yearly TIP: The mean yearly TIP represents the average annual revenue from the premium incentive, expressed as a fraction of the theoretical maximum TIP revenue (i.e., the revenue that would be obtained if all shared energy were incentivized at the maximum tariff rate, without any NRG-related reduction). Without NRG, this ratio remains stably high at approximately 0.12 across all scenarios, showing limited sensitivity to community size. With NRG, a progressive increase is observed, ranging from 0.09 to 0.10, reflecting the TIP reduction factor F applied when capital contributions are received (Eq. 3). This means that while the absolute TIP values are higher without NRG, the presence of NRG introduces a more consistent and progressive trend, linked to the particular calculation structure of the TIP which is reduced linearly with NRG and is proportional to the type of producers and consumers that contribute to the shared energy.

2) NPV Evolution: The temporal evolution of NPV reveals a clear distinction between the two macro-conditions, as shown in 3. With NRG, the NPV trajectories grow steadily across all $CS1$ and $CS2$ scenarios, with the investment becoming positive after approximately 6–7 years and reaching values of 250–300 k€ at the 25-year horizon. The trajectories are tightly grouped, indicating robust performance across different community compositions. Without NRG, the NPV curves grow more slowly, requiring approximately 8–9 years to cross into positive territory, and the final values are more dispersed, ranging from 180 to 350 k€. This greater variability reflects the sensitivity of the investment to community composition when public support is absent. The scenario $CS3_{20\%}$, which considers a community configuration with 20% of prosumers under the same business model applied in the previous analyses, shows a markedly different behavior compared to the $CS1$ and $CS2$ cases. The NPV remains deeply negative throughout the entire 25-year horizon, starting from around $-1{,}200$ k€, dropping further to nearly $-2{,}100$ k€ at year 10, and only partially recovering towards $-1{,}700$ k€ at the end of the period. At no point does the investment approach profitability. The main reason behind this underperformance lies in the imbalance between costs and benefits: the expenses linked to the acquisition of photovoltaic capacity and the repayment of related loans are simply too high when compared to the economic return generated within the community. Unlike in $CS1$ and $CS2$ scenarios, where scaling and NRG mechanisms improve the balance of revenues and costs, here the structural weight of debt servicing suppresses the potential benefits. This result clearly indicates that, under the current business model, the exploratory configuration $CS3_{20\%}$ is not economically viable.

3) NPV at 25 Years vs. Payback Time: Figure 4 provides a synthetic comparison of investment quality based on NPV at 25th year (NPV25) and PBT. With NRG, all $CS1$ and $CS2$ scenarios cluster tightly around an NPV25 of approximately 250–300 k€ with PBT of 2.4–2.6 years for $CS2$ configurations and 2.9–3 years for $CS1$ configurations. Without NRG, the performance is more heterogeneous: the NPV25 ranges from 180 to 350 k€ with PBT spanning 3.3 to almost 7 years. Only $CS1$ and $CS2_{pub}$ achieve reasonable results, but still below the NRG cases.

4) Revenue Distribution: The comparison of revenue distribution highlights two main trends, as shown in Fig. 5. The most significant variation occurs between the smallest configurations ($CS1$ and $CS2_{pub}$) and all other scenarios: when scaled by a factor of 10, these cases exhibit substantially higher per-capita revenues, reaching 350–400 x10,€/member, whereas larger communities show markedly lower values.

Across the remaining scenarios, per-capita revenues decrease as the community size increases, while total revenues

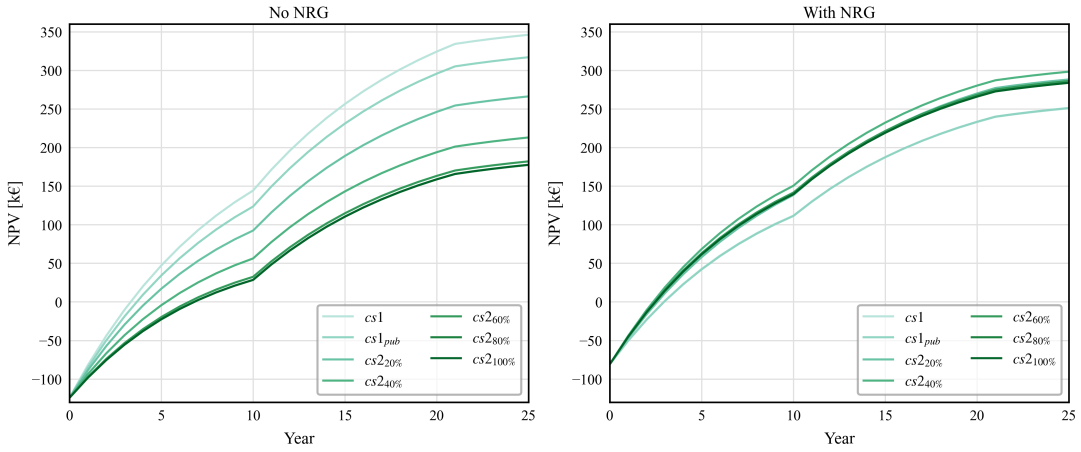

Fig. 3: NPV evolution over 25 years: wo/NRG (left) and w/NRG (right).

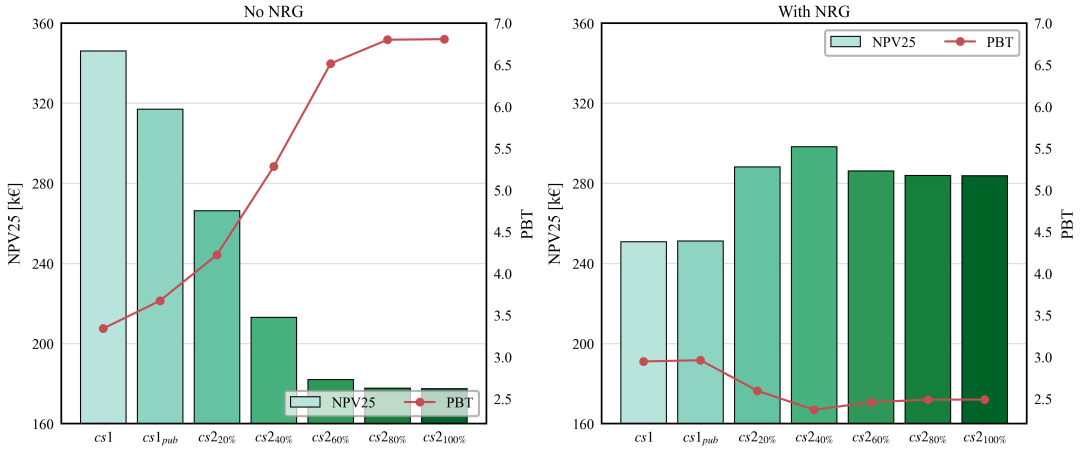

Fig. 4: NPV at 25h year vs. Payback Time: wo/NRG (left) and w/NRG (right).

grow and approach 900,k€, reflecting the scaling of the system. In contrast, the difference between configurations with and without NRG is relatively limited. While NRG slightly increases total revenues and marginally smooths the reduction in per-capita values, it does not significantly alter the overall trend. Overall, the results emphasize that community size plays a much more relevant role than NRG in determining revenue distribution, with a clear trade-off between higher individual gains in small configurations and larger aggregate benefits in bigger communities.

5) Bubble Plots: NPV, IRR, ROI, and PBT: The bubble plots combining the NPV25, IRR, ROI, and PBT provide a final synthetic view of the investment attractiveness. With NRG, the IRR is very high (45–48%), the annualized ROI remains stable around 10.7–10.8%, and the payback remains short. Among the mixed configurations, the best compromises are found in $CS2_{40\%}$ and $CS2_{20\%}$, which combine robust NPV with rapid recovery and strong ROI. Without NRG, the performance is clearly weaker: IRR values are lower (23–37%), ROI varies between 8.5% and 10%, and PBT is much longer, reaching up to almost seven years in some scenarios. Only $CS1$ and $CS1_{pub}$ achieve reasonable results, but still below the performance of the NRG cases.

V. Conclusion

This study demonstrated the effectiveness of the enhanced co-simulation platform, integrating an economic analysis module and a bifacial PV production model. By combining real metered data and representative load profiles, the platform supports the assessment of complex REC configurations under realistic data-availability constraints. The joint analysis of energy and economic indicators shows that NRG strengthens the economic outlook across all analyzed configurations. Among mixed scenarios, $CS2_{20\%}$ and $CS2_{40\%}$ offer the best compromise in terms of NPV, IRR, ROI, and payback time. Under the current generation capacity, including the entire residential population is not recommended: it would yield minimal per-capita benefits, risking dissatisfaction, while restricting participation to a few households would raise fairness concerns. The most effective strategy is therefore to include municipal buildings and public schools, maximizing economic returns while delivering a tangible community benefit. The exploratory

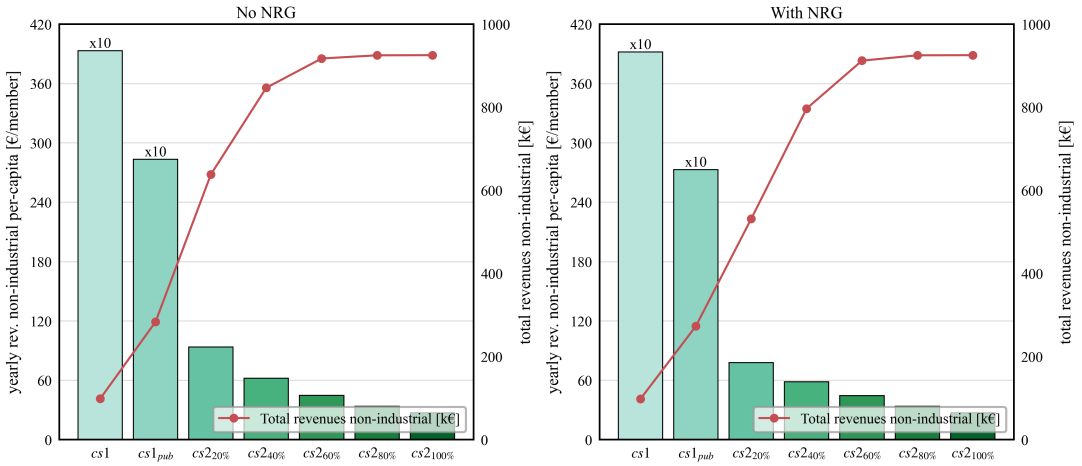

Fig. 5: Revenues per capita and total revenues: wo/NRG (left) and w/NRG (right).

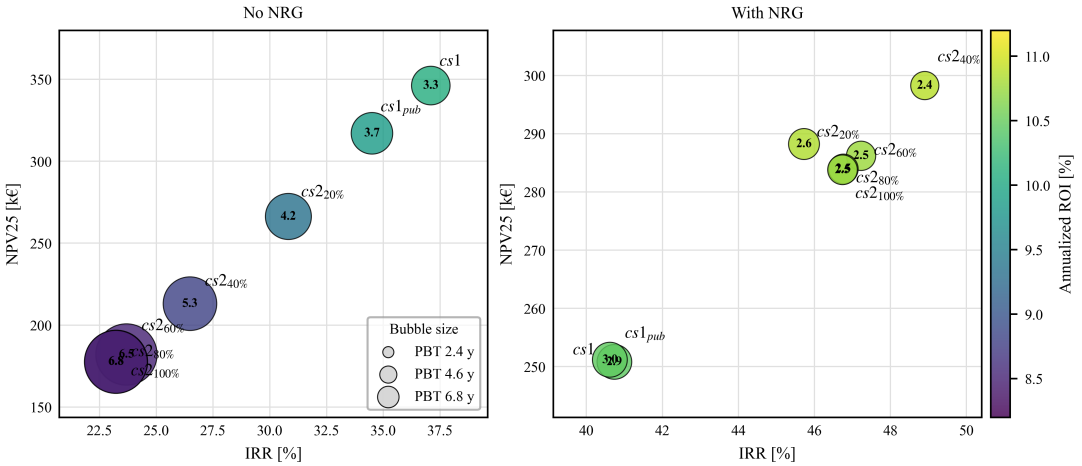

Fig. 6: Bubble plots: NPV25 vs. PBT with IRR (color) and ROI (size), wo/NRG (top) and w/NRG (bottom).

configuration $CS3_{20\%}$, in which residential consumers become prosumers, proved economically infeasible under the current business model.

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