



Performance Optimization of Renewable Energy Communities: The Case Study of Nearby Towns Around Parma, Italy

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<https://doi.org/10.18280/mmep.121034>

ABSTRACT

Received: 12 September 2025

Revised: 15 October 2025

Accepted: 21 October 2025

Available online: 31 October 2025

Keywords:

optimal energy mix, REC, performance optimization, sustainability, energy management

The load matching between electricity demand and energy production plays a crucial role in the design and operation of energy communities. To optimize the performance of renewable energy communities (RECs), it is important to accurately size the generation systems and select members with diverse load profiles. In this work, the performance of a REC in Northern Italy is optimized. The case study was selected by considering that in a nearby town around Parma (i.e., the municipality of Sorbolo-Mezzani), there is a large industrial facility that generates a large surplus of electricity. Based on the map of the electrical primary substation and on the load profile of the industrial facility, commercial, school, residential and industrial buildings were included within the REC. In particular, commercial buildings were included due to their extended operational hours, particularly during weekends when industrial facilities are typically inactive, while the industrial building was selected based on its high-energy demand profile. Several scenarios are investigated by changing the mix of the members involved in the energy community. To evaluate the performance of each scenario, a model in MATLAB environment was developed. The model accounts for the load profiles and the energy production of the photovoltaic systems.

1. INTRODUCTION

Over the past few years, energy community initiatives have gained traction in Europe to achieve energy transition goals, allowing citizens to be involved in energy production, consumption and distribution. The rising importance of renewable energy communities (RECs) has been highlighted by Ahmed et al. [1], who presented a comprehensive review of REC.

The energy shared within a REC, which is defined as the minimum on an hourly basis between the electricity produced by the renewable energy sources and the electricity supplied from the grid to members of a REC, enables the establishment of virtual self-consumption that brings both environmental and economic benefits to REC members.

The participants in the energy community can take on these roles: Producers, consumers, and prosumers, who are both producers and consumers.

An important challenge in the design and operation of energy communities is the effective alignment of energy demand and production [2, 3]. The community must be designed to maximise the self-consumption of renewable energy.

However, due to the intermittent nature of renewable sources and the absence of storage systems, the alignment between generation and demand largely depends on the consumption patterns of its members. To increase energy

sharing, members with diverse load profiles must be selected.

Lazzari et al. [4] proposed an optimization model based on genetic algorithms that maximize self-consumption, minimize excess solar energy, and achieve the shortest payback period. The optimization model was applied to a case study in Spain.

Volpato et al. [5] presented a novel procedure based on stochastic forecasts that supports decisions regarding the optimal design of multi-energy systems supplying RECs under uncertainties in solar irradiance and users' energy demand.

Cosic et al. [6] developed an optimization model for REC based on mixed-integer linear programming, which accounts for distributed photovoltaic systems, energy storage systems, different electricity tariff scenarios, and market signals. The optimisation model was applied to three case studies in Austria.

Laurini et al. [7] also presented an optimization model based on mixed-integer linear programming, which enables defining the optimal configuration of a REC, identifying the most suitable technologies, and selecting members. The optimisation model was applied to a case study in Italy.

The present study investigates the energy performance optimisation of a REC in Northern Italy. The case study was selected by considering that in a small town close to Parma (i.e., the municipality of Sorbolo-Mezzani), there is a large industrial facility that generates a large surplus of electricity (i.e., Cosmoproject S.p.A.). This important facility serves the global skin care and cosmetics, pharmaceutical and

international luxury brands.

To optimize energy sharing in the REC, different scenarios were explored by considering different energy user demands (i.e., different consumers and prosumers). The REC members were selected based on a map of the electrical primary substation (according to Italian legislation) and the load profile of the industrial facility. More specifically, industrial, commercial, school, and residential buildings located in the municipalities of Colorno and Sorbolo-Mezzani were selected. A simulation model developed in MATLAB[®] was employed to assess each configuration, accounting for load profiles and PV generation.

2. MODELING ENERGY COMMUNITIES

To assess the performance of the REC, a simulation model was developed in the MATLAB environment. This model enables the analysis of energy flows within the community on an hourly basis. The model accounts for the load profiles and energy production of photovoltaic systems.

In particular, hourly electricity loads can be derived either from simplified modeling approaches or by utilizing actual consumption data. In the case of simplified models, load profiles can be generated based on monthly energy consumption.

The REC analyzed in this study involved industrial, commercial, school, and residential buildings located in the municipalities of Colorno (PR) and Sorbolo-Mezzani (PR). Table 1 presents the main features of the considered building in terms of net floor area and electrical energy index, where *Ind₁* represents the Cosmoproject S.p.A., *Ind₂* is a nearby industrial building, *Com₁* is a large commercial building equipped with a PV system, *Com_{2,3}* includes small commercial buildings, and *Sch* represents the schools.

Table 1. Considered REC members

Building Name	Building Type	Net Floor Area (m ²)	Electrical Energy Index (kWh/m ²)
<i>Ind₁</i>	Industrial	37,000	90
<i>Ind₂</i>	Industrial	57,000	128
<i>Com₁</i>	Commercial	1,600	341
<i>Com₂</i>	Commercial	1,700	341
<i>Com₃</i>	Commercial	600	341
<i>Sch₁</i>	School	2,700	22
<i>Sch₂</i>	School	1,400	22

It is important to note that *Ind₁* was considered closed during the weekends and for three weeks in August and three weeks between December and January, while *Ind₂* was considered closed on Sundays and for three weeks in August and three weeks between December and January. Moreover, *Ind₁* and *Ind₂* were considered closed during national holidays.

The commercial buildings *Com₁* and *Com₃* were considered open every day, except for public holidays, while *Com₂* remained closed on Sundays and during public holidays.

The schools *Sch₁* and *Sch₂* were considered closed for three weeks between December and January. Moreover, *Sch₁* and *Sch₂* were considered closed on Sundays, while *Sch₂* during the weekends. In the summer, they were considered open only to administrative functions.

It is also important to note that electrical energy

consumption in industrial and commercial buildings also includes demands for heating and cooling.

Measured monthly energy consumption data were available only for *Ind₁* (i.e., Cosmoproject S.p.A.), whereas for commercial and school buildings, monthly electricity consumption data were estimated based on annual energy consumption data reported by national agencies (i.e., the Research on the Energy System – RSE, and the Italian National Agency for New Technologies, Energy and Sustainable Economic Development - ENEA). Table 2 presents the monthly energy consumption data for each REC member considered in this study.

For residential buildings, an annual electricity consumption of 2700 kWh per consumer was assumed [8].

The hourly photovoltaic system energy production can be estimated using simulation tools, simplified modeling approaches, or actual data. In the case of simplified modeling approaches, hourly energy production can be generated based on monthly energy production.

Table 2. Monthly electrical consumption of REC members

Month	<i>Ind₁</i> (MWh)	<i>Ind₂</i> (MWh)	<i>Com₁</i> (MWh)	<i>Com_{2,3}</i> (MWh)	<i>Sch</i> (MWh)
Jan.	317.41	470.68	40.92	65.32	17.27
Feb.	300.56	434.44	36.94	58.96	14.33
Mar.	255.89	338.35	39.12	62.44	13.97
Apr.	217.30	255.33	35.44	56.56	8.70
May	251.47	328.85	36.43	58.15	15.69
June	288.53	408.56	36.76	58.67	18.83
July	386.36	619.00	41.15	65.68	6.09
Aug.	326.65	490.56	40.92	65.52	6.09
Sep.	266.87	361.97	41.05	61.37	7.92
Oct.	225.48	272.93	38.45	58.15	11.73
Nov.	255.60	337.73	36.43	56.30	14.68
Dec.	288.49	408.48	35.27	61.02	17.21

The hourly electricity loads are estimated by using the daily load profiles for tertiary, industrial and residential typologies of loads presented in Figure 1 [9], while for the schools, the daily load profile was derived from the data reported by the and the Italian National Agency for New Technologies, Energy and Sustainable Economic Development - ENEA.

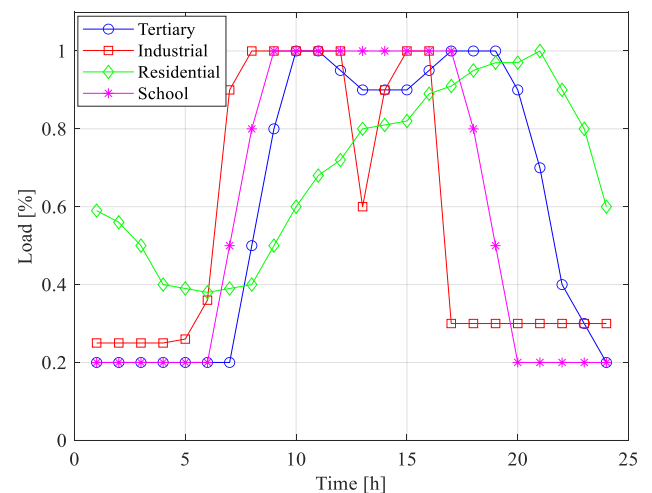


Figure 1. Daily load profiles

Monthly photovoltaic system energy production was

available only for *Ind₁*. The PV energy production of *Ind₂* and *Com₁* was estimated using PVGIS, corresponding to a peak power of 995 kWp and 70 kWp, respectively and accounting for mismatch losses [10]. Table 3 presents the monthly production for each PV system considered in this analysis.

The hourly electrical production from PV panels has been estimated using real monthly electrical production combined with hourly specific production profiles developed by the company that manage the incentive mechanisms aimed at promoting electricity generated from renewable sources (GSE), as shown in Figure 2.

Table 3. Monthly production from PV panels

Month	<i>Ind₁</i> [MWh]	<i>Ind₂</i> [MWh]	<i>Com₁</i> [MWh]
Jan	50.39	33.85	2.40
Feb	59.76	50.36	3.61
Mar	98.57	91.52	6.64
Apr	160.57	114.49	8.35
May	183.69	137.64	10.09
June	184.57	148.93	10.91
July	188.80	155.23	11.41
Aug	188.53	133.46	9.76
Sep	120.78	100.71	7.33
Oct	64.76	65.56	4.71
Nov	44.00	35.05	2.49
Dec	48.37	27.70	1.94

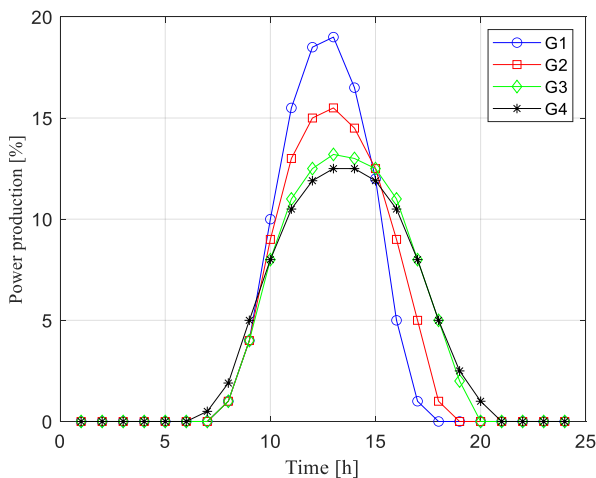


Figure 2. Hourly specific production profile of PV for four average days (G1: Jan-Nov-Dec; G2: Feb-Mar-Oct; G3: Apr-Aug-Sep; G4: May-June-July)

The operational performance of the REC is quantified through a set of key energy-related performance indicators (KPIs) [11].

Two widely adopted KPIs are the Self-Consumption Ratio (SCR) and the Self-Sufficiency Ratio (SSR), which capture the technical and energetic alignment between local generation and demand. Specifically, these indicators assess the temporal and quantitative correspondence between distributed energy production and consumption. The SCR quantifies the proportion of locally generated electricity that is directly self-consumed by REC members, while the SSR evaluates the extent to which the energy demand of the REC is met by its own photovoltaic generation. Notably, SSR also reflects the level of autonomy from the external power grid.

The SCR is calculated as follows:

$$SCR = \frac{E_{el, \text{shared}, \text{tot}}}{E_{el, \text{prod}, \text{tot}}} \quad (1)$$

where, $E_{el, \text{prod}, \text{tot}}$ denotes the total electrical energy generated within the REC, expressed in kWh, and $E_{el, \text{shared}, \text{tot}}$ refers to the amount of electrical energy self-consumed within the REC, expressed in kWh, i.e., the portion of energy generated and utilized locally through internal energy sharing.

The SSR is computed as follows:

$$SSR = \frac{E_{el, \text{shared}, \text{tot}}}{E_{el, \text{d}, \text{tot}}} \quad (2)$$

where, $E_{el, \text{d}, \text{tot}}$ represents the total electrical energy demand of the REC, also in kWh.

This indicator illustrates the extent to which the REC's internal production satisfies the electrical demand of its members—specifically, in terms of the quantity of electricity that is valorized and incentivized in accordance with the applicable Italian regulatory framework.

Moreover, a third KPI is considered, i.e., the electrical self-production rate (ESP), which is defined and computed as follows:

$$ESP = \frac{E_{el, \text{prod}, \text{tot}}}{E_{el, \text{d}, \text{tot}}} \quad (3)$$

3. RESULTS AND DISCUSSION

The REC members were selected by considering the following constraints: i) the members might be under the same primary cabin according to Italian legislation, and ii) the REC must include members with different load profiles.

The analysis of the buildings connected to the same primary substation, along with the load profiles of the Cosmoproject S.p.A., indicated that commercial, school, and residential buildings could be incorporated into the REC.

Commercial, school, and residential buildings were included due to their extended operational hours, particularly during weekends when the industrial facility was inactive. Moreover, the integration of another industrial building within the REC was considered due to its high electrical consumption and extended operational hours (i.e., this facility also works on Saturdays).

To optimize the energy shared within the REC, four scenarios were explored, as summarized in Table 4. In particular, the first scenario considered only the industrial building *Ind₁* and the commercial buildings *Com₁* and *Com_{2,3}*. The second scenario considered the integration of school buildings within the REC, while the third scenario also considered the integration of residential buildings within the REC. Finally, in the last scenario, the integration of another industrial building *Ind₂* was considered.

Table 4. Simulated scenarios

Scenario	Buildings Involved in the REC
1	<i>Ind₁</i> , <i>Com₁</i> and <i>Com_{2,3}</i>
2	<i>Ind₁</i> , <i>Com₁</i> , <i>Com_{2,3}</i> and <i>Sch</i>
3	<i>Ind₁</i> , <i>Com₁</i> , <i>Com_{2,3}</i> , <i>Sch</i> and <i>Res</i>
4	<i>Ind₁</i> , <i>Ind₂</i> , <i>Com₁</i> , <i>Com_{2,3}</i> , <i>Sch</i> and <i>Res</i>

The outcomes revealed that in the first scenario (i.e., only

Ind_1 and commercial buildings were included within the REC), approximately 186 MWh/a of energy was shared, resulting in a collective SSR of 3.7%. A total of 3,670 MWh/a was drawn from the grid.

The integration of the schools of the municipality of Colorno into the REC (i.e., the second scenario), around 192 MWh/a of energy was shared, achieving a collective self-sufficiency of 3.7%, with 3,818 MWh/a drawn from the grid.

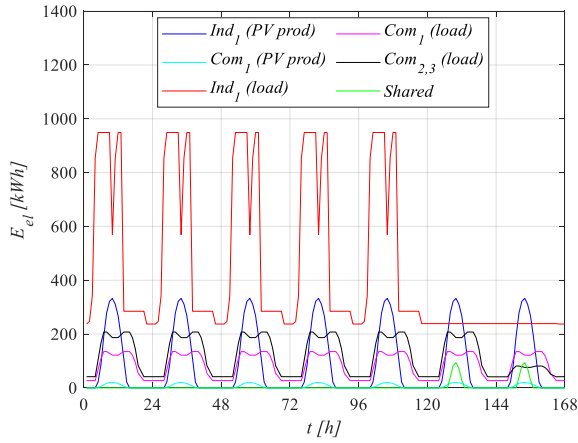


Figure 3. Energy flows for a sample week in February (Scenario 1)

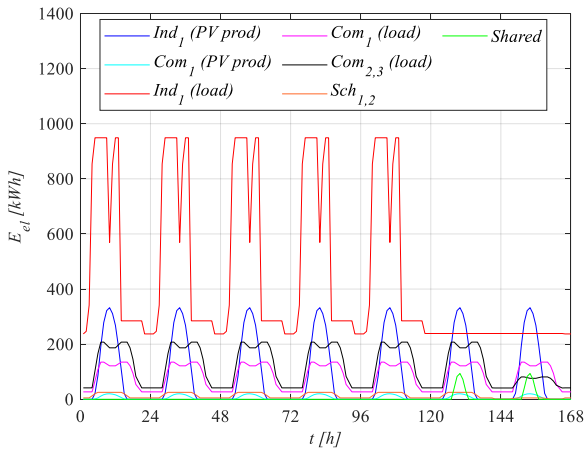


Figure 4. Energy flows for a sample week in February (Scenario 2)

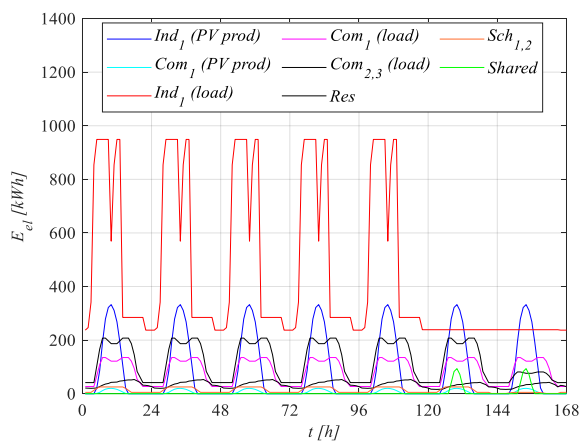


Figure 5. Energy flows for a sample week in February (Scenario 3)

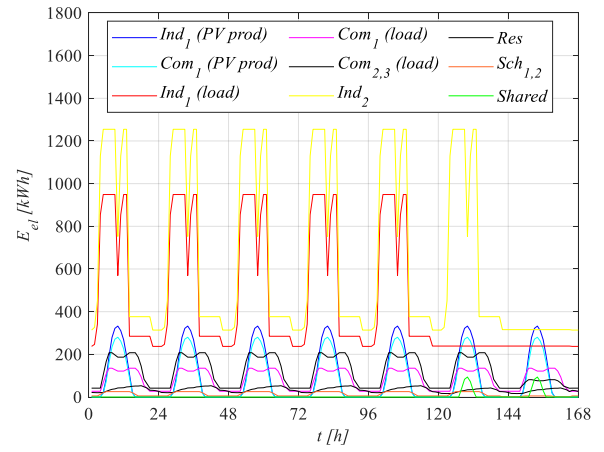


Figure 6. Energy flows for a sample week in February (Scenario 4)

The integration of residential buildings into the REC (i.e., scenario 3) increased the amount of shared energy to approximately 206 MWh/a, maintaining a self-sufficiency level of 3.8%, while 4,076 MWh/a was sold to the grid.

Finally, by including the nearby industrial building within the REC, the shared energy increased to approximately 230 MWh/a; however, the collective self-sufficiency dropped to 2.3%, and the energy drawn from the grid increased significantly to 7,697 MWh/a.

The simulation results in terms of energy flows within the REC for a sample week in winter are presented in Figures 3-6.

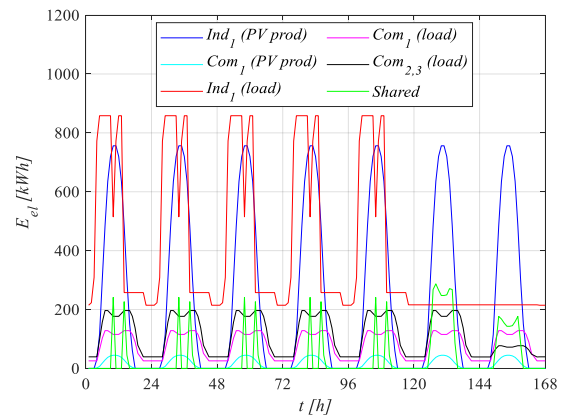


Figure 7. Energy flows for a sample week in June (Scenario 1)

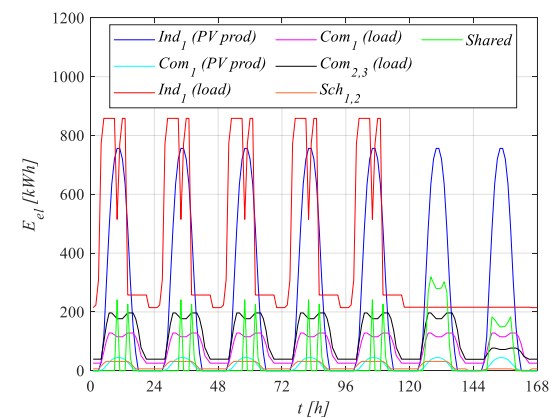


Figure 8. Energy flows for a sample week in June (Scenario 2)

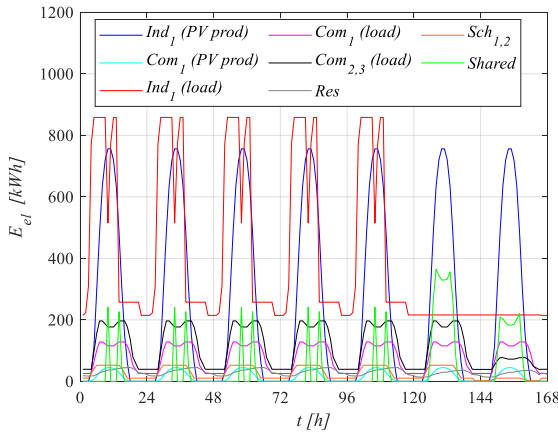


Figure 9. Energy flows for a sample week in June (Scenario 3)

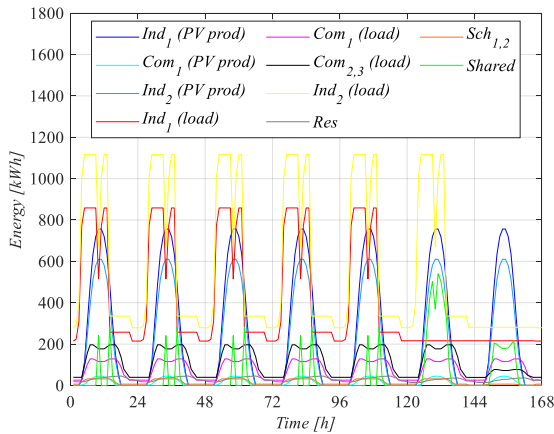


Figure 10. Energy flows for a sample week in June (Scenario 4)

As expected, in winter, the level of energy sharing within the REC was very low due to the high electrical consumption of *Ind₁*, which exceeded the energy production of the PV system, with the exception of the weekends in which the building was closed.

Figures 7-10 present the energy flows within the energy community for a sample week in summer (i.e., in June).

Although an increase in energy sharing within the REC was observed, the overall level remained low. This was primarily due to excess photovoltaic generation, which consistently surpassed the community's energy demand—particularly on weekends, when Cosmoproject S.p.A. was closed.

To gain deeper insights into the factors contributing to the low levels of energy sharing within the REC across all scenarios considered in this study, an analysis of energy flows during summer holidays was carried out.

It was found that in August, the amount of energy fed into the grid was very high, as shown in Figures 11-14, where the energy flows in August are presented for all the investigated scenarios.

It can be observed that although the commercial buildings are opened during the summer holidays, except for public holidays, their electrical consumption is very low with respect to the energy produced by the three PV systems.

However, the amount of energy shared within the REC was high during this period. More specifically, the shared energy in August is around 38 MWh, 40 MWh, 44 MWh, and 45

MWh for scenarios 1, 2, 3, and 4, respectively.

The simulation results in terms of KPIs are detailed in Table 5. The ESP decreases across the scenarios, as it reflects the ratio of total energy produced within the REC to total energy consumed—while production remains constant, overall energy consumption increases from the first to the last scenario.

The SCR and SSR fluctuate due to variations in energy sharing within the REC and in total electrical energy demand, which are influenced by hourly electricity load changes.

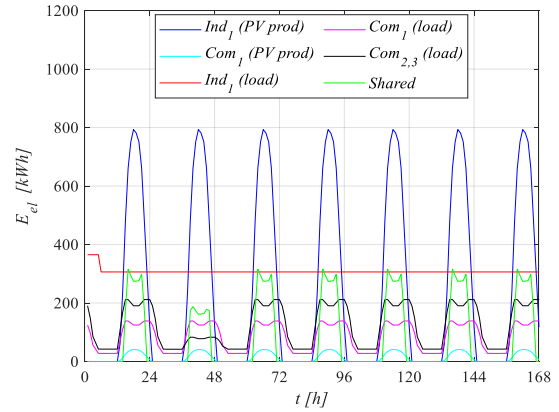


Figure 11. Energy flows for a sample week in August (Scenario 1)

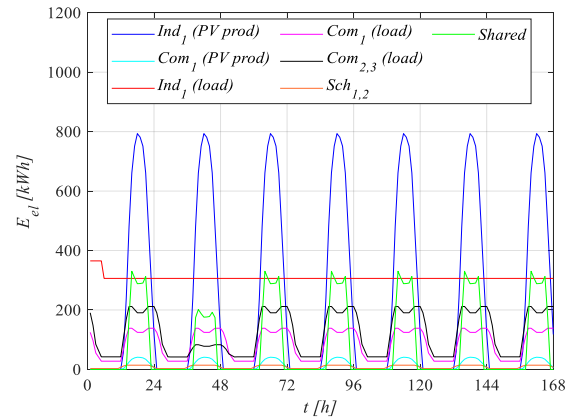


Figure 12. Energy flows for a sample week in August (Scenario 2)

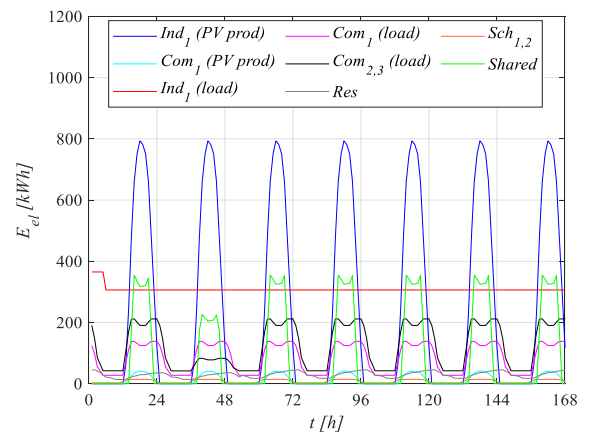


Figure 13. Energy flows for a sample week in August (Scenario 3)

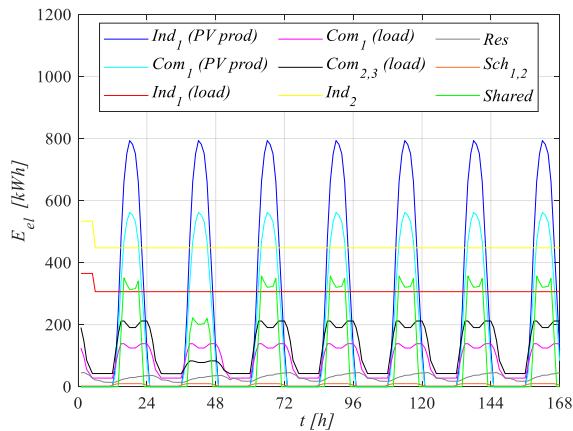


Figure 14. Energy flows for a sample week in August (Scenario 4)

Table 5. Results of scenario analysis in terms of KPIs

Scenario	ESP (%)	SCR (%)	SSR (%)
1	29.1	12.7	3.7
2	28.6	13.0	3.7
3	27.2	14.0	3.8
4	25.3	9.0	2.3

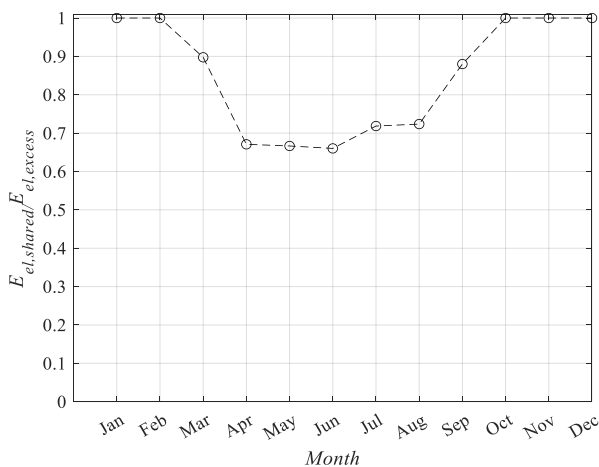


Figure 15. Monthly values of the ratio between the shared energy and the excess energy generated by the industrial facility (Scenario 3)

The scenario analysis revealed that the REC in which commercial, school and residential buildings presented the best energy performance, being characterized by the highest value of the SCR. In this scenario, a detailed analysis was conducted by examining the monthly ratio of shared energy to the excess energy generated by the PV systems. All excess energy generated by the PV systems during winter was shared within the REC, whereas in summer, only approximately 65% of the excess energy was distributed within the community, as shown in Figure 15.

4. CONCLUSIONS

In this work, the energy performance optimisation of a REC in Northern Italy is presented. The case study was chosen due to the presence in the municipality of Sorbolo-Mezzani, which is around 20 km northeast of Parma, a large industrial facility

that generates a large surplus of electricity.

To optimize energy sharing within the REC, multiple scenarios were analysed by accounting for varying energy consumption patterns among different users. The selection of REC members was guided by the geographical boundaries of the primary electrical substation, in compliance with Italian regulations, and by the load profile of the industrial facility.

The outcomes, obtained by means of a simulation model of the REC developed in MATLAB environment, reveal that the REC in which commercial, school, and residential buildings performed better. However, the level of energy sharing remains limited, primarily because photovoltaic production significantly exceeds the community's energy demand—particularly on weekends when the industrial facility is closed.

For the optimal mix of REC members, the monthly ratio of shared energy to the excess energy generated by the PV systems showed that, during winter, all excess energy was shared within the community, while in summer, only around 65% was distributed among REC members.

Future research will investigate the contribution of the electrical storage to the energy sharing within the REC.

ACKNOWLEDGMENT

This research is funded by the Emilia-Romagna Regional Development Fund PR-FESR 2021-2027 Program under the project SACER – Sviluppo e integrazione di Accumuli innovativi nelle Comunità Energetiche Rinnovabili, CUP J47G22000760003.

The authors gratefully acknowledge the support of Cosmoproject S.p.A.

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NOMENCLATURE

E

Energy, kWh or MWh

t

time, h

Subscripts

d

demand

el

electrical energy

excess

excess energy

prod

PV production

shared

shared energy

tot

total