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Renewable energy community design and evaluation according to the Italian regulation

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Renewable energy community design and evaluation according to the Italian regulation

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Abstract. The target of a Renewable Energy Community (REC) is to improve the renewable energy consumption without forcing the grid to work as a power backup and avoid the installation of large energy storage systems. The paper proposes a comparison between different REC configurations with the same annual energy consumption of 500 MWh corresponding to about 200 residential houses in northern Italy. The comparison includes different kinds of building destination (residential, commercial, industrial), and different photovoltaic (PV) installed capacity. The results highlight the fundamental role of a proper design of the Renewable Energy Community configuration. RECs based on members with complementary loads enhance the renewable energy consumption by increasing the fraction of shared energy. Different roles (consumer and prosumer) are fundamental to provide the proper energy distribution during the sunny hours by producing a win-win condition. Nevertheless, an increase of the PV capacity can produce a detrimental effect on the shared energy ratio due the non-contemporaneity of production and consumption.

1. Introduction

Many governments around the world are planning new green energy mix initiatives, such as in Europe, to improve renewable penetration and to reduce the CO_2 emissions. This new power generation mix often challenges load balance and grid stability [1]. To avoid major issues, the European Union supports with a strong policy and subsidies the creation of Renewable Energy Communities. The legal framework introducing and regulating the operation of national energy communities comes from two European Directives: the RED II Directive 2018/2001/EU on the promotion of the use of energy from renewable sources, and the IEMD Directive 2019/944/EU on common rules for the internal market in electricity [2]. The EU define, respectively, the concepts of the Renewable Energy Community (REC) and the Citizen Energy Community (CEC), which are similar but not completely overlapping. In the Italian legislative system, the REC is defined, according to the transposition of the European RED II Directive, as an association of local citizens, businesses, public administrations, small and medium-sized enterprises that produce and virtually shares renewable energy, reducing CO_2 emissions and energy waste.

The challenge includes improving citizens' knowledge of energy production and dispatching. Through the subsidies activated by the Italian government, the Energy Service Manager (GSE) aims to induce a modification in the members behavior. The goal is promoting a shift in the energy consumption, from peak loads in the evening to a major consumption in the sunny hours, in order to fit the photovoltaic production. The mechanism adopted to promote responsible energy consumption is called “energy sharing”. Shared energy is the energy produced from a renewable power plant of a REC member and consumed by a different member in the REC in the same hour.

The introduction of renewable energy communities in the energy markets opens several new research trends in the scientific community. Furthermore, the role in promoting the development of RECs is still an open question: Musolino et al. [3] highlight the role of different players such as professionals, institutions, NGOs or citizens, while Trevisan et al. [4] emphasize the need to encourage and involve members, with communication activities, support and dissemination. From the regulation side, Di Silvestre et al. [5], proposes a comprehensive review of the incentive system, network connection rules and the blockchain mechanism.

Nevertheless, a REC is not only a legal entity based on the energy balance. Many works in the literature emphasize the multidisciplinary nature of an energy community: Gjorgievski et al. [6] among others, define economic, environmental, technical, and social criteria, considering different possible technical and social arrangements. However, besides the regulation, many technical issues to increase the contribution of renewable energy are still open questions [7]. On the generation side, a possible strategy could be the adoption of polygeneration systems to achieve a more flexible production of renewables, as proposed by Bartolini et al. and Simões et al. [8,9]. Moreover, the increase of the self-consumption rate through integration with different systems, such as hydrogen production, as shown by for Pastore et al. [10] and other studies [11,12] represents a viable solution.

Despite different options, the adoption of photovoltaic systems remains the most common configuration for the users. In particular, results by Radl et al. [13] underline that the distribution of PV plants is not necessarily related to a reduction of electricity tariffs.

Other studies, like the one provided by Weckesser et al. [14], point out that the optimal capacity of PV is mainly depending on the community configuration and operating strategies. This result confirms that the key issue in energy communities is coupling production and demand profiles, which cannot be evaluated individually.

A further way to increase the benefits of a REC, especially in the set-up stage, is a targeted selection of its participants. For example, in the analysis performed by Lazzari et al., a subset of 7 users is selected from a set of 128 to create a community in the northern-east Spain that maximizes the self-consumption, minimizes the solar energy excess, and provides the lowest payback period [15].

Starting from the considerations of Casalicchio et al. [16] about the lack of modelling approaches that includes the impact of energy community composition and the distribution and capacity of photovoltaic plants, this manuscript presents a comparison of different community configurations, with an annual energy consumption of 500 MWh, based on different distributions of PV plants (i.e. different installed capacity) and different demand profiles (residential or other use). For all the considered cases a technical evaluation about shared energy and self-sufficiency is provided.

2. Renewable energy community simulation model

The work aims to evaluate the best REC configuration considering different user load profiles and different power plants to increase the electric energy self-sufficiency. To increase the autonomy rate of a REC, a simultaneity between power generation from renewable plants and power demand from any community members is required. For this reason, a detailed model to simulate and predict operation and behavior of plants and users in the community is required. The model must be able to evaluate on an hourly basis the power demand as well as the energy fed into the grid from every PV system. The energy systems have been dynamically modeled in MATLAB, according to the schematization presented in Figure 1. The hourly prediction of photovoltaic performance has been evaluated with the software Trnsys18, considering realistic ambient conditions based on the Meteonorm database [17]. The assumed performance parameters are shown in Table 1 and include the change in efficiency with temperature.

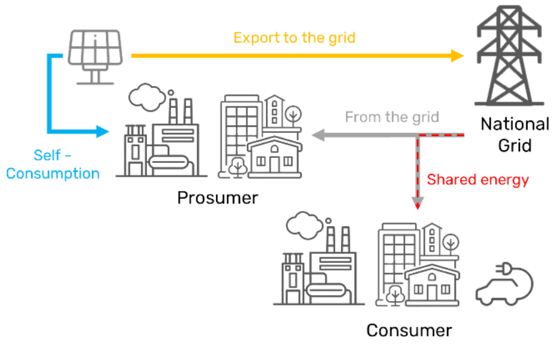


Figure 1. Renewable energy community energy flows and definitions

Table 1. Solar PV module specifications

Maximum power (Pmax)	W	375
Module efficiency (ηm)	%	20.1
Temperature coefficient Isc	%/°C	0.044
Temperature coefficient Uoc	%/°C	-0.275
Temperature coefficient Pmpp	%/°C	-0.350

The implemented model considers the energy fluxes for each time step (i) at different points of the virtual community grid with the following set of equations (Eq. 1-6), that respectively define:

1. The self-consumption of the k-th user ($SelfCons_k$), that compares the load demand and the plant production of each single user.
2. The energy injected into the grid by the k-th user ($E_{to\ grid_k}$), namely the PV plant surplus.
3. The residual load of the k-th user ($E_{load\ res_k}$), net of self consumption.
4. The shared energy (E_{shared}) calculated starting from the residual load of all users and the total surplus of PV.
5. The total surplus of the grid ($Export$).
6. The total deficit of the community grid ($Import$), namely the demand which is fulfilled by the national grid.

$$SelfCons_k\ (i) = \min\left(E_{load_k}(i), PV_{prod_k}(i)\right) \quad \text{(Eq. 1)}$$

$$E_{to\ grid_k}(i) = \min\left(0, PV_{prod_k}(i) - E_{load_k}(i)\right) \quad \text{(Eq. 2)}$$

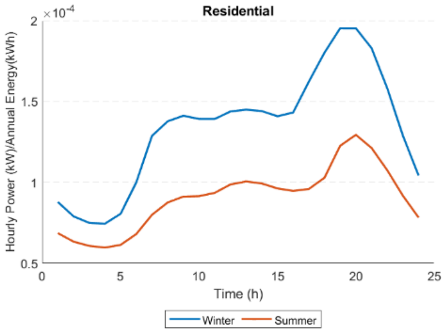
$$E_{load\ res_k}(i) = \min\left(0, E_{load_k}(i) - SelfCons_k\ (i)\right) \quad \text{(Eq. 3)}$$

$$E_{shared}(i) = \min\left(\sum_{k=1}^{N_{pros}} E_{to\ grid_k}(i), \sum_{k=1}^{N_{cons}} E_{load\ res_k}(i)\right) \quad \text{(Eq. 4)}$$

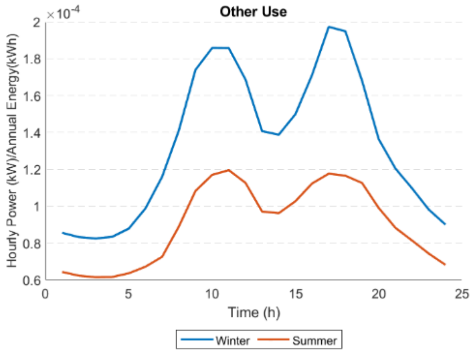
$$Export\ (i) = \min\left(0, \sum_{k=1}^{N_{pros}} E_{to\ grid_k}(i) - \sum_{k=1}^{N_{cons}} E_{load\ res_k}(i)\right) \quad \text{(Eq. 5)}$$

$$Import\ (i) = \min\left(0, \sum_{k=1}^{N_{cons}} E_{load\ res_k}(i) - \sum_{k=1}^{N_{pros}} E_{to\ grid_k}(i)\right) \quad \text{(Eq. 6)}$$

The definition of the hourly electric load of each user is a key point for the energy community performance. In case of the absence of an hourly meter reading, the Italian grid operator manager (GSE) applies two profiles to the monthly consumption, depending on the type of service contract: a residential profile in the case of a domestic supply or a generic "Other Use" profile. The trend of the pre-determined profiles, adopted in the current study, is presented in Fig. 2, showing the seasonal variability of the load.



(a) Residential



(b) Other use

Figure 2. Electric load profile for different types of users in winter (blue) and summer (orange).

3. Configuration settings and comparison

Under the suggestion of the available boundaries provided by the Italian energy regulation related to the creation of energy communities, the authors considered the influence of the following variables to implement users aggregation with a total annual demand of 500 MWh/year:

- Type of users (residential or other use, according the GSE definition);
- Capacity (kW_p) of each PV plant: 4, 6, 8, 10, and 20 kW;
- Definition of prosumer (owner of PV plant);
- Ratio between number of prosumer and consumer;
- Single user annual demand (kWh/year): 2500, 5000, and 7500 kWh.

In order to assess the simulation, the following hypotheses have been adopted: the prosumer and consumer are assumed to require the same load demand; the PV capacity is the same for each prosumer and climate conditions corresponding to Milan (I) area.

The influence of the various variables is investigated for three main scenarios:

1. All users (with single energy annual demand of 2500 kWh) have the same energy consumption profile (residential or other), but different consumer/prosumer ratios and different PV sizes are considered.
2. The consumption profile is half residential and half "other uses", and the individual user demand is 2500 kWh/year for any user; assuming that prosumers belong to only one user type, different ratios between consumer and prosumer and different PV sizes are considered.
3. Different ratios between consumer and prosumer, different PV sizes and different annual demand for single user are considered with a consumption profile entirely "other uses".

The different RECs analyzed are compared on the basis of two parameters:

- The energy sharing, which evaluates the amount of annual load demand provided by shared energy

$$Energy\ sharing = \sum_{i=1}^{8760}\left(\frac{E_{shared}(i)}{\sum_{k=1}^{N_{cons}} E_{load_k}(i)}\right) \quad \text{(Eq. 7)}$$

- Renewable fraction (RF), which evaluates the annual total demand met by renewable energy; this parameter also defines the self-sufficiency of the REC.

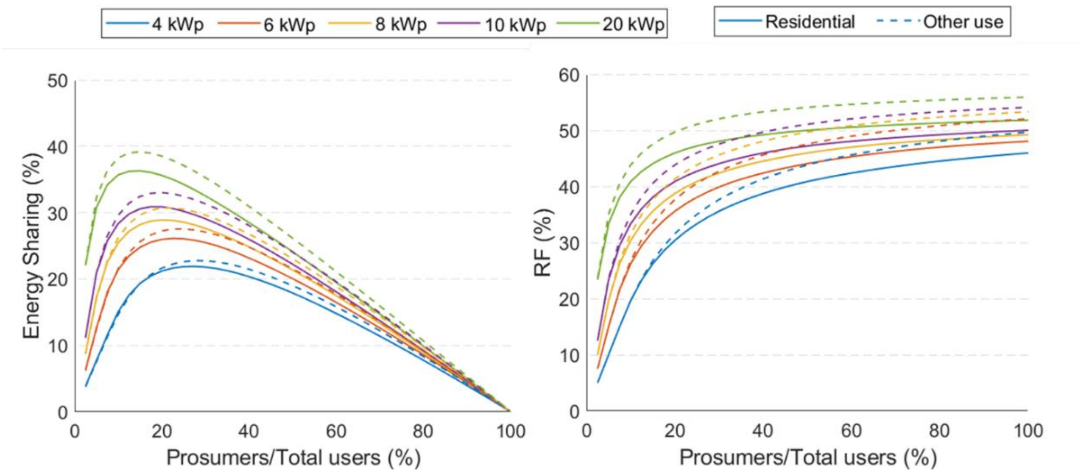
$$RF = \sum_{i=1}^{8760}\left(\frac{E_{shared}(i)+\sum_{k=1}^{N_{pros}} SelfCons_k(i)}{\sum_{k=1}^{N_{cons}} E_{load_k}(i)}\right) \quad \text{(Eq. 8)}$$

4. Results and discussion

The results of the scenarios analysis (including sensitivity analysis) are presented in Figures 3-5, according to the three scenarios introduced in the section 3. The REC energy performance is summarized according the two proposed parameters: the energy sharing on the left charts and the renewable fraction on the right.

In the first scenario where all users are of the same type (Fig. 3), it is worth noting that an optimum number of prosumers that maximizes the energy sharing in the community is clearly identified. For a number of prosumer lower than the maximum, the installed capacity is not sufficient to cover the load, confirmed by the lower RF; otherwise, for a greater number of prosumers the shared energy is reduced since the self-consumption is increased. In Figure 3, the solid lines correspond to the pure residential demand and dashed lines to the pure "other uses" demand. The same trend is observed for both type of loads. Furthermore, the demand for the nonresidential profile is more in phase with PV production, enhancing the energy sharing and the renewable penetration for a given installed PV capacity.

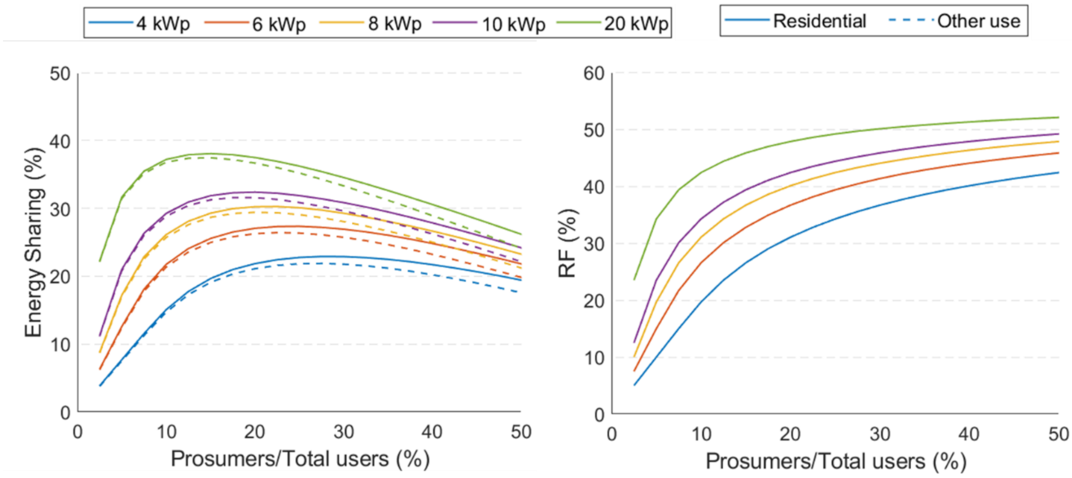
By increasing the size of photovoltaic systems, energy sharing increases, as more of the renewable energy production, after self-consumption, is available to other REC users and, consequently, the renewable fraction increases, due to a higher installed capacity. It is worth noting that a larger size of photovoltaic systems leads to more shared energy and the optimum is achieved with a lower percentage of prosumers, due to an increase in total installed capacity. Looking at the curves of the renewable fraction (Figure 3b), the increasing trend can easily be traced to the increasing power output of the PV plants moving along the x-axis. The progressive decrease in slope is linked to a saturation effect: above a certain size, the PV power production does not find a community demand to satisfy and must be exported into the grid.



(a) Energy Sharing (b) Renewable Fraction

Figure 3. Performance indices for RECs with all-residential (solid lines) or "other use" (dashed line) demand and variable PV capacity (scenario 1).

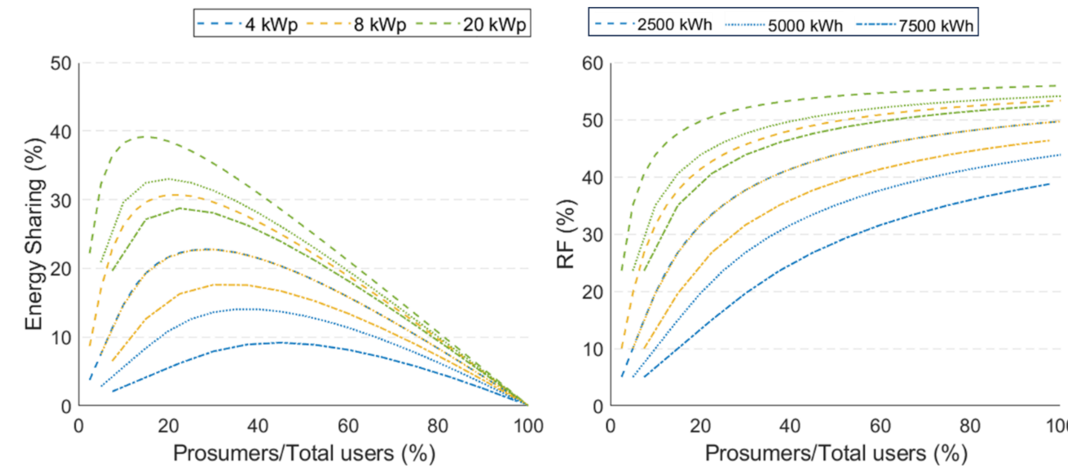
When a mixed consumption profile is considered (scenario 2), the influence of prosumer users' demand profile on REC performance is emphasized. The solutions in Figure 4 consider half residential users and half "other uses": solid lines refer to the configuration where prosumers are residential, whilst dashed lines correspond to "other uses" prosumers. The variation in the percentage of prosumers confirms the identification of a clear maximum point in the value of shared energy that, regardless of the type of demand, represents a trade-off between plant overproduction and residual demand. In contrast to the previous scenario, prosumers with "other uses" demand have a reduced energy sharing due to the greater portion of energy self-consumed. In Figure 4b, no different trends are observed between the two types of prosumers (solid and dashed line), since the sum of the contributions of self-consumed energy and shared energy (giving the renewable fraction) remains unchanged.



(a) Energy Sharing (b) Renewable Fraction

Figure 4. Performance indices for RECs with half residential and half "other uses" consumption, residential prosumers (solid lines) or "other use" prosumers (dashed line), and variable PV capacity (scenario 2).

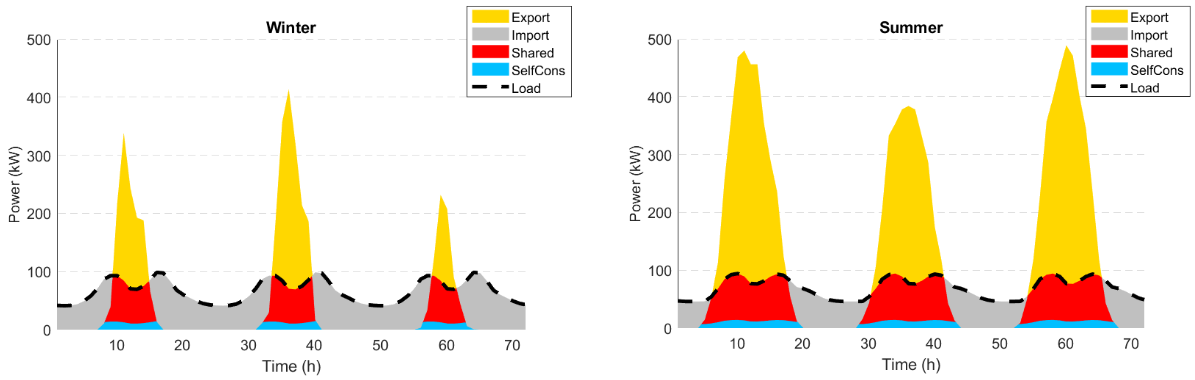
Finally, the correlation between individual energy demand and size of the production plant is presented in Fig. 5 (scenario 3). The lower is the annual demand of each user, for the same total energy, the higher is the community energy sharing. In fact, with the same number of photovoltaic systems installed, the percentage of energy that can be supplied directly is reduced, decreasing both the percentage of shared and self-consumed energy. For this reason, dashed blue line (2500 kWh/year and 4 kW_p) and dotted yellow line (5000 kWh/year and 8 kW_p) are perfectly overlapping, showing the same relationship between demand and production. For an increasing value of the annual demand/PV size ratio, the number of consumers maximizing energy sharing shifts to the maximum of 50%, which is the threshold above which self-consumption is greater than shared energy. Therefore, it can be concluded that in order to maximize the self-sufficiency of the REC, it is necessary to have a proper sizing between the PV system and the prosumer demand.



(a) Energy Sharing (b) Renewable Fraction

Figure 5. Performance indices for RECs with all "other use" demand, incremental individual demand, and variable PV capacity (scenario 3).

Concluding, a detailed full-year simulation is shown for one case among those investigated, maximizing the value of shared energy: a fully "other uses" demand profile with 20 kW as single PV plant size. A detail of the simulation reported in Figure 6 shows the second week of January and the last week of July, and Figure 7 shows the monthly energy flows into the REC. It can be noted that no import is observed during daily hours, but most of the output of the 600 kW PV capacity must be exported to the grid especially in summer. Comparing the trend of export and import energy in Figure 7, it can also be observed that the renewable plants could be sufficient to meet the entire demand of the community if an appropriate storage system were adopted.



(a) winter days (b) summer days

Figure 6. REC hourly energy flows.

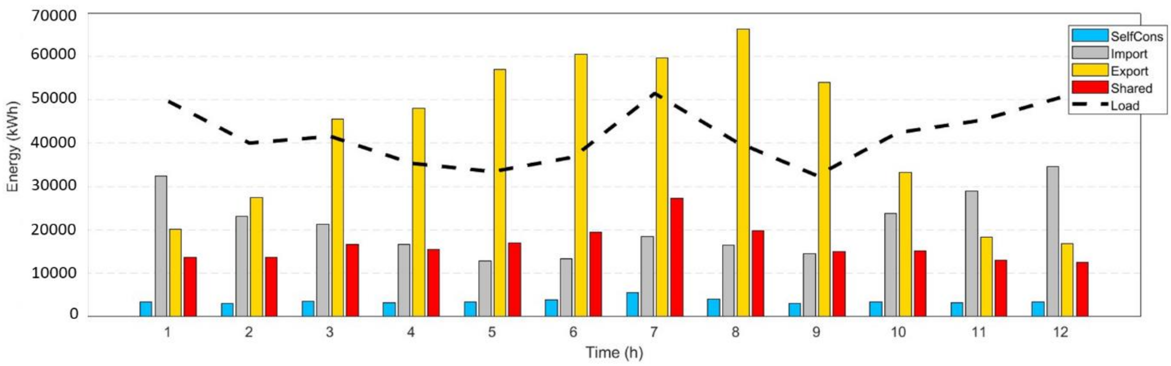


Figure 7. REC monthly energy flows.

5. Conclusions

The paper presents a preliminary sensitivity analysis to evaluate the performance of a renewable energy community in term of shared energy and self-sufficiency for different configurations. To assess a sensitivity analysis, for a community with 500 MWh annual energy demand in the northern Italy, four different variables have been investigated: load profile, annual demand of single users, single user installed PV capacity and different ratio between prosumers and consumers. Economic considerations, including investment costs, are deferred to later evaluations.

The analysis shows that a larger installed renewable energy capacity is not sufficient to create an efficient community: the requirement of simultaneous demand with PV generation leads to a mix of users with a predominance of non-residential demand. Residential prosumers guarantee a larger fraction of energy available for sharing. Finally, the relationship between individual user's demand and PV capacity has been addressed, showing that a consumer with a large energy demand, compared to its PV plant capacity, is not a virtuous member of the community, as it reduces self-sufficiency and shared energy.

The annual results for one of the solutions maximizing energy sharing show that a large portion of PV production is fed into the grid, and when compared to the portion of non-renewable energy imported from the grid, it may be worth considering the use of storage systems to improve the self-sufficiency of RECs.

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