ASSESSING ECONOMIC VIABILITY AND COMMUNITY INTEGRATION IN RENEWABLE ENERGY COMMUNITIES FOR A CASE STUDY IN ITALY

Elisa Moretti[1]*, Lucia Fagotti[2], Simona Stoklin[3]*, Ettore Stamponi[3]

[1]University of Perugia, Department of Engineering, Italy

[2]University of Perugia, Italy

[3]CIRIAF (Interuniversity Research Centre on Pollution and Environment “Mauro Felli”) - University of Perugia, Italy

*Corresponding Authors: elisa.moretti@unipg.it, simona.stoklin@dottorandi.unipg.it

ABSTRACT

Renewable Energy Communities (RECs) combine environmental responsibility with energy security, while also providing social benefits. Local energy production promotes significant independence from suppliers whose reliability in energy provision may be uncertain. Additionally, RECs play a vital role in fostering and educating social cohesion, which is an increasingly pressing issue. Participation, facilitated by open discussion and resource sharing, is a fundamental principle of REC. Despite the numerous benefits RECs offer in terms of energy, the environment, and social cohesion, their presence in Italy remains limited. The primary obstacle to their widespread adoption is the lack of awareness and understanding of their advantages. To attract interest from potential members, it is crucial to demonstrate that participation in a REC is economically worthwhile. This study aims to develop a method for assessing the economic viability of joining a REC, both as a prosumer (producer-consumer) and as a consumer. The research focuses on determining whether joining such a community is economically beneficial, given specific initial conditions. The proposed approach involves conducting a technical-economic analysis using a user-friendly tool designed for Renewable Energy Communities. The tool was developed for the creation of the first REC in the Municipality of Assisi. In this REC, the Local Authority will participate as prosumer, by installing photovoltaic systems on the roofs of municipal buildings such as offices, schools, gyms, and others. The tool can calculate self-consumed energy, shared energy, and revenue from incentive fees for RECs. This technical-economic analysis tool is a valuable asset for evaluating the feasibility of RECs. Its tailored application in the pioneering REC project in Assisi highlights its effectiveness in computing shared energy within the REC, providing valuable insights into the economic viability and community integration of such initiatives. Additionally, different configurations for the REC can be investigated and compared, as well as assuming the entry of new members and additional renewable production facilities to optimize the REC. This tool represents a versatile and replicable solution, enabling the assessment of the economic attractiveness and adaptability of REC’s. It fosters sustainable energy transitions across communities of various sizes and characteristics.

1 INTRODUCTION

The current state of our planet necessitates the reduction of climate-altering emissions and the mitigation of global warming’s impacts. Achieving an energy transition requires action on both the production and consumption fronts. At a regulatory level, this transition emphasizes the role of citizens (Cunha *et al.*, 2021), empowering individuals and transforming them from mere consumers into active participants, such as prosumers (Biresselioglu et al., 2021). Directive (EU) 2018/2001 (RED II) and Directive (EU) 2019/944 (Electricity Market Directive - EMD), both parts of the Clean Energy for All Europeans Package of 2019, provide provisions for Renewable Energy Communities (RECs), as well

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as for Citizen Energy Communities (CECs). The primary objectives of this Package are to improve energy efficiency, reduce emissions of climate-altering gases, increase social acceptance and development of decentralized renewable energy technologies, enable market participation by families who might otherwise be excluded, protect vulnerable consumers, and combat energy poverty. The shift to decentralized energy production offers numerous benefits, including the utilization of local energy sources, enhanced local energy security, shorter transportation distances and reduced energy losses. This transition also fosters community development and cohesion through the creation of local income sources and job opportunities. RECs are legal entities based on energy sharing, with members that can include citizens, research and training institutions, small and medium-sized enterprises (SMEs), and local authorities. These entities collaborate to install and manage shared renewable energy production facilities for self-consumption. Membership in a REC is based on voluntary and open participation, allowing for varying types and numbers of members. European Member States are required to transpose RED II and EMD into national law to facilitate the establishment of energy communities. The progress of national transpositions varies across countries (Fina and Monsberger, 2022). In Italy, RED II has been implemented through Legislative Decree 199/2021, while EMD has been implemented through Legislative Decree 210/2021 and subsequent decrees that govern incentives recognition methods and timing. Within the current Italian framework, this research aims to develop an easy-to-use tool for conducting technical-economic analyses of RECs. This tool calculates self-consumed and shared energy as well as the revenue from incentive fees. The selected case study is the first REC in the Municipality of Assisi, where the Local Authority acts as the promoter and a member. The proposed technical-economic analysis method can be used to assess the feasibility of RECs. Additionally, various configurations for the REC can be explored, also the potential inclusion of new members with attached renewable production facilities to optimize the REC.

2 RECs IN ITALY, THE STATE OF THE ART

A REC is an association of citizens, commercial activities, local public administrations, and small/medium enterprises that decide to join forces with the aim of producing and sharing energy from renewable sources. The energy is shared virtually among users connected to the same primary substation, as shown in Figure 1.

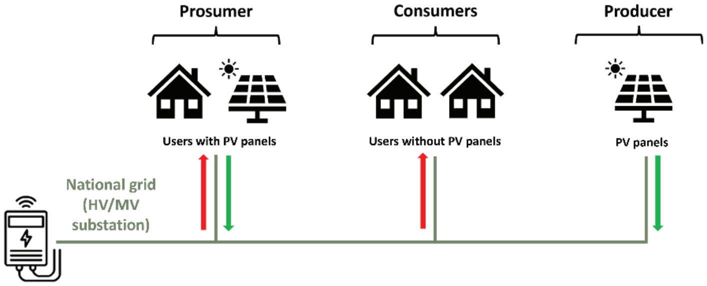

Figure 1: Schematic representation of the virtual energy sharing model within a REC.

In Italy, the initial regulatory framework for Renewable Energy Communities (RECs) emerged with the enactment of Law 8/2020. This regulation, enacted prior to the transposition of the Renewable Energy Directive II (RED II), anticipated the establishment of collective self-consumption groups exclusively for renewable sources, including the formation of energy communities.

On January 23, 2024, the Ministry of the Environment and Energy Security (MASE) issued Decree No. 414 following registration by the Court of Auditors and prior approval from the European Commission. Within thirty days of its enactment, precisely on February 23, 2024, the Ministry approved operational guidelines, following validation by ARERA and in consultation with the GSE (Italian Energy Service Manager). These guidelines delineate the procedures and timelines for incentive recognition.

Virtually shared energy, which is incentivized under the Italian legislative framework, corresponds to the minimum value between the energy fed into the grid and the energy withdrawn from the grid in

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each individual hour. Therefore, to maximize the economic incentive, it is essential to ensure that these two values are as equal as possible for each hour or at least do not differ significantly. Energy sharing is virtual, which means that an algebraic sum is performed among the delivery points (PODs) within the REC to calculate the minimum energy exchanged during each hour.

According to the latest semi-annual report on energy and climate in Italy published by GSE, as of June 2023, the count of active RECs stands at 35, while the number of collective self-consumption setups reaches 74. (Collective self-consumption denotes another form of virtual energy sharing, wherein members within the same building or condominium collectively utilize the locally generated energy). In terms of installed capacity, as of June 2023, there were collective self-consumption and REC installations totaling 2,7 MW, exclusively sourced from photovoltaic systems, with over 56% attributed to RECs. Moreover, there were 825 end customers connected to Collective Self-Consumption and RECs, with nearly 70% participating in Collective Self-Consumption.

In the "Comunità Rinnovabili 2022" report by Legambiente, a comprehensive list of RECs established in Italy during the transitional period is provided. Notably, several RECs with public participation stand out. One such example is the REC "Solisca," initiated in November 2021 by the Mayor of the Municipality of Turano Lodigiano in northern Italy. This REC allocates the premium received from the GSE among its members, comprising not only the Municipality but also the parish and approximately twenty low-income families. The objective is to extend the benefits of self-consumption to individuals at risk of being excluded from the transition towards renewable energy and to alleviate the burden of high energy costs. A 47 kW peak photovoltaic system was installed on various municipal structures, including the sports field, the municipal gym, and the canteen of the Post Office and Civil Protection building in Bertonico. This setup aims to foster synergy between clean energy production and electric mobility, thereby reducing dependence on fossil fuels.

Another noteworthy REC is "CERossini," established in January 2022 by the Municipality of Montelabbate in central Italy: the REC operates with a 15 kW photovoltaic system installed on the school roof, which functions as a prosumer within the energy community.

3 CASE STUDY

The highlighted case study focuses on the inaugural Renewable Energy Community (REC) established in the Municipality of Assisi, a quaint town nestled in central Italy. In 2020, Assisi adopted the Sustainable Energy and Climate Action Plan (SECAP), laying the groundwork for its sustainable energy initiatives. The Municipality leads the creation of the REC, assuming the role of a prosumer within the community. Aligned with the SECAP objectives (Stamponi et al., 2021), the REC endeavors to address various challenges, including combatting energy poverty, reducing energy expenses, and enhancing energy security.

Assisi, renowned for its architectural and scenic allure, operates under stringent regulations to preserve its aesthetic charm. Consequently, meticulous planning is imperative to devise solutions that seamlessly integrate with the surrounding environment. The REC project primarily harnesses photovoltaic energy, owing to its minimal visual impact and enhanced compatibility with the local landscape. This approach is reinforced by the prevalence of photovoltaic installations in the industrial and residential districts of "Santa Maria degli Angeli." As of July 2021, Assisi boasted 587 photovoltaic installations with a cumulative peak power capacity of 8.263 kW. Notably, residential installations (below 10 kWp) constituted 87% of total installations, contributing to 25% of the installed capacity (Moretti and Stamponi, 2023).

Despite the inherent challenges, Assisi residents exhibit a keen interest in embracing renewable technologies. Throughout the solar year 2023, the region witnessed the installation of 91 new photovoltaic systems, collectively generating a peak power output of 1,35 MWp. These installations predominantly comprised small-scale PV panels, typically ranging from 5 to 6 kWp, with a few larger-scale installations exceeding 200 kWp, primarily undertaken by local enterprises (see Figure 2).

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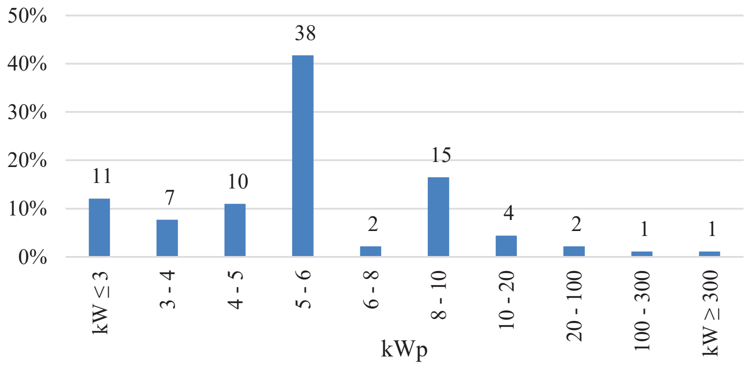

Figure 2: Photovoltaic systems in Assisi installed during solar year 2023 by power (number and %)

4 METHODOLOGY

4.1 Stakeholder Engagement and Data Collection

In order to implement a successful Renewable Energy Community (REC), it is necessary to define clear objectives, the number and types of user profiles and members, renewable source systems, the institutional and regulatory framework, as well as the development model. For the REC in Assisi, a top-down/PA-driven model was adopted, given the site characteristics and the political willingness and readiness to take concrete actions to spread renewable energies. This model, according to the literature (Tatti, *et al*., 2023), is considered one of the main developing models for RECs. In this model, the PA becomes the project promoter, responsible for the cost-benefits assessments, defining community management rules, identifying, and engaging members. In this sense, the Municipality of Assisi has committed to a series of tangible actions aiming to promote renewable energies and sustainable practices in the community. These actions include the establishment of a citizen's energy desk (Municipality of Assisi, 2022) to provide technical and practical support for residents, local enterprises, and other stakeholders. Additionally, the Municipality is organizing informative meetings and conferences on the theme, playing a catalytic role in engaging the population.

Furthermore, a questionnaire for the "Investigation of the establishment of Renewable Energy Communities" was made available on the institutional website of the Municipality of Assisi, aimed at evaluating the number and type of potential members of the REC. Through this survey, the Municipal Administration collected a series of data primarily concerning the annual user's electricity consumption and the possession of photovoltaic panels, potentially with their peak power capacity. The diffusion of the survey effectively integrated citizens interested in the project into the REC development process. Besides that, the collected data, as explained in the following paragraph, served as a crucial source for preliminary simulations using the developed tool.

The preliminary analysis provides the foundation for evaluating the REC, effectively addressing territorial needs, and integrating citizens who benefit from the project, thereby generating widespread interest in the population.

From a technical perspective, working with real data provides a deeper understating of the REC's requirements and the type of users that should be involved for an efficient and well-balanced configuration.

4.2 Tool development

The REC's operation is simulated through an algorithm, based on real collected data (Figure 3). The input of the algorithm considers the annual electricity consumption of private and commercial users and municipality properties, in addition to the photovoltaic capacity of the considered configuration. These data are used to generate production and consumption profiles for each user included in an Excel file, along with an identification code which defines their role within the REC (consumer, producer, or

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prosumer). The evaluation will consider consumption and production profiles for consumers and producers, respectively, and for prosumers, both will be considered.

The production profiles were defined using the PVGIS online tool (https://re.jrc.ec.europa.eu/pvg_tools/en/), which could generate energy profiles from 2005 to 2020 for a PV panel with a nominal power of 1 kWp, a slope of 20 degrees, an azimuth of 0 degrees, and system losses of 23%. From these profiles, the one selected was the energy generation profile for the year 2006, with a producibility of about 1200 kWh/kW. Starting from these data, the annual energy generation of the PV panels within the REC configuration can be evaluated multiplying the reference profile and the nominal power of the PV panel.

Hourly consumption profiles were defined for diverse types of users, considering data from both the municipality administration and private users who have expressed interest in the project through the survey. Users' withdrawal data were obtained from the website of a major Distribution System Operator (DSO) in Italy, responsible for managing Assisi's electricity distribution network. The platform allows the downloading of users' withdrawal data in 15-minute intervals over the past 18 months. For each user, withdrawals for a one-year period were downloaded and subsequently processed using Excel to generate annual hourly consumption profiles.

The consumption and production profiles are displayed in an Excel file, where more users can be included to develop more complex simulations and examine various REC's configurations. The input Excel file is processed by a MATLAB (Version 9.14.0.2254940 (R2023a) Update 2) algorithm which elaborates the data, considering the role of each user within the REC. The algorithm evaluates, hour by hour, the minimum between the electricity fed into the grid and the electricity consumed by the REC members, to define the energy shared by each user. This analysis highlights the members who contribute the most to energy sharing, revealing whether it is necessary to increase the energy balance between user's consumption and PV panels capacity. Moreover, the algorithm evaluates the energy production, consumption, and self-consumption within the REC's configuration on an hourly basis.

The output results provide a series of energy parameters to assess the optimization of the configuration. These performance indices are:

- Physical self-consumption index (Psc), which is the ratio between physical self-consumption and photovoltaic production.
- Virtual self-consumption index (Vsc), which is the ratio between the energy shared among community members and the total photovoltaic production.
- Total self-consumption index (Tsc), which is the total of Psc and Vsc, provides information about how effectively the configuration can use the overall energy produced.
- Energy self-sufficiency index (Ess), which is the ratio between the total of physical self-consumption and shared energy, and total energy consumption.

The tool can serve as a support for the economical assessment of the PV panels integrated into the REC configuration, since an additional output consists in the determination of the economic incentive provided by the Italian government to promote RECs development, evaluated as shown in Table 1.

According to the MASE decree, the premium rate for shared electricity is determined using the formula outlined in Table 1, with potential adjustments accounting for various insolation levels. The incentive includes the restitution of the electricity transmission fee, which is refunded by the Regulatory Authority for Energy, Network and Environment (ARERA) to the RECs members. The value of the transmission fee, updated to 2024, consists in 10,57 € per 1 MWh of shared energy (ARERA, 2023).

Table 1: Incentive formula and ARERA transmission fee restitution.

Power [kW]	Incentive formula [€/MWh]	Supplement according to insolation rate [€/MWh]	ARERA transmission fee restitution [€/MWh]
> 600	60 + max (0; 180 – Pz)	4 (for central Italy)	10,57
> 200 and ≤ 600	70 + max (0; 180 – Pz)		
≤ 200	80 + max (0; 180 – Pz)		

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The incentive rate varies based on the hourly zonal electricity price (Pz) and the power capacity of the PV system. Consequently, the total incentive is calculated by the algorithm within a specified range:

- A minimum value around 75 € per 1 MWh of shared energy, when the PV power exceeds 600 kWp and Pz reaches its maximum value.
- A maximum value around 135 € per 1 MWh of shared energy, when the PV power is below 200 kWp and the Pz reaches its minimum value.

This economic incentive should be assessed in conjunction with the existing benefits associated with solar panel ownership, including savings from self-consumption and revenue from surplus electricity sales to the grid.

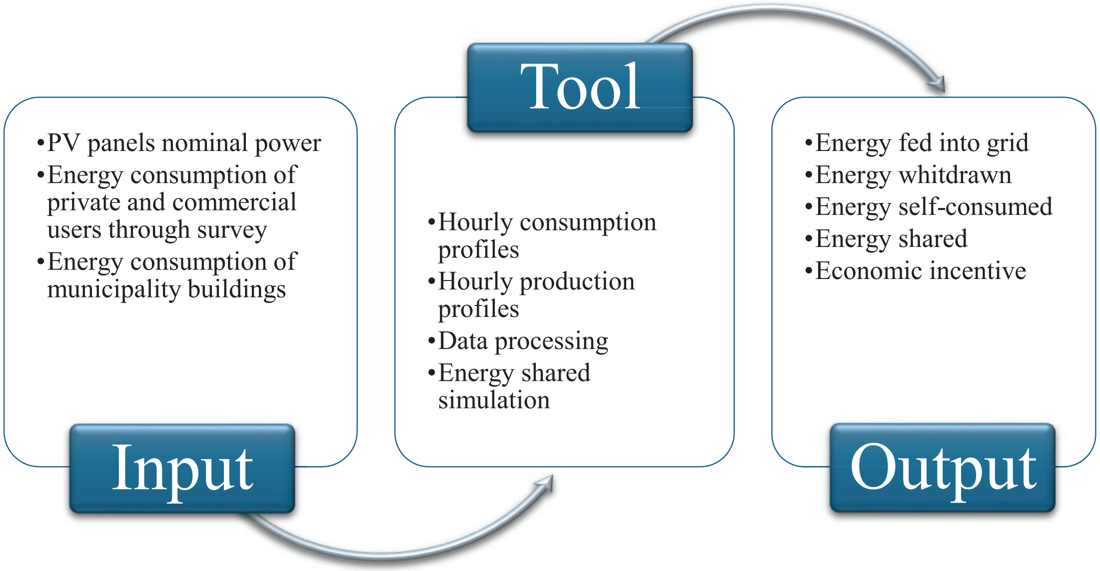

Figure 3: Simulation Tool scheme

5 RESULTS AND DISCUSSION

5.1 Data Analysis and Baseline Case Definition

The initial result obtained through the study involves a meticulous examination of substantial collection of real hourly electricity consumption data sourced from different users. The data were singularly examined with the purpose of validating their reliability. To make this analysis possible, the average hour electricity consumption was calculated for both workdays and weekends, across different seasons: winter (January, February, November, December), summer (June, July, August, September) and mid-season (March, April, May, October). These datasets were characterized by considerable Standard Deviations values, due to significant variability among measurements. To mitigate this instability, an outlier elimination process was performed to remove data points that were causing profile inconsistencies.

The data collected from individual users were then gathered to obtain typical profiles of consumption for various establishments in the municipality of Assisi, including schools, municipal offices, accommodation facilities, cafes, small factories, historical buildings and for cultural events, and residential users.

The analysis revealed that the average daily hour consumption patterns reflect the usage of these buildings, with specific consumption traits. The scholastic electricity consumption is concentrated during the central hours of the day, between 8 am and 6 pm, particularly during winter and mid-season; otherwise during summer, the daily consumption reduces significantly. In municipal offices, consumption is higher during work hours, between 9 am and 7 pm, with peaks during summer when cooling systems are in high demand. Regarding accommodation facilities, their consumption is relevant during evening hours, when guests are typically in their rooms, and during summer and highly touristic periods. Cafes display profiles that reflect their opening hours, with consumption increasing from 10 am, and higher values observed during festive days. Factories are the most energy-consuming users, presenting the highest annual electricity consumption concentrated in the central hours of weekdays, between 9 am and 6 pm, and with limited seasonal variability. Assisi is also characterized by a noticeable number of historical buildings, whose consumptions are widely variable according to the type, surface area and opening hours. Another kind of facility in the municipality of Assisi are buildings that host cultural and sporting events, such as theatres and indoor stadiums. Even in this case, they display varied consumption profiles, based on their utilization, with peaks mainly noticeable in the evening, when most of the events are usually scheduled. Lastly, the residential consumption patterns vary widely, depending on the number of occupants, their habits, the property size, and the potential presence of heating and cooling systems. Considering these variables, residential users were clustered in three diverse groups, according to their annual electricity consumption, as users with total consumption around 1.000 kWh, 2.000 kWh and 3.000 kWh. As shown in the Figure 4, the evolution of consumption during weekdays for the groups are similar, with values slightly higher during winter and mid-season, and peaks during morning, around 9 am, and during evening, around 8 pm, when users are usually at home from work.

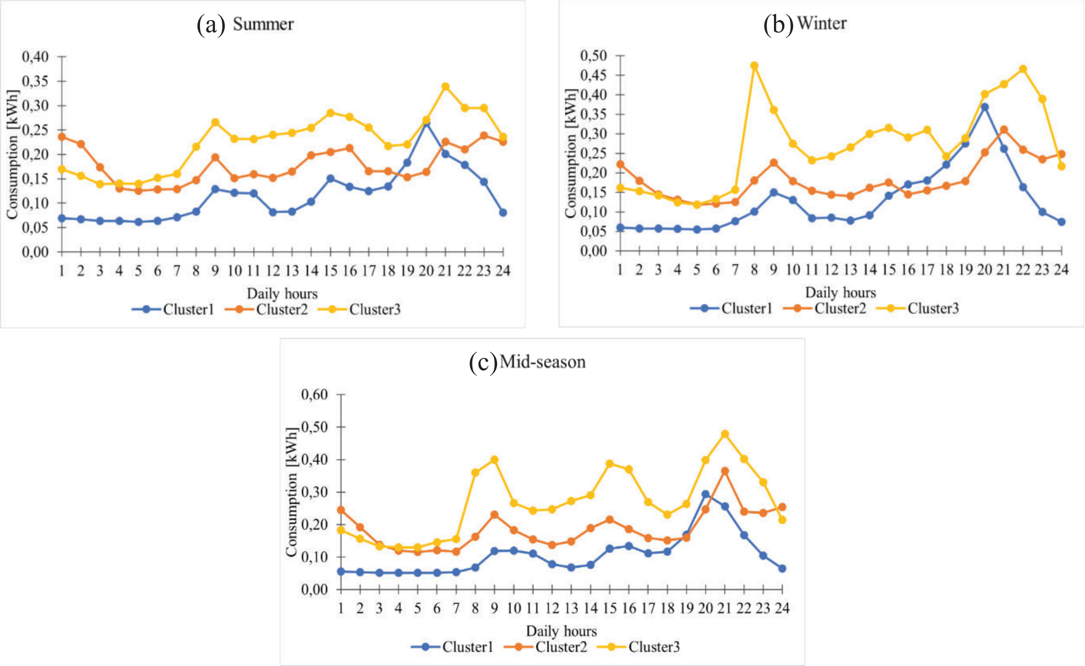

Figure 4: Consumption trend of residential user for weekdays during summer (a), winter (b) and mid-season (c)

The collection and analysis of this data were crucial in identifying the type of users that could significantly contribute to a well-balanced REC configuration. Based on the acquired results, an initial configuration hypothesis, denominated "Baseline Case", was formulated, and tested by the MATLAB algorithm. This configuration includes 62 total users, 40 consumers and 22 prosumers, with a total annual electricity consumption of around 4,6 GWh and a total peak power of photovoltaic systems of 1 MWp, structured as outlined in Table 2. The users involved in this configuration were chosen considering the expression of interest they pointed out in the survey. Some of them also made clear that they intended to install a photovoltaic system in the immediate future, so they were considered as prosumers in the configuration.

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Table 2: Configuration of "Baseline Case"

Users	Type of users	Number of users	PV System [kWp]	Annual Consumption [MWh]
School	Prosumer	3	147	167,04
Hotel	Prosumer	2	40	308,03
Cafè	Prosumer	2	40	115,90
Factory	Prosumer	2	654	2.850,00
Residential cluster 1	Prosumer	4	12	4,25
Residential cluster 2	Prosumer	4	18	6,44
Residential cluster 3	Prosumer	4	24	8,99
Rail warehouse	Prosumer	1	65	0,44
School	Consumer	6	-	136,27
Office	Consumer	2	-	115,99
Hotel	Consumer	4	-	616,06
Cafè	Consumer	4	-	231,80
Residential cluster 1	Consumer	8	-	8,51
Residential cluster 2	Consumer	8	-	12,87
Residential cluster 3	Consumer	8	-	17,98
Total		**62**	**1.000**	**4.600,57**

5.2 Results of the Baseline Case

The results derived from the simulation of the "Baseline Case", in Table 3, display the potential performance of the REC in Assisi, reflecting the current level of interest and involvement in the project among inhabitants. Key indices, such as the percentage of shared electricity, around 73%, and the Tsc around 90%, present positive values. Nonetheless, it is important to note that, for a REC to be considered well-balanced, the percentage of shared energy should ideally exceed 80%, indicating that there is still room for improvement in this regard. Additionally, to optimize the configuration under analysis, it would also be necessary to improve Vsc and Ess.

Table 3: Simulation results of "Baseline Case"

Parameters	Value
Energy consumption [MWh]	4.601
Photovoltaic production [MWh]	1.204
Physical self-consumption [MWh]	746
Physical self-consumption index (Psc) [%]	62,0
Energy fed into grid [MWh]	458
Energy fed into grid [% of production]	38,0
Energy withdrawn [MWh]	3.854
Shared energy [MWh]	334
Shared energy [% of grid fed in]	72,9
Virtual self-consumption index (Vsc) [%]	27,7
Total self-consumption index (Tsc) [%]	89,7
Energy self-sufficiency index (Ess) [%]	23,5
Minimum incentive [€]	30.408
Maximum incentive [€]	43.758

5.3 Improvement Scenarios

In order to investigate potential improvements to the baseline configuration, as well as the opportunities of analysis presented by the tool, a series of scenarios are formulated to assess the distinct contributions of various user types to the energy balance of the REC. Starting from the "Baseline Case", three

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different configurations, each with identical total consumption and PV peak power installed, are evaluated.

- Case 1.1: in this configuration it is assumed that none of the users intend to install a photovoltaic system, classifying themselves as consumers and not prosumers. Their power capacity is replaced with a large-scale PV plant with peak power of 1 MWp, as a producer, in accordance with the maximum power capacity permitted for REC configuration under Italian legislation. Due to regulatory constraint, ground-mounted PV installations cannot be implemented within the municipality of Assisi. However, the PV plant can be installed in industrial or agricultural areas in adjacent municipalities within the same HV/MV electrical substation.
- Case 1.2: this configuration excludes the municipality of Assisi as member of the REC, eliminating the contribution of schools, municipal offices, and rail warehouses. These members are substituted by a local company with equivalent annual consumption and PV power capacity.
- Case 1.3: in this configuration the residential users' contributions are excluded, replacing them with a hotel while maintaining the same overall annual consumption and PV power capacity.

Lastly, considering the intention of the municipal administration to establish a REC with a total PV power capacity of 2 MWp by 2030, a variation of the "Baseline Case", referred to as "Case 2", is analyzed. This scenario includes a new producer with an installed peak power of 1 MWp in addition to other users. The simulation results for the different configurations are summarized in Table 4.

Table 4: Simulation results of "Case 1.1", "Case 1.2", "Case 1.3" and "Case 2"

Parameters	Case 1.1	Case 1.2	Case 1.3	Case 2
Energy consumption [MWh]	4.601	4.601	4.601	4.601
Photovoltaic production [MWh]	1.204	1.204	1.204	2.408
Physical self-consumption [MWh]	0	847	760	746
Physical self-consumption index (Psc) [%]	0,0	70,3	63,1	30,9
Energy fed into grid [MWh]	1.204	358	444	1.662
Energy fed into grid [% of production]	100,0	29,7	36,9	69,0
Energy withdrawn [MWh]	4.601	3.754	3.841	3.854
Shared energy [MWh]	1.080	202	320	1.040
Shared energy [% of grid fed in]	89,7	56,5	72,0	62,6
Virtual self-consumption index (Vsc) [%]	89,7	16,8	26,6	43,2
Total self-consumption index (Tsc) [%]	89,7	87,7	89,7	74,2
Energy self-sufficiency index (Ess) [%]	23,5	22,8	23,5	38,8
Minimum incentive [€]	80.530	17.620	29.112	81.416
Maximum incentive [€]	123.728	25.703	41.909	123.010

The outcome illustrates that "Case 1.1" exhibits the highest values of shared electricity percentage, Tsc and Vsc, due to the presence of the producer. This member, by definition, does not self-consume electricity, allowing other members of the configuration to utilize (virtually) the total electricity produced. Moreover, the economic incentive, already significant as result of elevated quantities of shared electricity, can be further increased by selling the excess produced electricity, generating additional profits. The "Case 1.2" and "Case 1.3", on the other hand, present results that are not significantly different from each other, but are slightly inferior to those outlined in the "Baseline Case", particularly concerning the amount of shared electricity generated and profits in terms of economic incentive. This outcome suggests that REC optimization benefits from a heterogeneous configuration, where various user types are present, contrarily the performances deteriorate when users are excessively similar to each other. "Case 2" exhibits good performances from an energy perspective, with quantities of shared electricity, Ess and Vsc, above those in the "Baseline Case". However, it allows a reduction in the ratio between shared and fed into grid electricity. This scenario appears to be particularly convenient from an economic perspective, as it offers one of the higher economic incentives among configurations. Nevertheless, it is also necessary to consider the economic investment required for installing a PV plant with peak power of 1 MWp.

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Another consideration that can be made concerns the baseline case. All hours of the year have been analysed, revealing that the hours when energy withdrawal exceeds fed into grid amount to 92%. If we narrow this analysis down to only the hours of actual grid fed in (4.200 hours out of a total of 8.760), thus excluding all nighttime hours, we observe this percentage drops to 84%, still a remarkably high value. Examining when injection exceeds withdrawal, in green on Figure 5 (a), we notice this occurs only during the central hours of holidays. This can be seen even better if we zoom out by going to consider a week in April (Figure 5 b), where the input exceeds the withdrawal exclusively in the hours when the withdrawal is low and there is good production from PV.

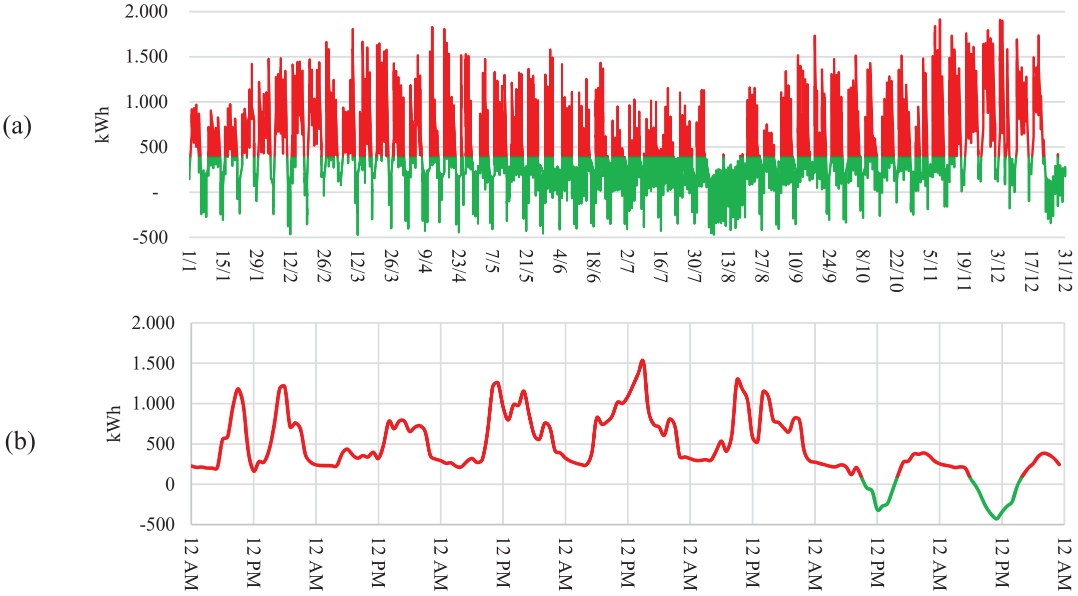

Figure 5: Difference between energy withdrawn and fed into grid; a) Whole Year, b) a week in April.

This outcome was expected since the largest consumers are local companies and municipal offices, which are closed on weekends. Considering the preceding observation and simulation results, improving the shared energy within the REC requires actions during time slots characterized by a surplus of energy production compared to consumption, defining strategies to efficiently utilize the renewable energy generated within the configuration. This improvement can be achieved by adjusting the types of consumption profiles within the REC, involving consumers with significant energy demands even during periods of surplus, such as hospitals.

Another approach could be for the energy community to invest in storage systems capable of storing the Community's production surplus to use it during evening hours, when energy generation exceed consumption. This strategy offers a dual benefit: it avoids withdrawals and maximizes the utilization of shared energy (Korjani *et al*., 2021). Yet another strategy could be the installation of charging stations for electric vehicles and encouraging charging during hours of surplus, or the more general strategy of raising awareness, for example, among residential members, incentivizing consumption during those time slots.

6 CONCLUSION

A Renewable Energy Community requires a scientifically rigorous preliminary study if it aims to accurately predict which members and installations are most needed to increase the shared energy within it, thereby making it more economically sustainable.

A public administration-initiated and supported Renewable Energy Community can more easily achieve this goal, as the involvement of all stakeholders through broad public administration engagement can foster the inclusion of those potential members who could play a key role in the balance of the

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community through their distinctive installations or consumption profiles. To achieve this goal, the developed tool is of crucial importance. Thanks to the tool, the analysis of the hypothetical Baseline case was made possible, built on the received responses and questionnaires submitted by various stakeholders, which already highlighted significant initial results. Indeed, the shared energy index stands at approximately 73%, indicating that the energy community shares a massive portion of its energy but still has room for improvement.

With the tool, it was also possible to hypothesize and analyse other configurations, wherein entire user clusters were replaced with others already present, or the community's renewable energy production was increased by adding a large producer. In the former case, it was observed that reducing consumer variability by inserting more profiles of the same type decreases all energy sharing indices. This implies that a Renewable Energy Community shares more energy the more heterogeneous it is, i.e. the more diverse and complementary the withdrawal profiles of its users are. The other result from these analyses was that adding a renewable energy production plant certainly improves all energy-sharing indices but entails increased investments.

Ultimately, it was observed how the energy community hypothesized in the baseline case feeds into grid a significant amount of energy on weekends and holidays. Strategies to improve the virtual self-consumption rate were proposed, such as the installation of storage systems or policies incentivizing energy consumption during certain time slots rather than others.

In conclusion, this work demonstrates how using a dedicated tool, it is possible to thoroughly analyse the configuration of a renewable energy community regardless of its size and complexity. This is particularly important, since in large and complex Renewable Energy Communities, hypothesising a priori solutions, unsupported by simulation results, even if seemingly common sense, could lead to worse results regarding shared energy given the complexity of the system.

Finally, future developments of the work will include comprehensive cost-benefit analysis.

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