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The maximization of shared energy in RECs in disadvantaged areas in terms of population density: the case study of Osidda in Sardinia

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ABSTRACT

Even if the first examples of free associations of citizens for the exploitation of local energy resources date back to the end of the nineteenth century, it is with the EU Directive 2018/2001 RED II that the concept of Renewable Energy Community is introduced for the first time. It is an association of ordinary citizens, commercial activities, public administrations, small and medium-sized enterprises, aimed at the production and maximization of the use of energy produced on site. Alongside the social (greater energy independence, awareness of environmental issues) and environmental (promotion of renewable energy and reduction of CO2 emissions) aspects, the economic one is equally relevant in order to contribute to the dissemination of RES, maximizing its self-consumed share in the production site and therefore reducing the loads of overproduction on the transmission network.
In this paper, the authors analyze in detail the regulatory aspects and the technological solutions that are contributing to the diffusion of these communities at national level, also in the light of the recent ARERA Resolution for widespread self-consumption. The critical issues associated with their implementation in disadvantaged area in terms of population density will be discussed. The case study of the Municipality of Osidda in Sardinia will be presented, where the provision of social services and the achievement of energy independence represent the tools to combat the rapid depopulation suffered in recent years. The model developed by the authors starts from an initial careful collection of data, aimed at overcoming the problems of measuring and estimating the energy consumption of very different users (residential and public), identifying the possible solutions able to maximize the shared energy produced by RES, inside the RECs and consequently the economic return connected to national economic incentives.

INTRODUCTION

In recent years, the topic of energy-conscious design has taken on a dominant interest over other aspects, focusing attention on the sustainable use of resources and to climate change effects.
In March 2023, EU Parliament negotiated a provisional deal with the Council to raise the EU's binding renewable energy target for 2030 to a minimum of 42.5% and aim to reach 45%, which is almost the twice the current share of renewable energy in the EU [1].
European Union is convinced that the objectives set are achievable only if the fundamental role of the active participation of people (also associated), in their dual role of "*prosumers*" and "*consumers*" [2], is recognized.
According to Renewable Energy Directive II (RED II), the Renewable Energy Community (REC) must be based on the "open and voluntary participation" of its members, identifying among its main

objectives to "provide environmental, economic or social benefits at the community level to its shareholders [...], rather than financial profits" [3] thus excluding profit motive.

Energy Communities are a key element in the energy transition scheduled by the European Community. [4]

They involve the private investment sector and contribute to the public acceptance of energy projects that will benefit from renewables in the long run. Moreover, the resulting benefits for community members are not limited only to the cost reduction of electricity but include reducing pollution and revitalizing the local economy by creating new jobs. [5]

As regard the Italian regulatory framework the Red II Directive has been transposed into law DL 162/19 ("Decreto Milleproroghe") and subsequently into Dlgs 199/2021 and Dlgs 210/2021. In Article 42-bis of the “Decreto Milleproroghe” [6] an incentive fare was established to remunerate instantaneously self-consumed energy, also through storage systems. In order to be eligible for the incentives, the production systems must be new, i.e. installed after 01/03/2020. Installations before 01/03/2020 can also join as long as they do not exceed 30 per cent of the total capacity under REC [7].

On 4 January 2023, the ARERA resolution, known as TIAD “Integrated text for widespread self-consumption” was adopted and came into force on 1 March 2023. The TIAD regulates the requirements, methods and procedures for access to the supply of the service for diffuse self-consumption, updating the relevant regulatory framework and simplifying some procedures.

The main innovations, compared the previous regulations, concern the configurations for RECs, extending its legal limits within the larger area of the primary HV/MV conversion cabin, and allowing access to incentives to production plants up to a maximum of 1 MW. These technical limits are finalized to maintain the 'social' and 'community' character of RECs, preventing them from turning into production companies.

To facilitate their spread RECs are financed by a series of incentives [Ministerial Decree of the MISE of 16 September 2020], up to a maximum power limit of 5 GW, with a time limit set at the end of 2027. In addition, for small municipalities (less than 5000 inhabitants), the PNRR has allocated 2.2 billion to finance up to 40% of the costs related to setting up a new plant or upgrading an existing one. These funds were also allocated to promote repopulation or limit the rapid depopulation suffered by the country, and by small municipalities in general, in recent years.

In accordance with the Community directives, the Region of Sardinia has also issued the regional law n. 15 of 13 October 2022 [8], aimed at guaranteeing the sustainable development of the regional energy system, promoting the reduction of climate altering emissions and ensuring fair access to energy resources by all actors: producers, consumers and public administrations involved in the energy transition. With Resolution 35/108 of 11/22/2022 [9] a specific incentive campaign was envisaged in favour of the Municipalities of Sardinia, for the creation and establishment of energy communities from renewable sources, with priority given to the municipalities without a methane network and less population density.

In order to make local renewable energy more accessible [10], peer-to-peer (P2P) energy trading is gaining ground. P2P trading also aims to enable consumers to make better use of their energy resources. It works by creating an online marketplace where prosumers, who produce electricity through distributed energy resources (also called self-consumers) can exchange electricity with consumers at an agreed price. By limiting the involvement of utilities in transactions, P2P models allow buyers to save costs and sellers to make more profit. In addition, they allow customers to choose the source of electricity supply [11]. P2P trading helps the grid by providing ancillary services and reducing peak demand, as well as saving citizens money on their electricity bills. [12]

Despite the many advantages of RECs, their diffusion is slowing down, partly due to the difficulty of spreading the benefits not only of an economic but also of a social nature, and partly due to the correct evaluation of consumption (the Region of Sardinia has allocated EUR 15,000 for each small municipality to carry out specific feasibility studies).

In the literature it is possible to find different approximation models in the calculation of energy consumption at community level (country, district, etc.), each with different input data and consequently, often with different final predictions. In general, they can be divided into micromodels and macromodels [13].

Macromodels can be further subdivided into economic (depend on prices, incomes and other parameters) and technological (based on equipment survey) [14].

These two models, however, make it difficult to take into account all influencing factors, such as social, economic and natural factors also because they tend to influence each other.

Yu, Li, Lei and Liu, in [15]**,** discuss the current status and shortcomings of the currently existing domestic energy consumption models, and then propose a back propagation (BP) based on the Neural Network (NN) model. NN models were originally developed to generalize the human nervous system into one or more mathematical models [16].

The NN models are particularly advantageous when dealing with complicated non-linear relationships between input and output systems, having the ability to continuously make adjustments according to the current situation. They have been shown to be more reliable in predicting energy consumption than other statistical approaches, due to their ability to handle non-linear structures with high calculation speed and accuracy [17] [18].

To arbitrarily represent the electricity usage of the different consumers in a house, three neurons can be drawn in the hidden layer [19]: heating H, ventilation V, air conditioning AC, lighting L and appliances A, each with its own input function $\boldsymbol{p}$, weight function $\boldsymbol{w}$ and bias function $\boldsymbol{b}$ aimed at producing the result $\boldsymbol{a}$:

$$a= f(wp + b)$$

Top-down and Bottom-up models are also used for consumption modelling. Top-down models use estimates of total consumption in the residential sector and other relevant variables and then attribute energy use to the entire residential sector. They operate on an equilibrium framework that balances historical energy consumption with that estimated on the basis of input variables. The strengths of the top-down model are the use of that widely available data, its simplicity and its reliance on historical data on the residential energy sector, which give the model inertia.

In contrast, Bottom-up models calculate the energy consumption of individual or groups of houses and then extrapolate the results to represent the region or nation. The Bottom-up approach includes all models that use input data from a lower hierarchical level of the sector understood as global [13].

Among the various existing statistical models, linear regression has already shown promising results due to its accuracy and ease of implementation compared to other methods. [20]. However, it can be used more effectively as a method of assessing the accuracy of the various models compared.

In this paper the authors propose a model for estimating consumption for a municipal area in Northern Sardinia interested in setting up a REC, especially to combat the rapid depopulation suffered in recent years. The model is based on a bottom-up methodological approach, easily implemented on BIM (Building Information Modelling) technology, integrated with the digital information obtained from the site of the Sardinia Region and from historical consumption analyses. The model was subsequently validated on the consumption data made available by the municipal authority and some residential users, allowing to identify the critical issues related to the goal of maximizing the energy shared by RES and consequently the economic return connected to national economic incentives.

MATERIALS AND METHODS

The case study is Osidda, a small Sardinian municipality covering an area of 25.78 km^2, located in the north-central part of the province of Nuoro, south-east of Montacuto, between the municipalities of Bitti, Nule (SS), Pattada (SS) and Buddusò (OT). It currently has 219 inhabitants and is the least populous centre in the province. In line with almost all the municipalities of central Sardinia, it is experiencing a demographic crisis; in fact, its population has decreased by about 17% over the last 20 years (source: ISTAT). Osidda is part of the 'Unione dei Comuni del Montalbo' (Covenant of Mayors) along with the municipalities of Bitti, Lodè, Lula, Onanì, Orune, Posada, Siniscola and Torpè. Winter heating requirement is mostly met by a fireplace fueled by wood and the addition of a pellet stove. Domestic hot water is produced with electric boiler, while summer air conditioning is mostly entrusted to the mass of the envelope and to shading solutions.

To assess the heating energy needs of the municipality of Osidda a digital geometric model of the whole country was created. For this purpose, the ARCHLine.XP software, based on BIM (Building Information Modeling) technology, was used. It allows the creation of an information multidisciplinary model, containing all the information useful for the digital representation of the building works and related services. The flow of information from CAD/BIM to other applications was realized by means of IFC format exchange file.

The 2D map of the village was initially imported directly from Google Maps, integrated into the platform and subsequently scaled and georeferenced. Then the model was constructed by drawing the plan of the current buildings in the village on the above-mentioned maps.

The typical building in the municipality of Osidda consists mainly of single-cell (~20 m^2) or two-cell dwellings with one or two-pitch roofs (Figure 1) with an approximately 30% slope. The structures predominantly comprise one (43%) or two floors (39%), while the average inter-floor heights are 2.5 m, with an average dwelling volume of approximately 215 m^3.

Single cell on the ground floor with single-pitch roof

Two or more cells on the ground floor with single-pitch roof

Single cell on the ground floor with gabled roofs

Two or more cells on the ground floor with gabled roofs

Two-level single-cell with single-pitched roof

Two or more levels cells with single-pitched roof

Single cell with two or three levels with a gabled roof

Bi-cell with two or three levels with gabled roofs

Three or more cells with two or three levels with a gable roof

Three or more cells with four or five levels with a gable roof

Figure 1 - Traditional building types in Osidda

The cataloguing work was carried out in an accurate manner, taking advantage of the low number of buildings and the relatively small size of the built environment.

In order to assess the dispersive characteristics of the building envelope, the buildings were divided into the construction periods <1968, 1969-1978, 1979-1999, >2000 (Figure 2), thus succeeding the different construction methods, construction materials and technological innovations progressively introduced over the years, capable of making significant differences in the building's energy requirements. This was achieved through the analysis of orthophotos related to the municipality of Osidda, made public on the website of the Sardinian region [21], for different time periods.

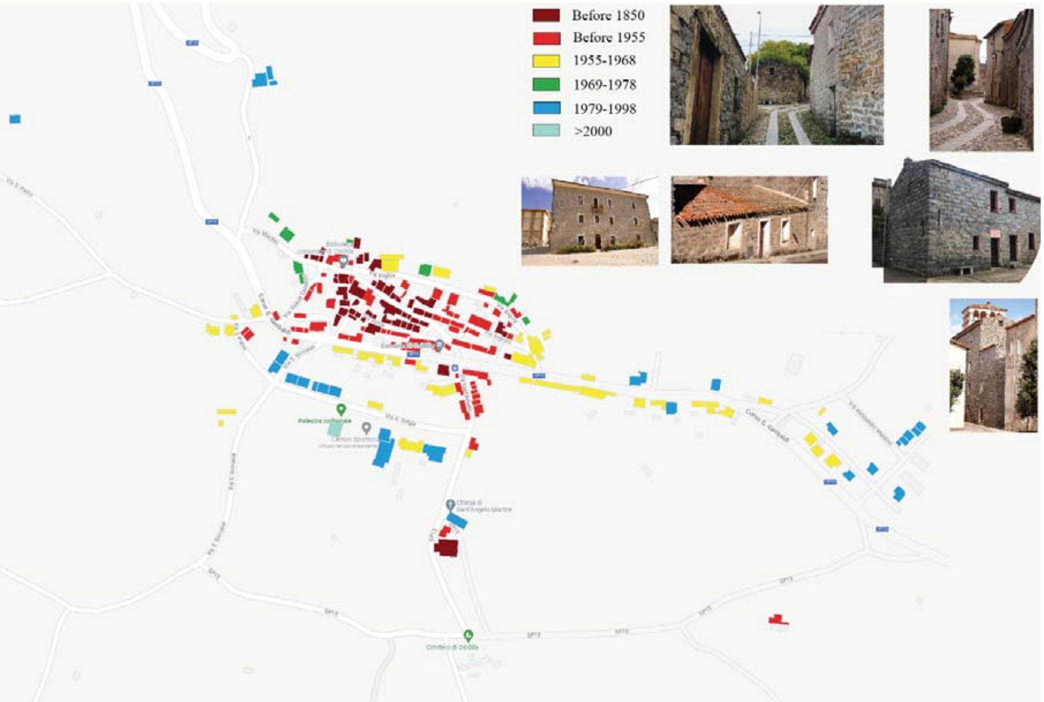

Figure 2 - Classification of buildings by historical age

The predominant type of envelope consists of uninsulated granite load-bearing walls, with thicknesses varying in height from 60 to 40 cm, sloping roofing with pantiles and wooden window frames with single-glazing and shutters. For building interventions carried out after 1955, it is possible to find elevations with concrete blocks and transformed roofs (e.g. from a pitched roof to a flat roof).

The characteristics of the envelope, together with the gross building volumes (obtained individually) and the climatic reference data for Osidda (obtained from [UNI/TR/10349-2]) allowed the evaluation of the energy needs of individual buildings, according to the UNI/TS 11300 technical standards [22]. The buildings currently in a state of ruin (4%) and/or serious structural subsidence and instability (10%) were excluded from the calculation. Heating loads are satisfied mainly using biomass (fireplaces) and to a lesser extent with traditional LPG generators. In the historic centre, due to landscape limitations, but also partly due to the mass of the envelope, summer air-conditioning systems are not widespread, except for public facilities (municipal offices, library) and the tertiary sector (toy library, hotels and accommodation facilities). In contrast, heat pump systems are prevalent in buildings constructed after 1968 for winter and summer air conditioning.

To take these aspects into account in the electricity consumption forecasting model, two different "residential" typologies were considered, which on average collected the most valid information possible for the entire inhabited volume: the typical historic centre building and the typical newer suburban area one. For the first type, electrical consumption is only attributable to electric heaters for hot water and lighting; for the second type, the main share of electrical consumption is due to the air conditioning system.

The electricity consumption obtained from the calculation model was compared with the consumption data discretized by energy vector in the PEAS, drawn up in 2011 by the union of Montalbo municipalities and in 2013 specifically for the municipality of Osidda. To further validate the model, the following were used: i) consumption data provided by "Enel Distribuzione" for the years 2020 and 2021 and relating to all municipal, residential, public lighting and tertiary sector utilities; ii) energy bills of all individual municipal utilities, which made it possible to discretize consumption in the various time slots; iii) quarterly consumption data for a sample residential building considered to be representative of the average residential type equipped with a heating pump air-conditioning system.

As regard the production aspect, all the PV plants in Osidda surveyed also on the GSE company [23] were initially taken into consideration, with particular attention to those prior to 01/03/2020 and excluding plants (and the buildings benefiting from them) already incentivised in the "Conto Energia" [24], for which there is neither possibility nor convenience in becoming part of a constituting REC.

The only operating plants, or currently being completed, that are qualified to be a productive part of the REC are those serving the municipal swimming pool and the former ex-barrack building. The plant serving the municipal swimming pool is composed of 48 panels of 410 Wp each, positioned above the multi-pitch roofing surface, with about 16° azimuth and with a 30° tilt angle. The second one, serving the ex-barrack building, consists of 13 panels of 380 Wp each, also with the same azimuth and tilt angles. The annual production on an hourly basis was obtained for both by using the PVGIS sw [25]. The energy bills for the two connected utilities made it possible to estimate, again on an hourly basis, the self-consumed energy and, consequently, the residual energy fed into the grid, so-called "available energy" for RECs. [26] [27] [28]

The comparison with the estimated hourly consumption of the various utilities made it possible to assess the "shared" energy recognized as financially incentivized share by the GSE [29] and equal to the minimum, in each hourly period, between the electricity produced and fed into the grid by the renewable energy plants and the electricity withdrawn by all associated end customers. For each MWh of electricity shared in the REC, the GSE pays, for a period of 20 years: a unit fare, equal to 9 €/MWh, which takes into account the avoided transmission and distribution losses for low-voltage users, and a premium fare equal to 110 €/MWh.

To maximise the percentage of shared energy (and thus the incentives), the set of buildings focusing their consumption during PV production (the hours of sunlight) has been evaluated: the swimming pool and the ex-barrack building, as *prosumers*, and residential buildings as *consumers*.

RESULTS

In figure 3a total annual electric consumption relating to the three types of users considered in this study is reported, while figure 3b shows the relative hourly absorptions on a typical winter day. Daily summer consumption is decidedly reduced for the two least energy-intensive users, the ex-barrack building and residential building, due to the lower energy requirement induced by the massive walls. The significant contribution made by the swimming pool is evident with a total of about 75 MWh per year, with peak power on average around 12 kW (figure 3b) in the central hours of the day, due to the heating of the pool water and internal air conditioning. The other two users have consumption equal about to 7.2 MWh and 1.8 MWh per year with peak powers not exceeding 6 kW for the ex-barrack building, in the time slots 12-13 and 16-18 and 2 kW for the residential building in the time slots 8-9 and 17-20.

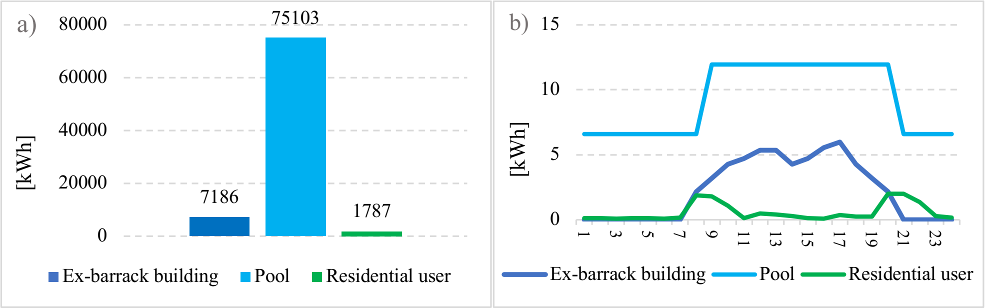

Figure 3 - Comparison of annual and daily utility consumption

In order to maximize shared energy, the trend in residential consumption would appear not optimal, as the greatest absorption is concentrated in time slots with little sunshine. However, even if to a lesser extent, residential summer consumption is spread over the time slots 14-20, thus contributing to the recovery of a large part of the energy produced by RES in that period. Figure 4 shows the comparison between the hourly production values of the two PV plants and the annual hourly absorption of the users making up the REC, among which the participation of at least 10 residential users is assumed.

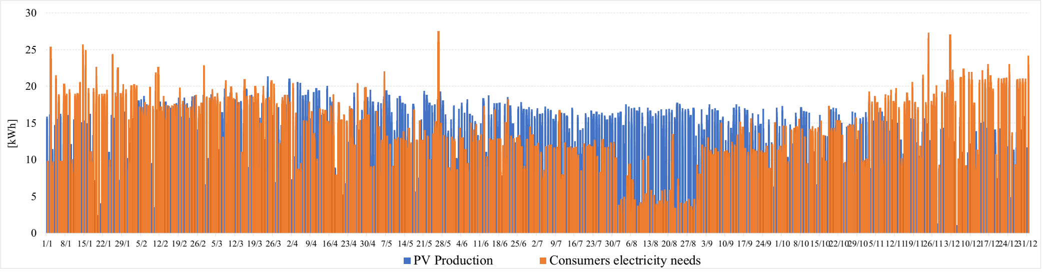

Figure 4 - Energy produced and consumed annually by the REC involving 10 residential consumers

It is significant how residential users contribute to fully cover the lower production in winter months, with redundancies even higher than 50% in more unfavourable climatic conditions. On the other hand, with only 10 residential users, in the months from April to September, about 25% of the energy produced is fed into the grid and not recovered. This value is on average higher than 80% in the month of August when there is no absorption by the swimming pool, due to summer closure. In the following figures 5 and 6 this difference is highlighted by comparing a winter month (January) and a summer month (July).

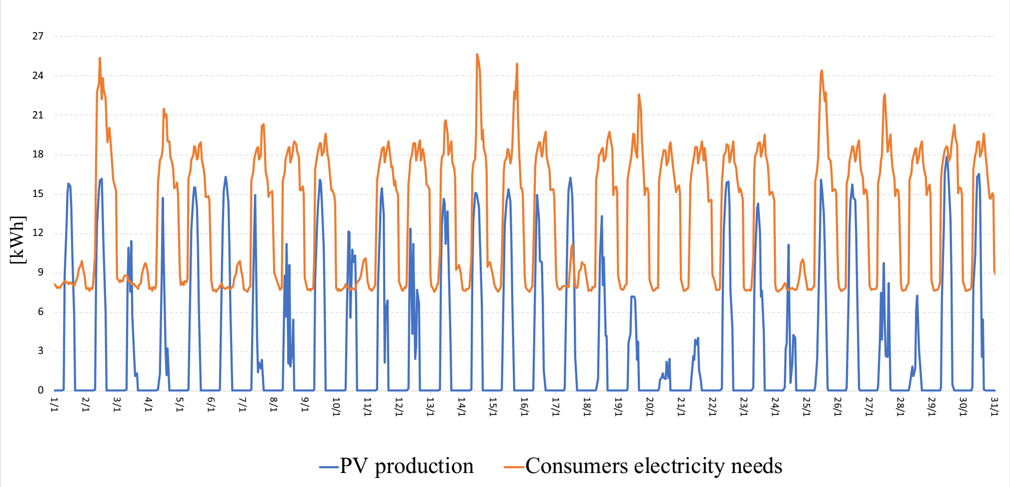

Figure 5 - Energy produced and consumed in January by REC involving 10 residential consumers

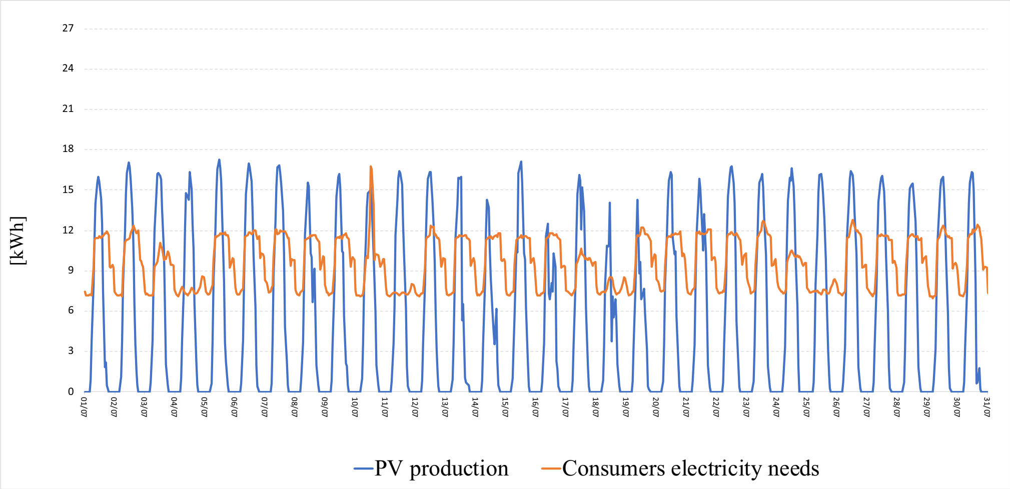

Figure 6 - Energy produced and consumed in July by REC involving 10 residential consumers

In Figure 7, the energy fed into the grid is compared with the shared energy in the case of 10, 20 and 30 residential consumers.

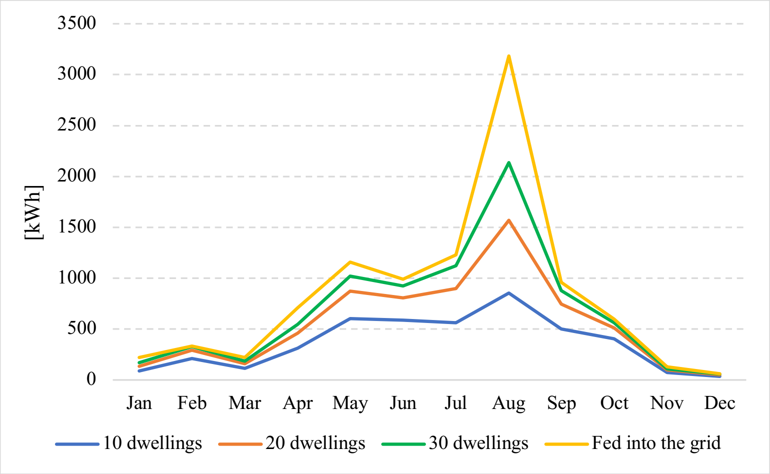

Figure 7 - Energy shared by the REC in relation to energy fed into the grid

Bearing in mind the calculation logic of shared energy, as the number of residential users increases, it tends to coincide with the energy fed into the grid. For the case study considered, even with 30 residential consumers, there is still a significant margin of energy available in the summer months. According to the developed model, it would take 120 residential consumers to have a shared energy exactly equal to the energy fed into the grid, thus maximizing the shared energy. However, this may not necessarily be economically viable. Indeed, increasing the number of residential users has two further effects (Figure 8): the absolute incentive will grow less and less until it reaches a plateau close to 50 dwellings, while the relative incentive, which roughly corresponds to the per capita quota due to the individual consumer, will obviously decrease. It is legitimate to hypothesize that, for the case study analysed, the shares are not very significant, and this is obviously attributable to the not enough power of the two plants considered, not sufficient to increase the perception of sharing and social responsibility which remains one of the cornerstones at the basis of the Community proposal to encourage the diffusion of RECs.

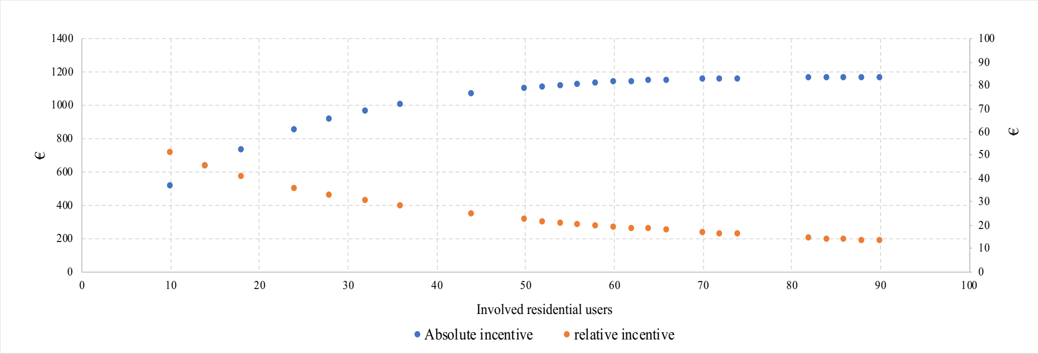

Figure 8 - Comparison of absolute and relative incentive in relation to the number of residential users involved

CONCLUSIONS

In this paper, the authors analyze the regulatory aspects and the technological solutions that should contribute to the diffusion of the Energetic Communities at national level, also in the light of the recent ARERA resolution for widespread self-consumption. To correctly evaluate the energy needs of the different (and numerous) users making up the REC and to compare it with the energy fed into the grid from the prosumers, a specific model on an urban scale was developed. The model is based on a bottom-up methodological approach, easily implemented on BIM (Building Information Modeling) technology, integrated with the digital information obtained from the site of the Sardinia region and from historical consumption analyses, elaborated in more or less recent municipal SEAPs and from monthly invoices. The model was then applied to the Municipality of Osidda in Sardinia, where the provision of social services and the achievement of energy independence represent the tools to combat the rapid depopulation suffered in recent years. This allowed to highlight the critical issues associated in the establishment of REC in disadvantaged areas in terms of population density, identifying the possible technological solutions capable of maximizing the energy shared by RES and consequently the economic return connected to national economic incentives.

The results have highlighted the criticality induced by the presence of particularly energy-intensive users with significant pause times (summer closure). In this case the contribution is essentially linked to the consumption of other users unable to cover a significant portion of the energy made available on the grid and, therefore, minimizing the simultaneous economic contribution.

In the case of RECs based exclusively on solar sources, the participation of residential users with peak consumption in time slots with little sunshine (and therefore production) must be carefully evaluated. With the same energy produced, the increase in the number of residential users leads to an ever-smaller increase in terms of economic benefits until a plateau is reached, which does not necessarily correspond to a condition of maximum advantage.

The relative contribution received by individual consumers is a function of the installed and available power and represents a necessary evaluation parameter if we do not want to fail the diffusion, among the participants themselves, of the perception of sharing and social responsibility.

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