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Technical-economic feasibility study of a Renewable Energy Community and participation in grid flexibility services

Case study: Fossano

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Index

Abstract

Climate change represents one of the most urgent and complex challenges of our time, requiring quick and targeted solution to mitigate its effects on the environment and human society. Among the many response strategies, the adoption of renewable energy sources emerges as a key solution. Renewable sources, such as solar, wind, hydropower and biomass, offer a sustainable alternative to fossil fuels, significantly reducing greenhouse gas emissions and contributing to the conservation of natural resources.

In this context, renewable energy communities (REC) are gaining increasing attention as innovative models of energy production and consumption. These communities rely on cooperation among citizens, to generate, share and consume renewable energy, promoting a distributed approach of energy production. This model not only promotes the optimal use of local resources, but also helps creating a strong and independent energy system.

Renewable energy communities not only contribute to the reduction of carbon emissions, but also offer socio-economic benefits. They create local job opportunities and encourage active citizen participation in the management of energy resources. In addition, they promote a culture of sustainability and environmental responsibility, which is essential for meeting the challenges of climate change.

The thesis begins with an overview of the current framework of REC's especially in Italy and then analyse a real Case Study, the REC CER-a promoted by "Confartigianato Cuneo" an association of companies based near Cuneo. It has been built through a partnership with Environment Park, the company that realize the feasibility study of CER-a and where I did the internship.

The diffusion of distributed renewable plants highlights some weakness of the actual power network that was designed to be suitable for the presence of big, concentrated plant and monodirectional power flows, for this reason flexibility of power network is one of the most challenging issues.

The feasibility study is the starting point of the analysis performed in the thesis. The study highlights a new opportunity for the REC in participating actively to the flexibility of the distributed power network. In the Cuneo area, one of the main Italian distribution system operators (DSO), "E-distribuzione", started a pilot project (EDGE) allowing the participation of medium-small operator in the flexibility of power network. This analysis explores how REC, in particular CER-a, can aggregate resources and participate in the flexibility of the network. Trought this case study, the thesis aims to demonstrate the potential of REC not only in producing and consuming renewable energy but also in playing a crucial role in future of energy network.

Chapter 1: Renewable Energy Communities

Introduction:

The concept of Renewable Energy Communities (RECs) has emerged as a promising and innovative approach to accelerate the transition towards sustainable and decentralised energy systems.

A Renewable Energy Community refers to a group of individuals or organizations who collaboratively participate in generating, consuming, and managing renewable energy resources within a localized area. These communities focus on reach energy self-sufficiency, reduce greenhouse gas emissions, and promote social, economic, and environmental sustainability. The main characteristic of these communities is their reliance on a wide range of renewable energy source: solar photovoltaic, wind energy, hydroelectric and biomass. By utilizing the power of these clean resources, REC aims to minimize dependence by fossil fuels and promote a decentralized energy system.

Community ownership and governance:

One of the main principle of RECs is community ownership and active participation. Differently from traditional energy models characterized by large corporations, and usually, big, centralized plants monopolizing the energy market, RECs are often organized as cooperative, this structure allows members to engage in decision making processes regarding energy project, resource allocation and revenue distribution. This democratic and inclusive approach fosters a sense of ownership and pride, but also ensure that the benefits of renewable energy are shared equitably among the community members.

Benefit of Renewable Energy Communities

Environmental Sustainability:
Generating energy with renewable resources significantly reduce greenhouse gas emission and reduce dependence from fossil fuels, contributing to environmental sustainability.

Energy efficiency and Security:
Local energy generation minimizes the transmission losses and increase energy efficiency. RECs also provide energy security, making them less vulnerable to interruption in centralized power grids.

Economic development:
RECs contribute to local economic development by creating investing opportunities for business and organization to invest in local renewable energy projects. These investments provide an interesting financial return and contribute to the community energy independence.

The revenues that come from the REC are spread between the members of the community and a portion need to be destinated to localized social initiatives in the territory.

Sustainable Development goals (SDG):

The RECs have a crucial role reaching a high number of Sustainable Development Goals (SDG) [1] expressed by the European Union fundamental for promoting an economic, social, environmentally sustainable development:

- **SDG 7: affordable and clean energy [2]**
- **SDG 10: reduced inequalities [3]**
- **SDG 11: sustainable cities and communities [4]**
- **SDG 12: responsible consumption and production [5]**

Limits

The main limitation associated with RECs includes:

Intermittency of Renewable Energy Sources:

Renewable energy generation is often affected by environmental factors, leading to high variability in supply. For example, solar energy production decline in absence of sun, while wind plants are highly dependent on wind availability instead biomass and hydroelectric plants have a more stable power production.

Challenges in obtaining founds:

Initiatives for building renewable energy plants usually require a consistent amount of money (CAPEX) and even if has the potential for long term cost savings, could be challenging finding financial support.

Informing the public:

There is also the need of increase of public education in energy usage. To increase the awareness in using energy in an efficient way, as in this configuration every member of the REC become an active player in balancing the system.

Regulatory European

The European Union has regulated Renewable Energy Communities (RECs) using two important legal documents, the Renewable Energy Directive (RED II) [6] and Internal Market for electricity IEM [7]. Implemented in 2019, both regulations are from what is known as the Clean Energy for All Europeans Package (CEP) [8], which includes a range of actions aimed at aligning European energy policy with EU climate and clean-tech goals.

RED II Directive: The RED II directive (2018/2001) stipulates that EU member states must collectively guarantee a share of 32% renewable energies in the Union's total gross final energy consumption by 2030. Another ambitious target is to reach the 14% of consumed energy for transport sector comes from renewable energy sources. All states need to create financial incentives to reach the goal of 2030.

IEM directive: *"This Directive establishes common rules for the generation, transmission, distribution, energy storage and supply of electricity, together with consumer protection provisions, with a view to creating truly integrated competitive, consumer-centred, flexible, fair and transparent electricity markets in the Union".* The directive also sets the rules to the cooperation between member states to produce, share, transmit and consume energy form renewable source. For create a more sustainable energy market and decrease the

RED II, the IEM directive introduces several increasingly complex roles to encourage participation by end-users and others in the electricity market. The first two roles are that of the active customer, or collectively active customers, which constitute a final customer or a group of final customers who consume or store electricity generated on their premises within a defined area or, if allowed by a member state, on other premises. They can also sell self-produced electricity or participate in flexibility or energy efficiency mechanisms, provided these activities do not constitute their primary commercial or professional activity.

The directive further introduces citizen energy communities (CECs), defined as a legal entity that:

- Is based on voluntary and open participation and is effectively controlled by members or shareholders who are natural persons, local authorities, including municipalities, or small enterprises.
- Aims primarily to provide environmental, economic, or social community benefits to its members or shareholders or to the areas where it operates, rather than generating financial profits.
- May engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, storage of energy, energy efficiency services, or charging services for electric vehicles or provide other energy services to its members or shareholders.

Together, the two directives institutionally recognize the two regulatory concepts of REC and collective self-consumption, thus enabling their consistent development at the level of individual national territories.

A study published in January 2023 on the scientific journal Nature [9] explore the initial trend of the RECs especially analysing the difference in different country of the Union.

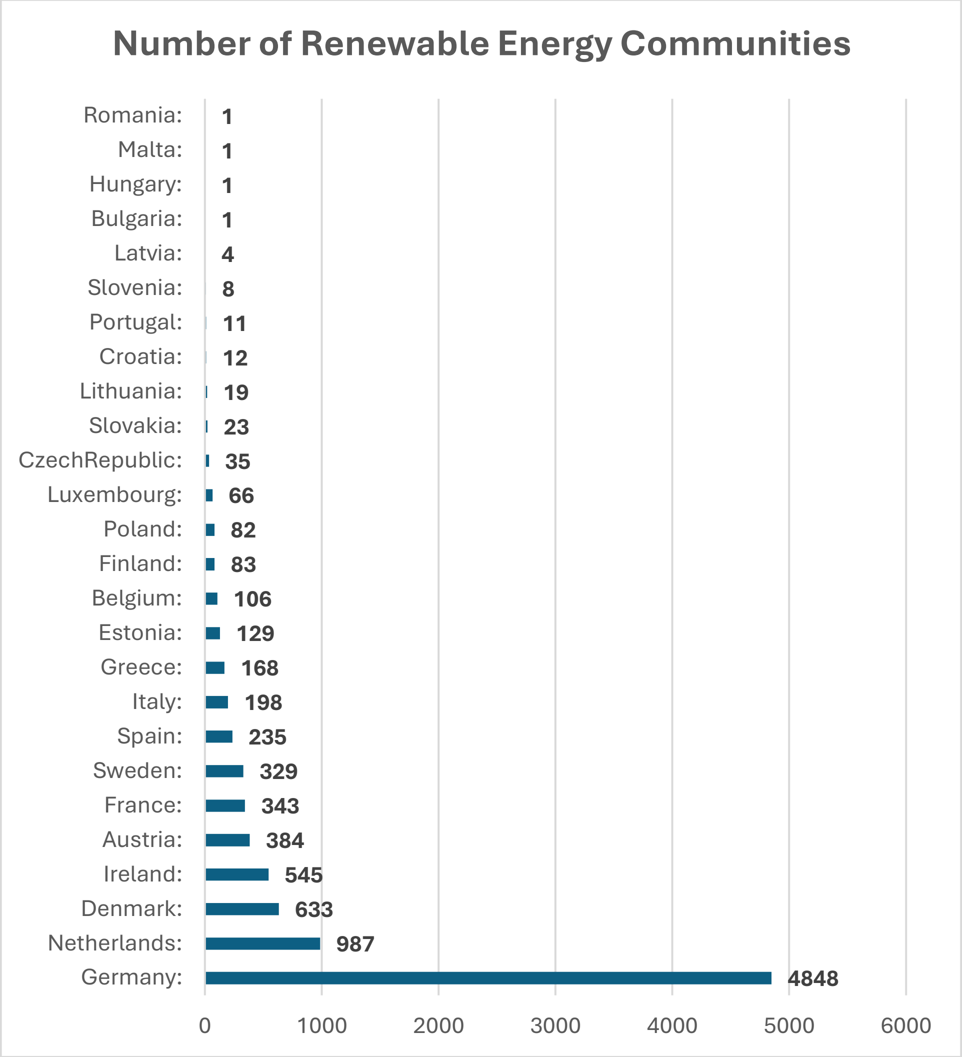


Figure 1:Number of RECs in EU country (2023)

There is an enormous difference in number of communities inside the European Union that account to 9525 communities, almost a half of that is in Germany.

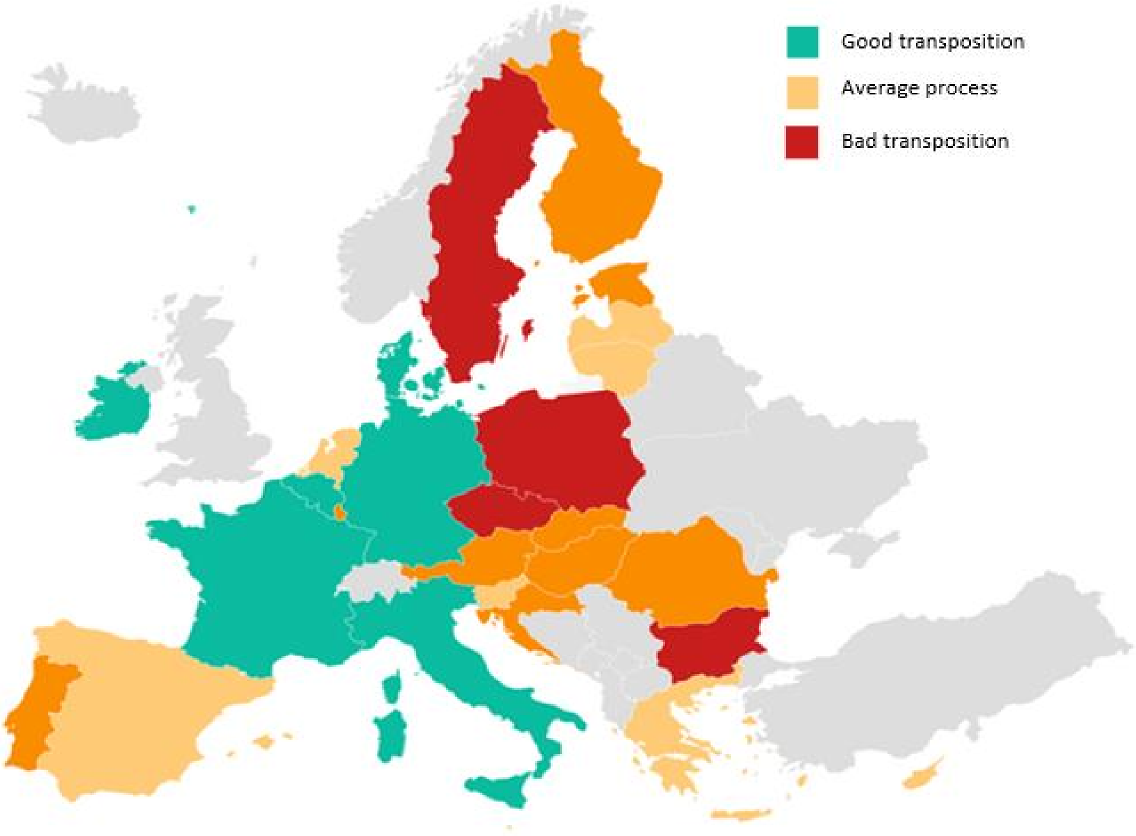


Figure 2:EU country behaviour to good practice.

According to REScoop.eu [10], which is continuously updated and monitored, taking a snapshot of the situation up to December 2023, only six European countries have good practices in the implementation of the Directives: Belgium, Denmark, France, Germany, Ireland and Italy.

Other member states despite having transposed the directives has critical elements. In Spain, for example, the type of legal entities that can constitute energy communities has not been concretely delimited, and since there is no regulatory authority with oversight power, there could be abuses of the legislation, going to undermine public confidence in this type of initiative. Something like this seems to have already happened in Greece where, due to a transposition of EU law that gives wide interpretation on how these communities can be established, many energy communities have been created by private investors rather than citizens.

There are also cases, such as Romania, where although European directives have been transposed this has been done with little clarity, setting up a situation whereby the lack of precise procedures and criteria makes it difficult to create energy communities with legal certainty.

Finally, some states have yet to enact laws on energy communities, with borderline cases such as Bulgaria and Czechia where there is still not even a draft law.

Italian Framework

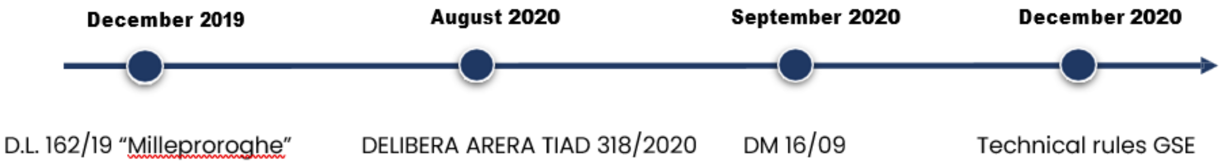


Figure 3: timeline legislation self-consumption groups.

The regulatory framework in recent years has undergone several developments: in Italy, following the **European RED II** [3] regulation of 2018, several concepts are introduced, such as

- In 2019, Italy publishes the **D.L. 'Milleproroghe' [11]** where, in Art. 42 bis, is described the transposition of the European RED II directive in an early and transitional form, introducing energy communities and collective self-consumption groups into Italian law.

- In August 2020**, ARERA DELIBERA 318/2020 [12]** was published, which regulates the modalities for the economic regulation of shared energy.

- in September 2020**, DM 16/09 [13]** regulates the incentive tariffs for RES plants included in collective self-consumption configurations.

- in December 2020, the **GSE's technical rules [14]** are published, which describe the requirements for accessing and activating the shared energy valorisation and incentive service.

The GSE is the ministerial body dedicated to the management and administration of the request for incentives, also dedicated to the creation of energy communities and configurations of widespread self-consumption.

The 2018 European **RED II Directive** [3] also provides, among other regulations, for financial support to the production and self-consumption of electricity from renewable energy sources. It can be argued that only the utilisation of renewable energy sources will facilitate the realisation of a fair and sustainable energy market that will bring about environmental, social, health and economic benefits.

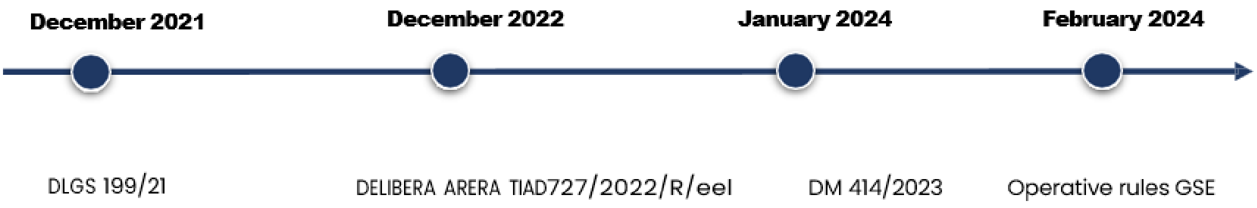


Figure 4:timeline legislation self-consumption groups.

The sequence of publication of regulations that define the final framework for the transposition of European legislation starts with:

- December 2021, Legislative **Decree 199/21 [15]**, entitled 'Final transposition of Directive 2018/2001', was enacted.

- December 2022 by **ARERA DELIBERA DELIBERA TIAD 727/2022/R/eel [16]**, which replaced the previous ARERA deliberation. The **TIAD** acronym, standing for **'Testo integrato di autoconsumo diffuso'**, regulates the modality for the evaluation of self-consumption diffused for the configurations foreseen by the **D.LGS 199/21**. It replaces the 2020 deliberation.

- January 2024, the **'DM 414/2023'[17]** regulates the incentive tariff for renewable energy plants included in the configurations of diffuse self-consumption, along with the methodologies for accessing the PNRR contribution and collective self-consumption in municipalities with a population of up to 5,000, were published.

- February 2024. were set out the **DECREE CACER [18]** and **TIAD,** which also outlined the operational rules for accessing the service for diffuse self-consumption and the PNRR contribution. This was published by the GSE [19].

- On 8 April 2024, the GSE online portal [20] will open, and the first configurations of diffuse self-consumption will be able to be registered.

About the sizing, connection, and age of plants producing electricity from renewable sources, Legislative **Decree 199/2021[15]**, "Final transposition of Directive 2018/2021," relaxes the requirements, establishing that they can have a total capacity of up to 1 MW and be connected to the electricity grid through the same primary substation corresponding territorially to approximately 3-4 small municipalities depending on their surface area.

Furthermore, renewable energy plants that were already in existence at the time of the Legislative Decree's enactment may also become part of the energy community if they do not exceed 30% of the total power output.

The market price is applied to all energy fed into the grid, thereby conferring a significant economic benefit on members of an energy community. This is achieved in a relatively short timeframe, with an estimated return on investment within a few years. This is intended to encourage energy sharing within the REC.

The configurations that are eligible for both the incentive tariff and the contribution for the valorisation of self-consumed electricity are as follows:

The categories of consumers include:

- **Remote self-consumer.**
- **Group of self-consumers.**
- **Renewable energy community (REC).**

The model of diffuse self-consumption and energy sharing is designated the 'virtual' regulatory model. It was developed by ARERA and allows for the valorisation of diffuse self-consumption without the necessity of new physical electrical connections, or new metering equipment.

The end customers organised in one of the configurations of diffuse self-consumption maintain their rights as end customers, including the right to choose their own supplier. They may withdrawal from the self-consumption configuration at any time without any agreed fees in the case of early withdrawal for the sharing of investments must be fair and proportionate. Finally, relations are regulated through a private law contract that considers the provisions and unambiguously identifies a party responsible for the distribution of shared energy. Participating end customers may also delegate to this party the management of payments and collection items towards sellers and the GSE.

Configurations of diffuse Self-consumption

These are the key features of the configurations defined by **TIAD** and **DM414/23[17]:**

	Individual 'remote' renewable energy self-consumer using the distribution network	**Group of self-consumers of renewable energy acting collectively**	**Renewable energy communities**
configurations	End customer and producing entity located within areas at the full disposal of the end customer	Set of end customers and/or producers located in the same building or condominium	Not-for-profit legal entity whose members are end customers and/or producers
plants	Renewable energy plants	Renewable energy plants	Renewable energy plants
Boundary of sharing	POD and plants in the same market area	POD and plants in the same building	POD and plants in the same market area
Boundary of incentive	POD and plants in the same primary substation	-	POD and plants in the same primary substation

Table 1: configuration of TIAD

Renewable energy community

A **Renewable Energy Community (REC)** is a legal entity empowered to produce, consume, store and share renewable energy among its members:

- which is based on open and voluntary participation, is autonomous and is effectively controlled by members who are in the nearby of renewable energy plants.

- whose shareholders or members are citizens, SMEs, territorial authorities and local authorities, including municipal governments, cooperatives, research bodies, religious bodies, third sector and environmental protection bodies.

- whose main objective is to provide environmental, economic or social benefits at community level to its shareholders or members or to the local areas in which it operates, rather than financial profits.

Incentivised Plants:

There are specific requirements for renewable plants to access the incentives of the decree CACER:

- belong to REC, Self-Consumption Group or Remote Self-Consumption configurations.
- be subtended by the same primary substation.
- have been realised through new construction or upgrading of existing plants.
- have a maximum power of 1MW.
- be commissioned from 16 December 2021, for RECs only, after the regular establishment of the Community.
- not be aimed at hydrogen projects resulting in greenhouse gas emissions exceeding 3 tonnes of CO2 equivalent per tonne of H2.
- comply with the requirements of the DNSH (Do No Significant Harm) principle, as further specified in the Rules.
- in the case of plants fuelled by biogas or biomass, comply with the criteria defined in the GSE Rules
- be built exclusively with newly constructed components if photovoltaic, while for plants other than photovoltaic the use of regenerated components is also envisaged.
- The production plants must be connected under the same primary substation to which the configuration refers.
- In the case of plants with a capacity greater than 1 MW, only the contribution for the valorisation of self-consumed electricity will be recognised.

Boundary of sharing

The boundary of sharing energy for the REC, is the perimeter of the **primary substation** available on the portal of GSE [21].

Primary substations, also known as primary cabins, play a crucial role in the electrical distribution network. They serve as key nodes where high-voltage electricity from transmission networks is transformed into medium voltage suitable for distribution to consumers. In the context of renewable energy sharing, the boundaries of energy distribution within primary substations are defined by their capacity to manage the flow of electricity generated from renewable sources like solar or wind. These substations ensure that the energy is efficiently routed and distributed within a specific geographic area, optimizing the use of locally generated renewable energy while maintaining grid stability. The sharing boundaries are limited to the area served by the primary substation, which acts as a hub, balancing supply and demand and integrating renewable energy into the grid.

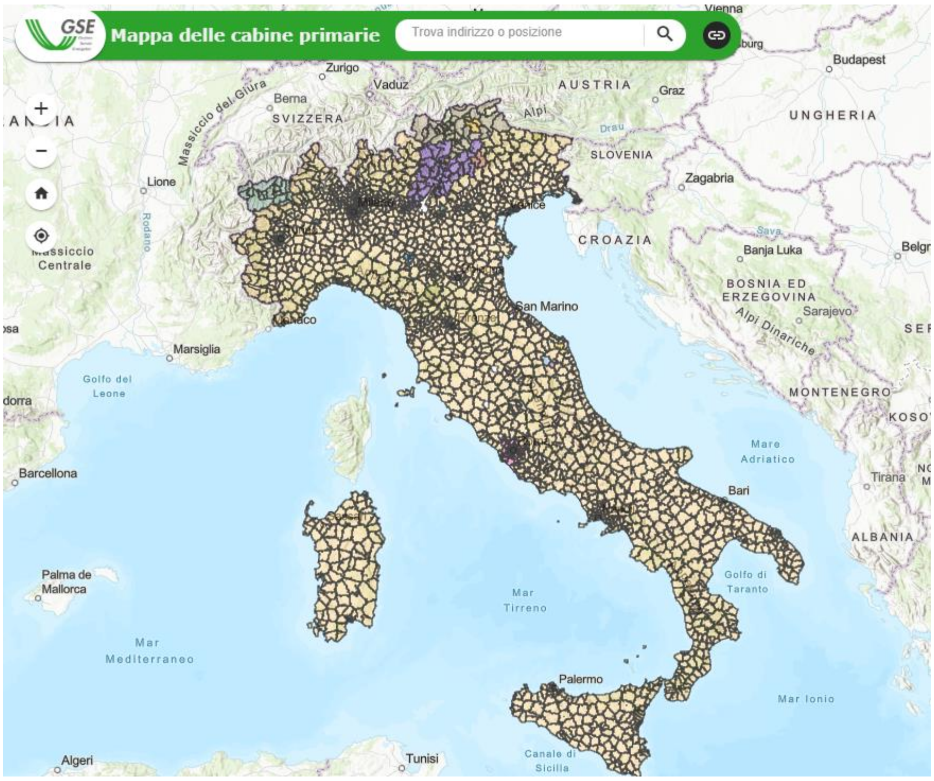


Figure 5: map of primary substation portal GSE.

Incentives and energy shared:

In the following Figure the aggregate load profile of the users of a REC is shown (i.e., the withdrawal of electricity from the grid by member users) together with the plants photovoltaic production. When the production and demand curves overlap, there is energy sharing within the REC. Finally, it is useful to remember that the REC represents a dynamic context to which a list of withdrawal (consumers) and/or input (producers/prosumers) PODs are associated. The hourly energy flows related to these PODs determine the shared energy within the energy community. This list may vary over time, with new members or recessions, and consequently the REC hourly withdrawal and production profiles may also vary, as well as the amount of shared energy created.

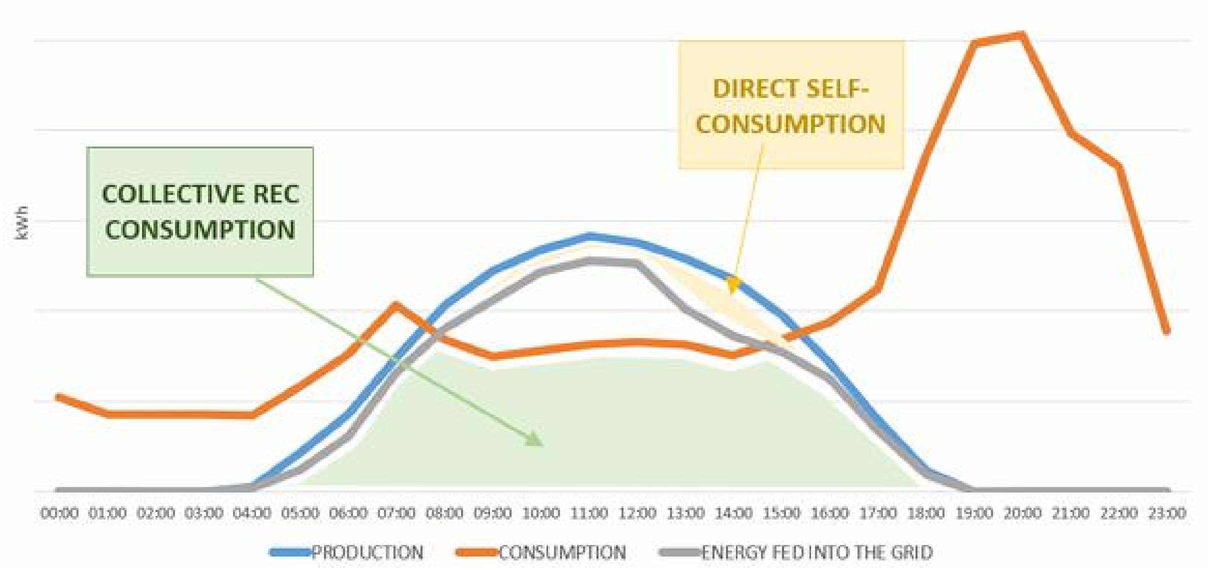


Figure 6:aggregate REC load profile with PV plants production.

The performance indicators to be monitored for a REC are:

- the percentage of **shared energy**, compared to the total energy produced by its RES plants (thus obtaining a % parameter of energy self-consumed in a shared and synchronous way).
- the overall share of **energy injected** into the grid and therefore self-produced compared to the total taken.
- the overall share of **energy withdrawn** from the grid.

To encourage the development of RECs, the Authority (**GSE**) provides for recognition of an incentive tariff made up of three main components:

1. refund of tariffs for avoided energy transport and distribution and energy sharing.

2. premium tariff linked to the quantity of shared energy.

3. dedicated withdrawal of the share of energy injected into the grid.

The MASE Decree draft regulates two types of economic benefits for those who intend to start a REC or CSC configuration:

- **Tariff incentive** is an incentive on the share of shared energy in REC and CSC configurations. To get this incentive the maximum nominal power of the single plant must not exceed 1 MW, and the plant must be part of the area beneath the same primary substation. The incentive is recognized as a premium rate from the date of entry into operation for a period of 20 years. The premium rate is made up of a fixed and a variable rate. Furthermore, for PV plants the rate is corrected depending on the geographical location (4 €/MWh extra in Central Italy and 10€/MWh extra in the North). The incentives can be combined with PNRR contributions but, in this case, the incentive is reduced with a maximum of 40% of PNRR contributions.

- **PNRR** contribution provide non-repayable contributions up to 40% of the eligible costs for the development of new renewable plants in RECs and CSC in municipalities with fewer than 5.000 inhabitants. PNRR resources are equal to 2,2 billion euros and expenses cover renewable plants only in municipalities with fewer than 5.000 inhabitants. GSE provides the benefit, dividing it into several instalments, according to the progress of the works.

Tariff incentive

Energy shared and consumed in the Renewable energy community generate the incentive tariff that varies depending on several factors such as plant size and location.

Size plant [kW]	Incentive [€/MWh]	Minimum Incentive Value [€/MWh]	Maximum Incentive value [€/MWh]
P < 200 kW	80 + max (0; 180 - Pz) €/MWh	80 €/MWh	120 €/MWh
200 kW < P < 600 kW	70 + max (0; 180 - Pz) €/MWh	70 €/MWh	110 €/MWh
P > 600 kW	60 + max (0; 180 - Pz) €/MWh	60 €/MWh	100 €/MWh

Table 2: premium tariff

The graph below shows the behaviour of the incentive tariff when the zonal price changes.

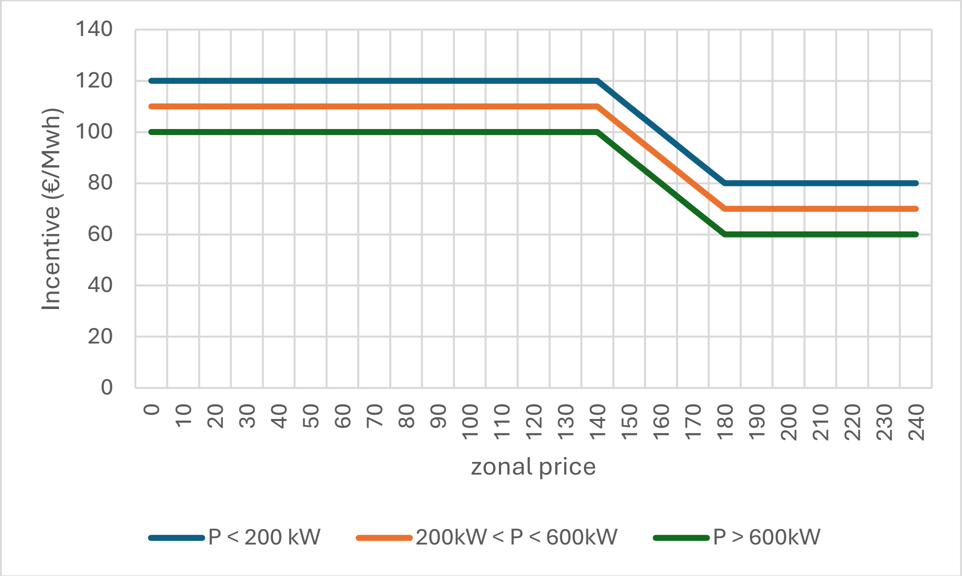


Figure 7: premium tariff/zonal price.

Additionally, to this value, in the case of photovoltaic plants there is a correction factor to consider the different levels of insolation related to the different geographical areas.

Region	**Correction factor**
Lazio, Marche, Toscana, Umbria, Abruzzo	4 [€/MWh]
Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardia, Piemonte, Trentino-Alto Adige, Valle d'Aosta, Veneto	10 [€/MWh]

Table 3:correction factor

In addition, a further contribution is made for the energy shared and consumed for avoided operating and transmission costs that correspond to 8/9€/MWh.

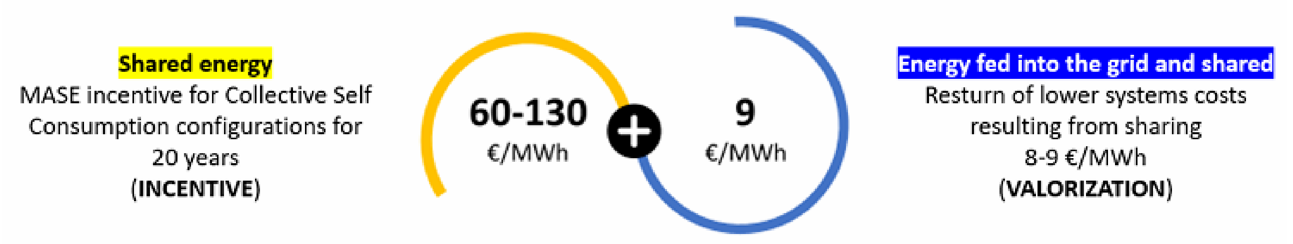


Figure 8:tariff incentive with the contribution for avoided contribution cost.

PNRR contribution:

The "Piano Nazionale di Ripresa e Resilienza" **(PNRR)** provides an important capital grant for the construction of renewable energy plants in RECs and CSC in municipalities with fewer than 5.000 inhabitants. The capital contribution from the **PNRR** is at its peak 40% of the costs incurred for the construction of RES plants, up to the following maximum eligible expenses and investment costs depending on the power size:

Plant size	PNRR maximum eligible costs
P < 20 kW	1.500 €/kW
20 kW < P < 200 kW	1.200 €/kW
200 kW < P < 600 kW	1.100 €/kW
600 kW < P < 1000 kW	1.050 €/kW

Table 4: PNRR ceilings

PNRR resources account for 2.2 billion € available until 30 June 2026 for the realisation of a total capacity of at least 2 GW.

The premium tariff can be reduced by half if it is fully utilised, i.e. covering 40% of the total investment.

The incentive tariff become:

$Incentive\ Tariff$ = Incentive Tariff (without reduction) *(1-(0.5*(perc. PNRR)/40%)

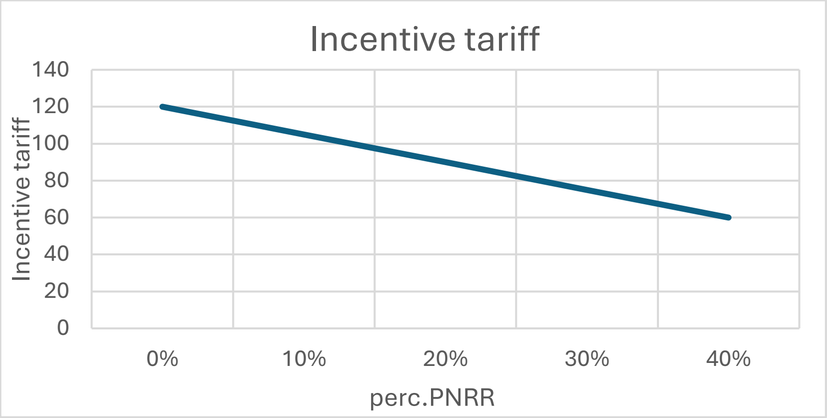


Figure 9: premium tariff with PNRR contribution.

Chapter 2: Case of study of Fossano

This thesis aims to examine the feasibility study of a Renewable Energy Community (**REC**) in the Fossano area, an innovative initiative promoted by Confartigianato Cuneo and commissioned to Environment Park S.p.A. The idea behind this project is to create a sustainable model of energy production and consumption that can not only reduce energy costs for participants, but also foster the transition to a low-carbon economy. This is in line with national and European sustainability development goals (**SDG**).

Renewable energy communities represent one of the most promising responses to the global challenges of climate change and energy sustainability. They are aggregations of citizens, businesses and local governments working together to produce, share and consume renewable energy collectively, maximizing self-consumption and minimizing grid losses. By sharing energy resources, RECs make it possible to optimize the use of renewable sources, such as photovoltaic, wind and biomass, and reduce dependence on fossil fuels.

The Fossano project fits into this innovative context, with the aim of exploring the feasibility of a Renewable Energy Community that can actively involve local actors, from families to small and medium-sized enterprises and public bodies. The role of Confartigianato Cuneo was crucial in identifying potential participants and promoting awareness of the benefits of participating in a REC, such as reduced energy bills and the possibility of generating new economic opportunities in the area.

Environment Park S.p.A., a leading company in the field of sustainable technological innovation, was commissioned to carry out the feasibility study. This study analyses several crucial aspects for the realization of the energy community: the analysis of the area's energy potential, the assessment of available renewable technologies, the design of participatory governance models, and the simulation of economic and environmental benefits.

This thesis, therefore, does not only present the results of a feasibility study, but also intends to offer a critical reflection on the role of energy communities in the future of the Italian energy system, highlighting how such initiatives can contribute to sustainable economic growth and greater equity.

Consumer type

Within the Renewable Energy Community (REC) of Fossano, consumers and producers/consumers (prosumers) play a crucial role, as they are the active participants in the production and consumption of renewable energy. In order to ensure optimal management, the participants were grouped together after a census, classified according to the intended use of the buildings, such as residential, commercial or various types of small industry. All the electricity bills of the buildings involved were analysed to verify consumption and identify energy habits.

The analysis begins with a census of all the buildings and craftsmen concerned located inside the primary substation (AC001E01062). All these buildings were classified according to their intended use:

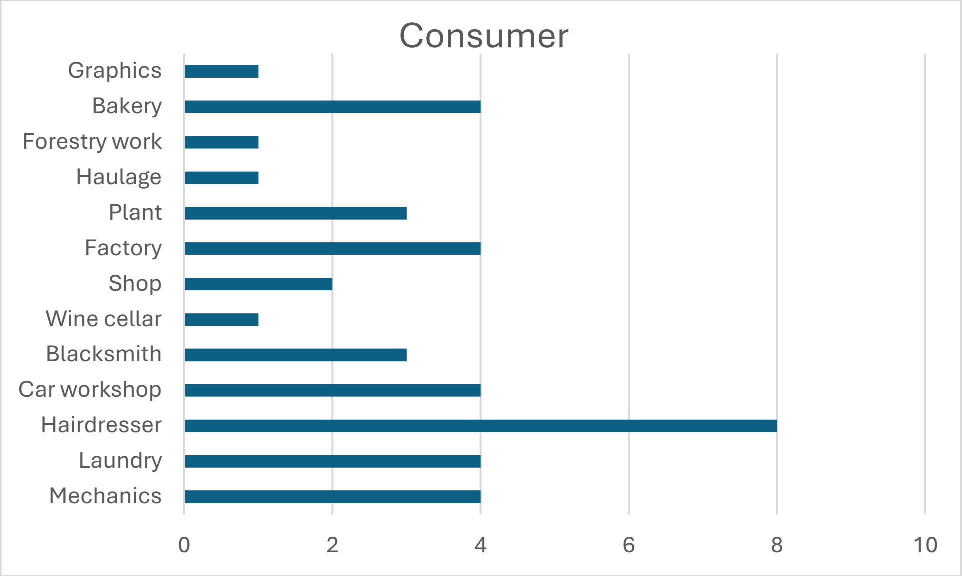
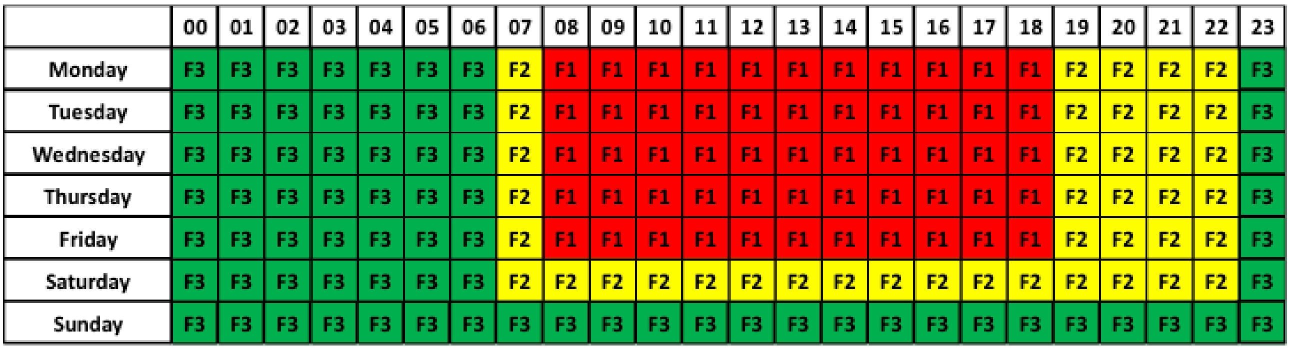


Figure 10:members of Confartigianato Cuneo

The meters installed for measuring electricity consumption, can detect the customer's consumption by distinguishing the time slot in which these occur. Even if a lot of these meters belongs to the second-generation (giving an hourly resolution of the energy consumed) all the operators, in electric bill, use the time slot division which leads to a less accurate analysis. The time slots, defined by ARERA, are periods of time to which different energy prices correspond, and they are divided in time slot as follows:



	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Monday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Tuesday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Wednesday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Thursday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Friday	F3	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3
Saturday	F3	F3	F3	F3	F3	F3	F3	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F3
Sunday	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3

Figure 11:hourly bands.

When comparing monthly electricity bills among consumers belonging to the same categories, it was observed that consumption was very similar, and a breakdown of monthly consumption by band is shown in Figures 12, 13, 14,15:

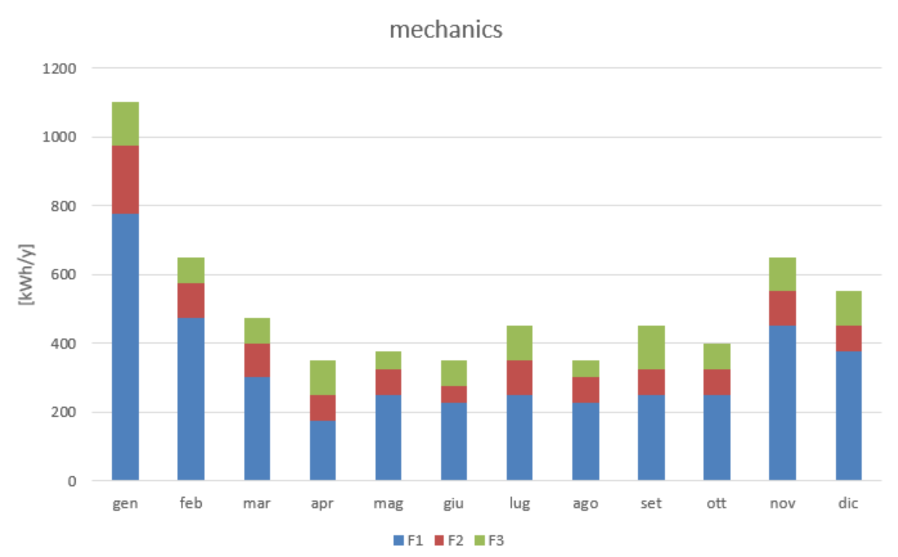


Figure 12:Mechanics monthly consume divided in bands.

Figure 13:hairdresser monthly consume divided in bands.

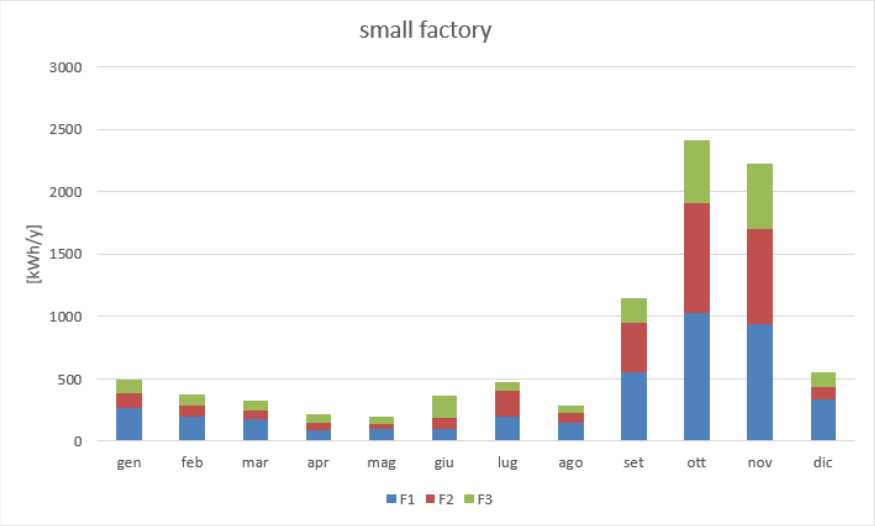


Figure 14: Small factory monthly consume divided in bands.

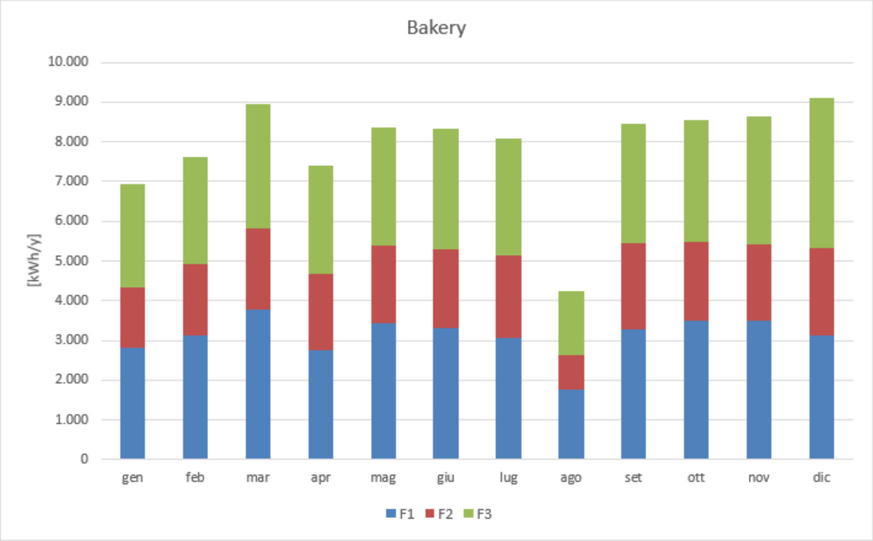


Figure 15: bakery monthly consume divided in bands.

It is evident from the analysis of the graphs that the distribution of consumption over the months depends on the intended use of the craft activities. For example, the bakery and confectionery sector has considerable consumption in the F3 band, which corresponds to night hours. Mechanical workshops, on the other hand, workday shifts corresponding to the F1 band. Hairdressers work particularly late afternoons, evenings and weekends and present considerable consumption in the F2 band. Finally, small factory has consumption very variable during the month of the year.

Consumption profiles

Once the consumption of the reference buildings recorded in the bills was defined, an hourly profile was reconstructed using normalised curves.

The normalised curves vary depending on the day and the specific use of the building. Each curve reflects distinct consumption patterns based on whether the building is used for different end use, as well as differences between weekdays, weekends, and holidays. By incorporating these differentiated curves, we were able to accurately recreate hourly consumption profiles tailored to both the building type and daily fluctuations, offering a more precise representation of energy demand across the year.

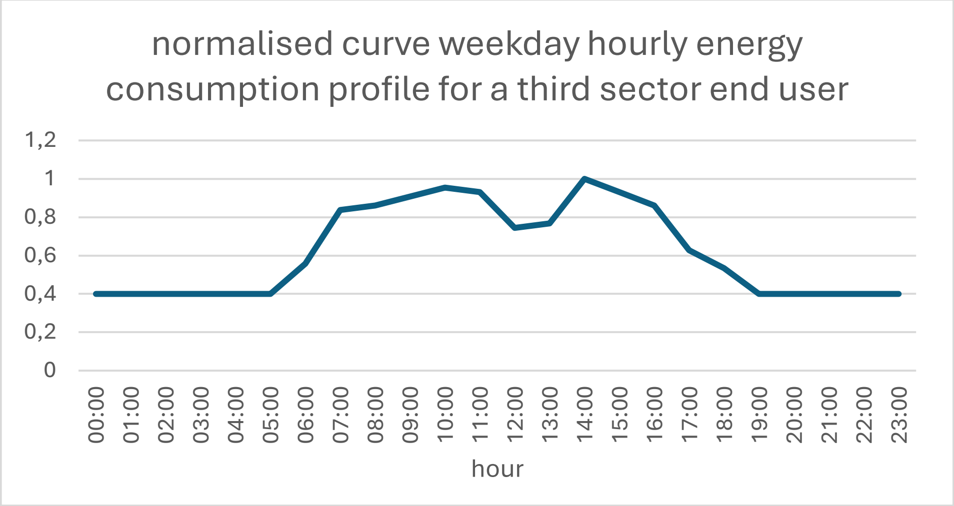


Figure 16: normalised curve for a working day generic third sector end user.

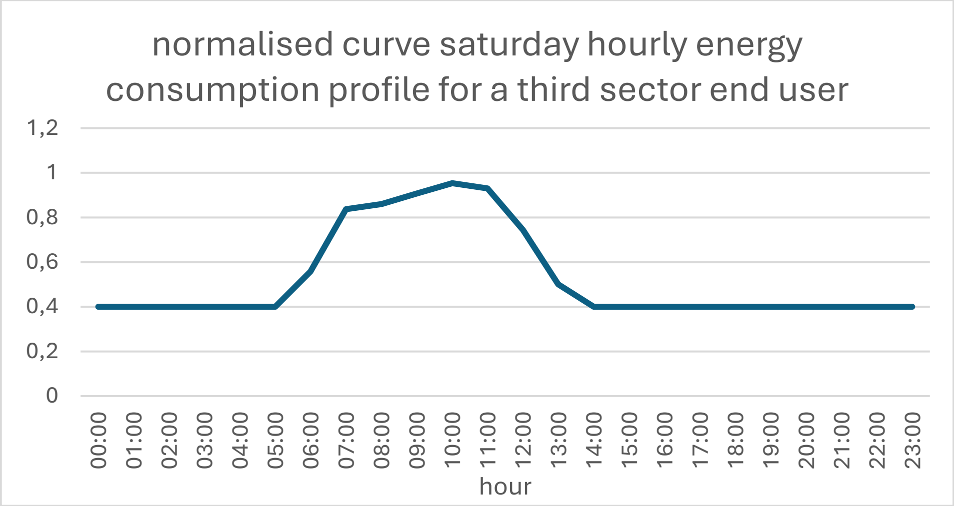


Figure 17: normalised curve for Saturday third sector end user.

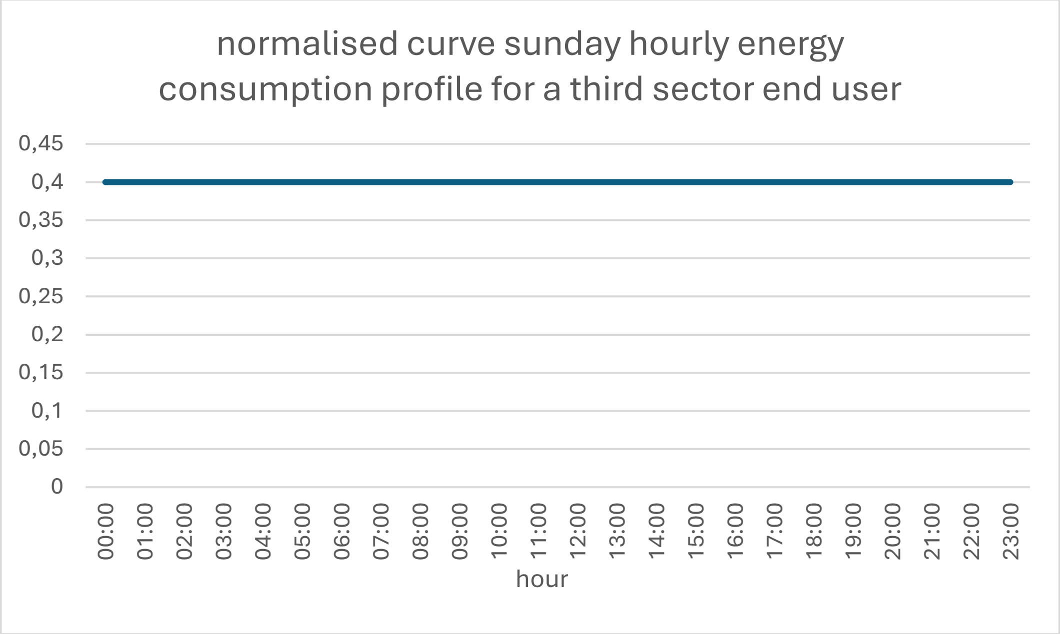


Figure 18:: normalised curve for Saturday third sector end user.

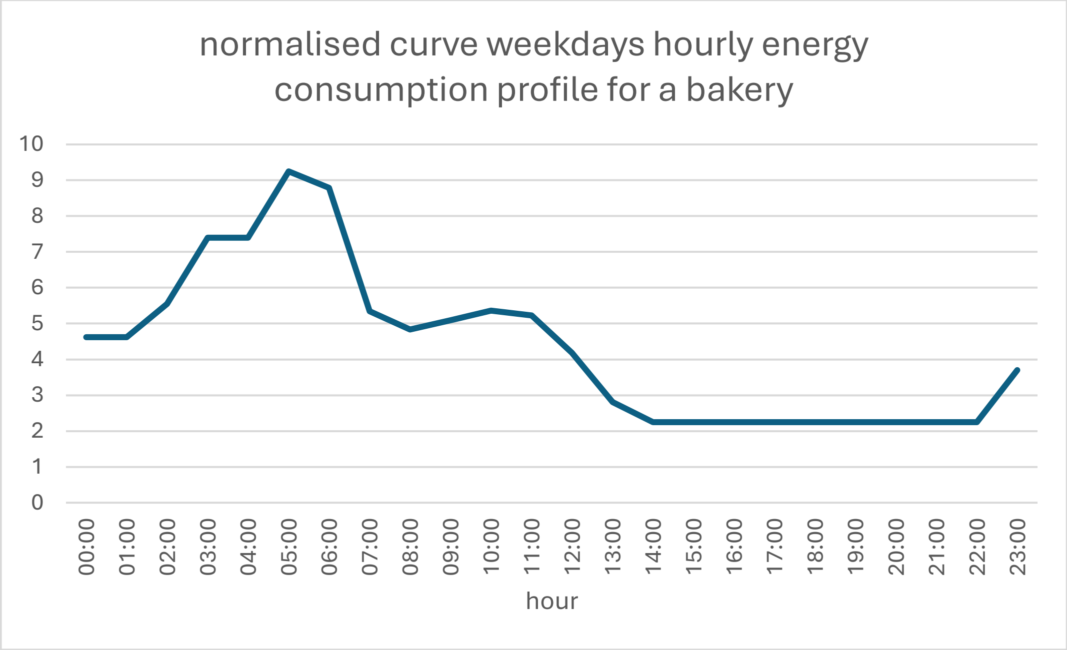


Figure 19:normalised curve working day for a bakery.

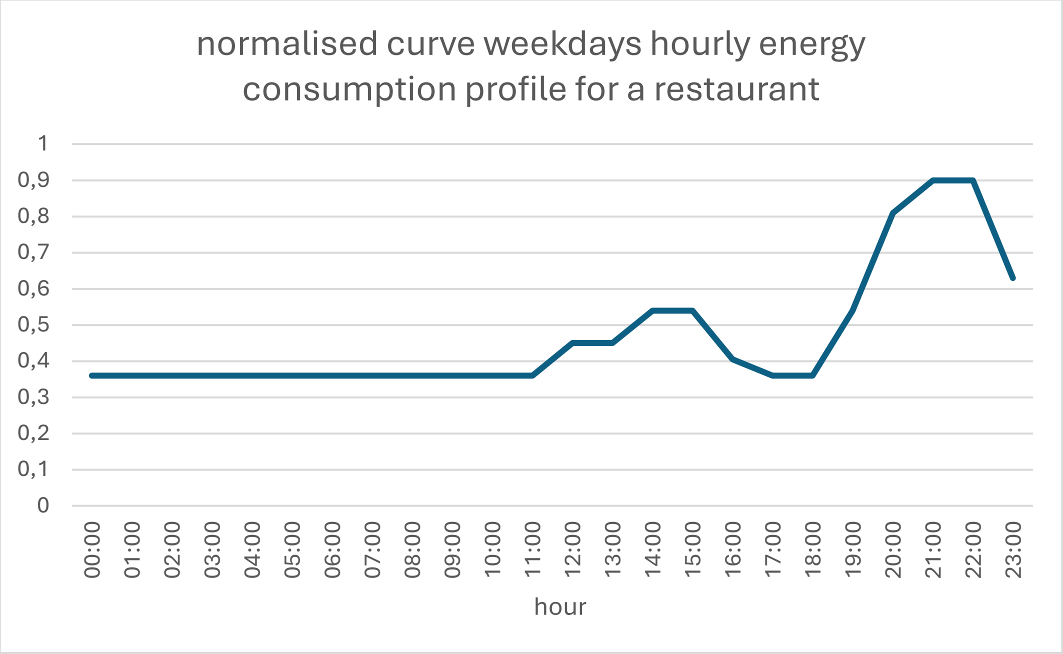


Figure 20:normalised curve for a working day in restaurant.

Another consumption profile analysed was that of Electric vehicles recharging infrastructure (profile available on the GSE website[22]):

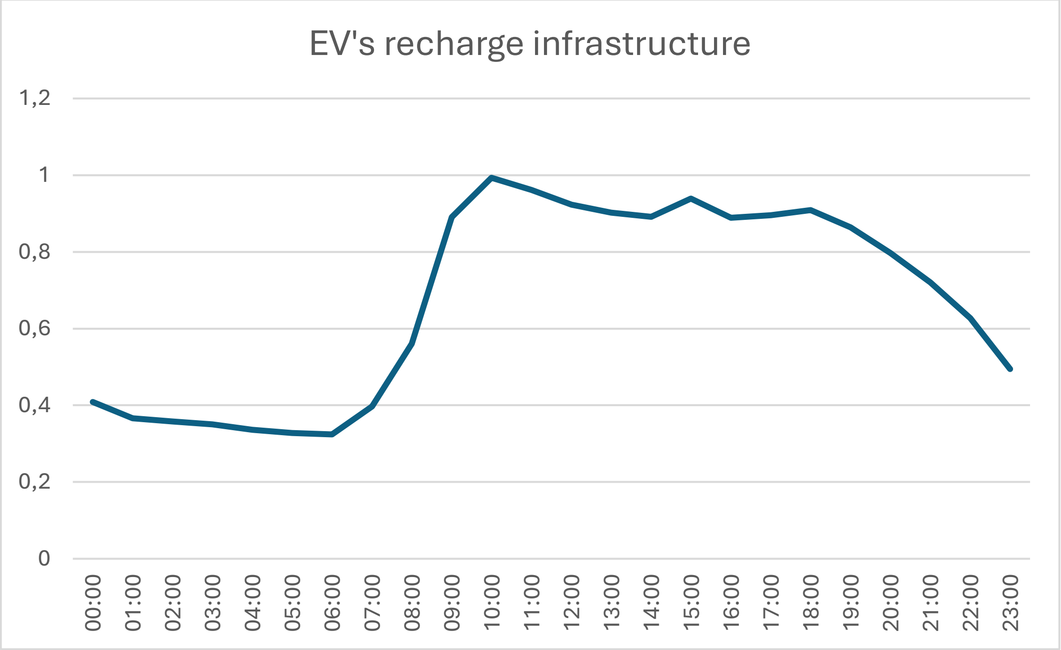


Figure 21: normalised curve of EV's recharge infrastructure.

The monthly consumption of the analysed buildings is therefore known divided by band and daily consumption profiles have been assumed. These two categories of information represent a constraint that must be respected in the reconstruction of hourly consumption for the typological year.

A normalised annual consumption pattern was then constructed with hourly resolution that respected the previously defined daily profiles.

At that point, the normalised values belonging to a given F-range were multiplied by a factor so that the sum of all consumption in that range and in a given month was equal to the known value (electric bill).

It was then verified that by satisfying the equality of the monthly consumption per band, the profiles retained an appropriate trend for the given usage class.

This procedure inevitably has a manual calibration component based on experience and knowledge of the various building types since only point values of monthly consumption divided by band are known.

The results that we obtained is a consumption value for every hour of the year and every day has a consumption profile similar to one of the previously described:

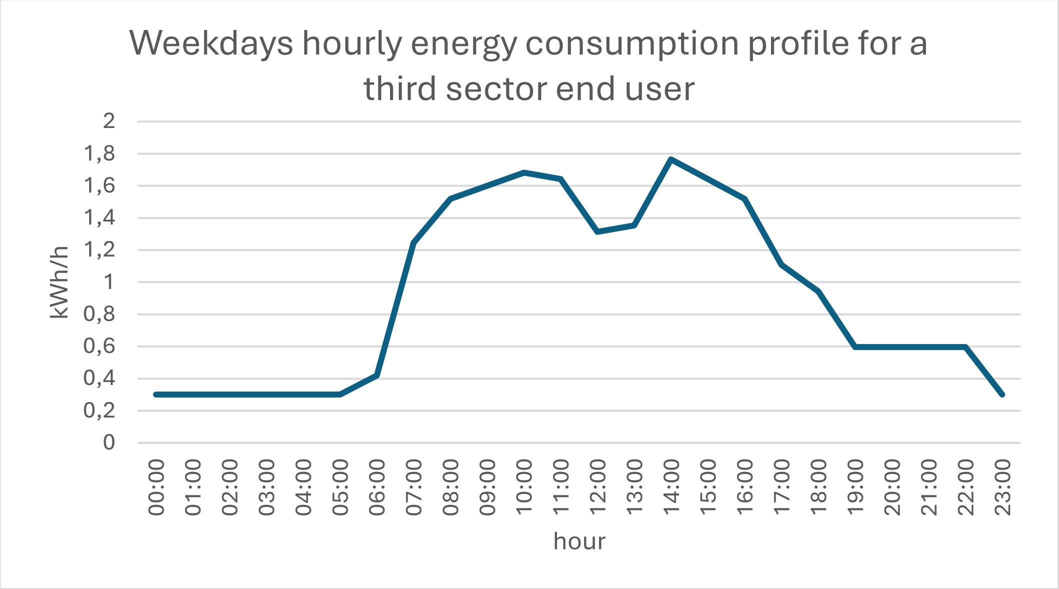


Figure 22:consumption curve for a generic day a third sector end user.

As an example, the daily profile of a weekday of a building has been shown. The factor satisfying the summation of the monthly consumption per bracket has already been applied to the normalised profile; the curve has retained a shape comparable to the normalised profile from which it started, and for this reason the hourly values can be considered validated and true.

The same methodology was applied for the various daily profiles of each building by performing a manual calibration.

Chapter 3: REC Fossano evaluation

Methodological approach

Prior to undertaking the analysis, it is necessary to undertake a preparatory activity involving the collection and preprocessing of the essential data. The methodological approach is described in the following figure.

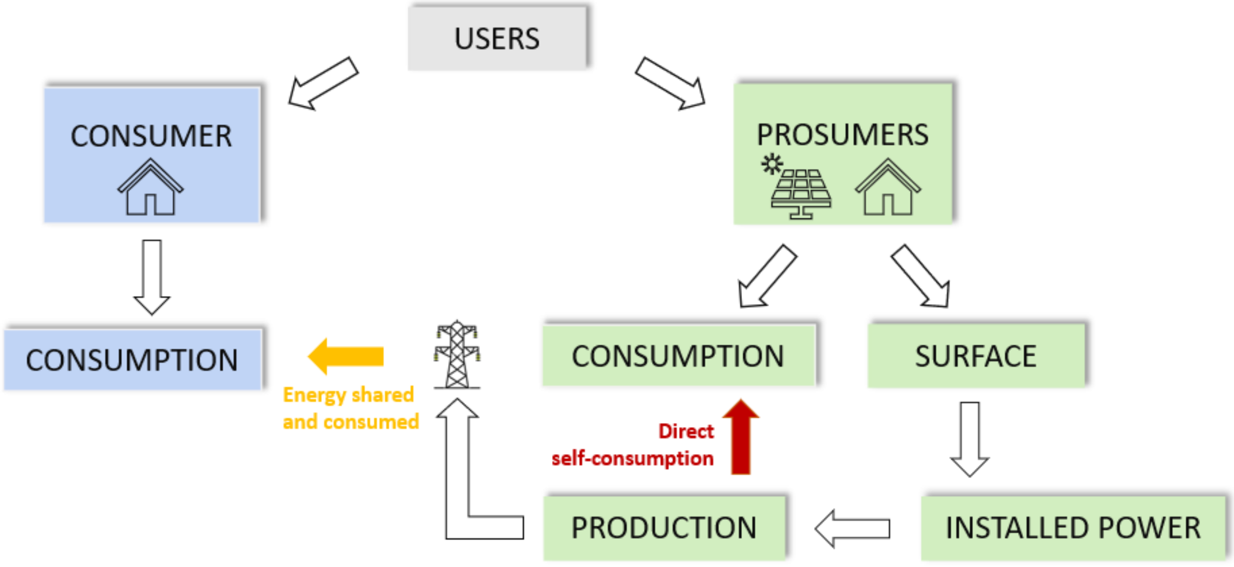


Figure 23: explanatory diagram of REC (graphics by Mimi)

The methodological approach followed some basic step:

1. **Initial census:**

- First fundamental step: take a census of Confartigianato Cuneo members interested in the REC project.
- Verification that the POD of the interested user belonged to the primary substation in Fossano.

2. **Identification of prosumers:**

- Second step: having identified the users, the availability of surface area for the installation of photovoltaic panels was verified.
- The users with available surface area became the so-called prosumers.

3. **Photovoltaic system simulation:**

- For prosumers, the installation of a photovoltaic system was simulated.
- The hourly producibility of the system was calculated.

4. **Production-consumption comparison:**

- The hourly producibility was compared with the previously described hourly consumption curve.
- This comparison allowed the direct self-consumption to be calculated.

5. **Excess energy:**

- The excess energy produced is fed into the grid.
- Concurrently, a REC consumer extracts energy from the grid, thereby triggering the application of the feed-in tariff.

Step 1 & 2:

The outcome of the census is:

CODE	POD	ROLE
FOS 2	IT001E00440908	prosumer
FOS 3	IT001E05366785	consumer
FOS 4	IT001E05366940	consumer
FOS 5	IT001E01252420	prosumer
FOS 6	IT001E00344586	prosumer
FOS 7	IT001E06361433	prosumer
FOS 8	IT001E04704394	prosumer
FOS 9	IT001E00504063	prosumer
FOS 10	IT001E00528633	consumer
FOS 11	IT001E05364591	prosumer
FOS 12	IT001E00402329	consumer
FOS 13	IT001E04704405	prosumer
FOS 14	IT001E02443486	prosumer
FOS 15	IT001E05327537	consumer
FOS 16	IT001E00520241	prosumer
FOS 17	IT001E05326904	prosumer
FOS 18	IT001E04464748	prosumer
FOS 19	IT001E02227568	prosumer
FOS 20	IT001E10121322	consumer

FOS 21	IT001E05366205	prosumer
FOS 22	IT001E05366316	consumer
FOS 23	IT001E04156049	prosumer
FOS 24	IT001E02648667	prosumer
FOS 25	IT001E05374133	consumer
FOS 26	IT001E05368284	consumer
FOS 27	IT001E00435368	prosumer
FOS 28	IT001E04704356	prosumer
FOS 29	IT001E02560937	prosumer
FOS 30	IT001E04297402	consumer
FOS 31	IT001E05366949	prosumer
FOS 32	IT001E04761188	prosumer
FOS 33	IT001E04016086	consumer
FOS 34	IT001E04399909	consumer
FOS 35	IT001E05369978	consumer
FOS 36	IT001E04399889	prosumer
FOS 37	IT001E02595920	prosumer
FOS 38	IT001E04399906	consumer
FOS 39	IT001E04177028	prosumer
FOS 40	IT001E04704312	prosumer
FOS 41	IT001E01281209	consumer

Table 5: Confartigianato Cuneo members

For all these buildings, it was verified that the corresponding POD belonged to the primary AC001E01062 substation:

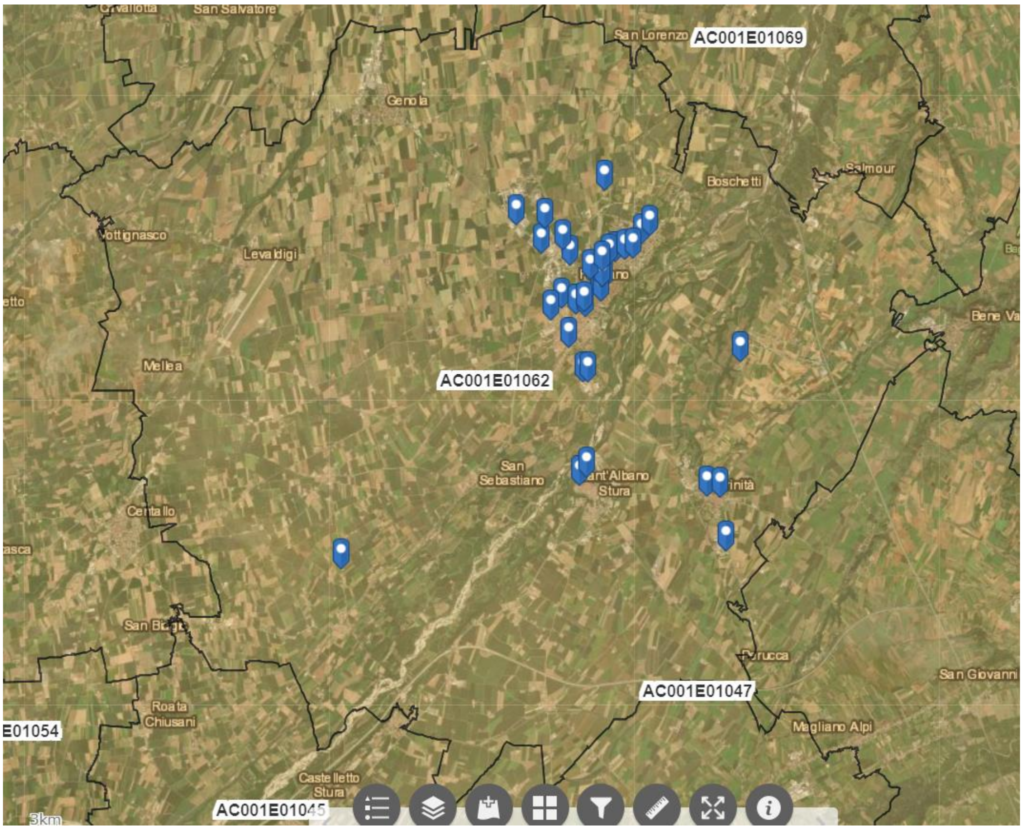


Figure 24: primary substation AC001E01062 and location of buildings.

Production profiles

Step 3 & 4:

For this case of study, the only Renewable energy plant considered is the solar photovoltaic plant.

The producibility of photovoltaic systems for each hour of the year was obtained through the use of the PVGis (Photovoltaic Geographical Information System) Tool, which provides information on radiation and producibility for each location in Europe and Africa

The input data required by the PV GIS Tool are:

- Latitude and Longitude of the plant: calculated directly by PV GIS after locating the building on the map provided by the Tool.
- Solar radiation: calculated directly by PV GIS based on geographical coordinates.
- Photovoltaic technology: mainly monocrystalline silicon photovoltaic modules were considered, apart from possible curved roofs where thin-film technology was selected that can be more easily integrated into roofs of this type.

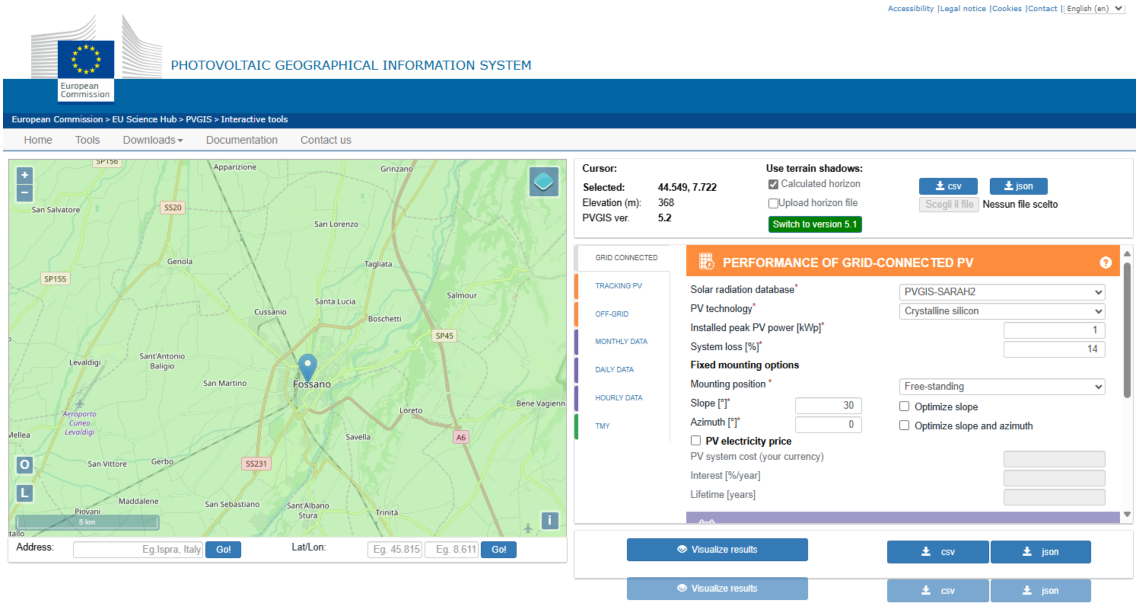
- Plant power: the plant power was calculated for each building based on the available roof area using the following formula $P_{peak}=S_{PV} * P'_{peak}$

Where:

- P_{peak}: peak power of the plant
- S_{PV}: Surface available for plant installation (m2)
- P'_{peak}: plant peak power per unit area = 0.18 (kW/m2)

The available area was calculated using Google Earth

- System losses that reduce the energy produced by the system (e.g. due to losses in cables, inverters, dirt accumulated on the modules, etc.) = 14%.
- Mounting system: for buildings with pitched roofs the system of integrating the modules into the roof covering of the building was chosen, for buildings with flat roofs the option chosen was the support structure.
- Inclination: in the case of buildings with pitched roofs the indicated inclination was 30° in the case of flat roofs the optimized solution was chosen (almost 40° for that latitude)
- Azimuth: the angle of the photovoltaic modules with respect to the south was defined on the basis of the orientation of the roof pitches where inclined, in the case of flat roofs the orientation indicated was South (0°, optimal one)



Cursor:
Selected: **44.549, 7.722**
Elevation (m): 368
PVGIS ver. **5.2**

Use terrain shadows:
☑ Calculated horizon
☐ Upload horizon file
Nessun file scelto

PERFORMANCE OF GRID-CONNECTED PV

Solar radiation database*: PVGIS-SARAH2
PV technology*: Crystalline silicon
Installed peak PV power [kWp]*: 1
System loss [%]*: 14

Fixed mounting options

Mounting position *: Free-standing
Slope [°]*: 30 ☐ Optimize slope
Azimuth [°]*: 0 ☐ Optimize slope and azimuth
☐ **PV electricity price**
PV system cost (your currency)
Interest [%/year]
Lifetime [years]

Figure 25: PV GIS interface simulation photovoltaic solar plants.

The following is a summary table of prosumers:

Prosumer				
CODE	Available Surface (m^2)	Orientation	Power (kWp)	Annual production (kWh)
FOS 2	544	E - W	98	106.786
FOS 5	170	SE	31	37.784
FOS 6	563	SW - NE - SSW	101	118.029
FOS 7	221	SSW	40	47.465
FOS 8	112	SW - NE	20	22.307
FOS 9	54	S	10	11.662
FOS 11	392	E - W	71	76.949
FOS 13	482	SE	87	101.294
FOS 14	552	SE - SW -NE	99	112.208
FOS 16	80	E	14	15.689
FOS 17	672	SE - NW	121	131.645
FOS 18	770	SE - NW	139	150.843
FOS 19	262	SW - NE	47	51.435
FOS 21	70	W	13	13.754
FOS 23	896	SW - NE	161	175.632
FOS 24	20	S	4	4.327
FOS 27	536	SE - NW	97	105.002
FOS 28	55	W	10	10.846
FOS 29	21	SW	4	4.426
FOS 31	224	SE - NW	40	43.882
FOS 32	137	SSW	25	29.408
FOS 36	294	E - W	53	57.711
FOS 37	440	SE	79	97.794
FOS 39	336	S - N	60	65.724
FOS 40	132	E - W - S	24	26.226
TOT			**1.448**	**1.618.826**

Table 6: prosumer production

First scenario: Maximum power installed.

Energy analysis

In the feasibility study different scenario has been analysed. The first scenario concerns a REC configuration in which PV systems are implemented on the entire available surface area of prosumer buildings (mostly roofs). By analysing the behaviour of each prosumer individually, focusing on their hourly production and consumption curves throughout the entire year, the following graphs shows the behaviour of the two curves in 2 random days one in summer and the other in winter.

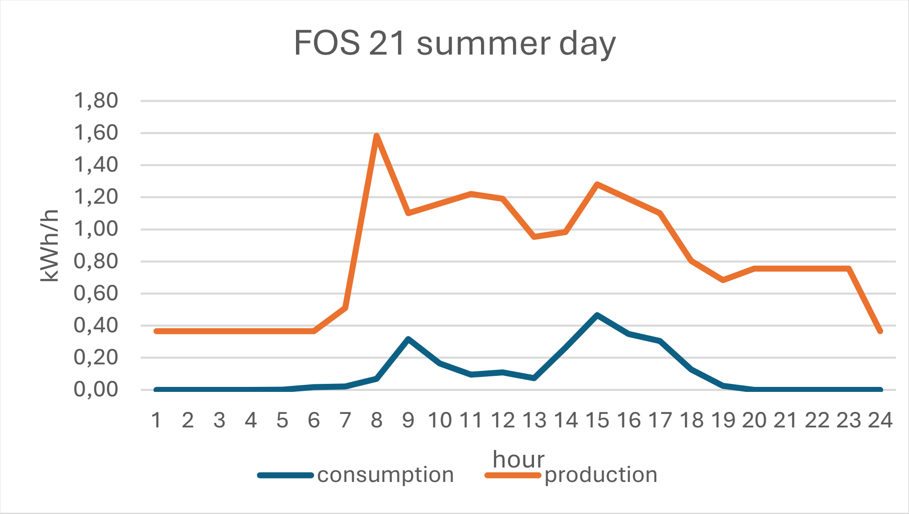


Figure 26: behaviour of consumption-production curve summer day

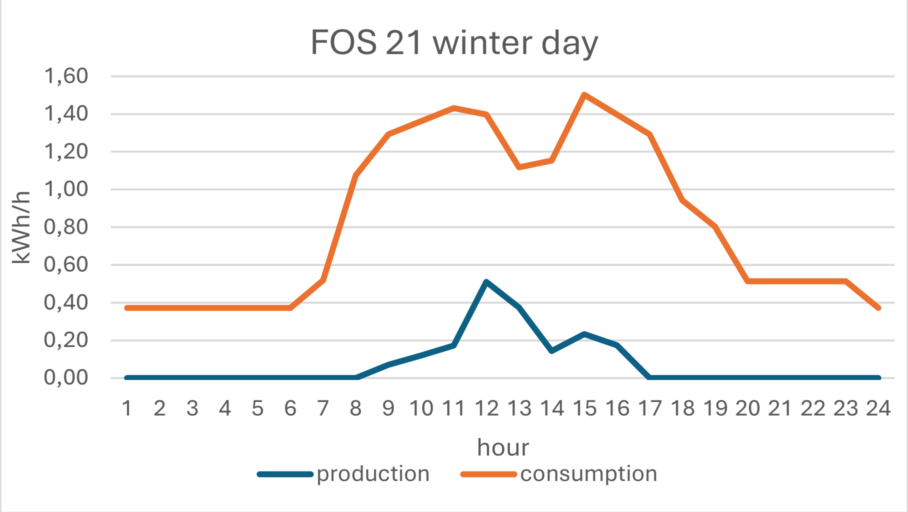


Figure 27: behaviour of consumption-production curve winter day.

The combination of the results of the analysis of hourly consumption with those of the producibility of the installable photovoltaic systems (where possible) made it possible to estimate the value of energy produced, directly self-consumed within individual buildings and that fed into the grid. The prosumers are listed below, indicating both energy self-sufficiency, which corresponds to the energy consumed by the prosumer from its own photovoltaic system, and self-consumption, i.e. the ratio between the energy consumed by the prosumer and the energy produced. The greater the self-sufficiency percentage, the higher the discount on the bill for the prosumer, while self-consumption highlights the efficiency of the system in relation to direct self-consumption; in general, the higher this percentage, the faster the return on investment. The respective percentage values of self-sufficiency and self-consumption are shown below for each building:

FOSSANO							
Prosumer							
CODE	Power (kWp)	Annual consumption (kWh)	Annual production (kWh)	Energy direct self-consumed (kWh)	Energy injected grid (kWh)	Self-sufficiency %	Self-consumption %
FOS 2	98	6.186	106.786	4.211	102.575	68,1%	3,9%
FOS 5	31	22.452	37.784	12.057	25.727	53,7%	31,9%
FOS 6	101	3.635	118.029	2.673	115.356	73,5%	2,3%
FOS 7	40	3.801	47.465	1.321	46.144	34,7%	2,8%
FOS 8	20	2.518	22.307	1.075	21.233	42,7%	4,8%
FOS 9	10	7.132	11.662	4.181	7.481	58,6%	35,9%
FOS 11	71	8.005	76.949	5.037	71.912	62,9%	6,5%
FOS 13	87	2.079	101.294	1.585	99.709	76,3%	1,6%
FOS 14	99	4.955	112.208	2.768	109.441	55,9%	2,5%
FOS 16	14	5.502	15.689	2.103	13.586	38,2%	13,4%
FOS 17	121	3.001	131.645	2.242	129.403	74,7%	1,7%
FOS 18	139	53.420	150.843	38.292	112.552	71,7%	25,4%
FOS 19	47	2.232	51.435	1.000	50.435	44,8%	1,9%
FOS 21	13	6.286	13.754	3.513	10.241	55,9%	25,5%
FOS 23	161	5.003	175.632	3.850	171.782	76,9%	2,2%
FOS 24	4	6.267	4.327	2.962	1.365	47,3%	68,5%
FOS 27	97	3.801	105.002	2.509	102.493	66,0%	2,4%
FOS 28	10	95.180	10.846	10.811	35	11,4%	99,7%

FOS 29	4	37.064	4.426	4.426	0	11,9%	100,0%
FOS 31	40	2.568	43.882	1.345	42.536	52,4%	3,1%
FOS 32	25	3.557	29.408	2.217	27.191	62,3%	7,5%
FOS 36	53	10.063	57.711	5.966	51.746	59,3%	10,3%
FOS 37	79	21.149	97.794	12.691	85.103	60,0%	13,0%
FOS 39	60	63.024	65.724	28.005	37.719	44,4%	42,6%
FOS 40	24	5.498	26.226	4.308	21.918	78,4%	16,4%
TOTAL	**1.448**	**384.378**	**1.618.826**	**161.146**	**1.457.680**		

Table 7: Scenario maximum power energy value and indices

All this value has been obtained as follows:

Annual consumption:

$$E_{cons} = \sum_{i=1}^{12} E_{i,monthly}$$

Where $E_{i,monthly}$ is the sum of the energy monthly consumed indicated in the electric bill.

Annual production:

$$E_{prod} = \sum_{i=1}^{8760} E_{i,hourly}$$

Where:

$E_{i,hourly}$ is the hourly energy produced by every plant in every hour of the year.

E_{prod} is the energy produced during all the year by the PV plant.

Energy direct self-consumed:

$$E_{sc} = \sum_{i=1}^{8760} if(E_{i,prod} > E_{i,cons}: E_{i,cons}, E_{i,prod})$$

Where:

E_{sc} is Energy produced by the prosumer and then self-consumed (analysis made for every hour of the year).

Energy injected grid:

$$E_{inj} = \sum_{i=1}^{8760} max\left(E_{i,prod} - E_{i,cons}, 0\right)$$

Where:

E_{inj} is the surplus of energy produced injected in the grid (analysis made for every hour of the year).

Self-sufficiency index:

$$SSi = \frac{E_{sc}}{E_{cons}} * 100$$

Where:

SSi self-sufficiency index is the percentage between the energy self-consumed (E_{sc}) over the consumption (E_{cons}).

Self-consumption index:

$$SCi = \frac{E_{sc}}{E_{prod}} * 100$$

Where:

SCi self-sufficiency index is the percentage between the energy self-consumed (E_{sc}) over the production (E_{prod}).

In order to optimise a REC configuration in which the self-consumed and incentivised energy constitutes a minimum of 80 per cent of the energy fed in, it is necessary to envisage other end consumers situated below the same primary substation joining the REC. In this scenario, the end consumer assumed to be connected is the household.

The summary tables are presented below for reference.

FOSSANO		
Energy injected (kWh)	**Energy self-consumed (kWh)**	**Percentage energy self-consumed in REC**
1.457.680	**1.137.902**	**78,1%**
PROSUMER (CODE)	**Power PV**	**Energy injected (kWh)**
FOS 2	98	102.575
FOS 5	31	25.727
FOS 6	101	115.356
FOS 7	40	46.144
FOS 8	20	21.233
FOS 9	10	7.481
FOS 11	71	71.912

FOS 13	87	99.709
FOS 14	99	109.441
FOS 16	14	13.586
FOS 17	121	129.403
FOS 18	139	112.552
FOS 19	47	50.435
FOS 21	13	10.241
FOS 23	161	171.782
FOS 24	4	1.365
FOS 27	97	102.493
FOS 28	10	35
FOS 29	4	0
FOS 31	40	42.536
FOS 32	25	27.191
FOS 36	53	51.746
FOS 37	79	85.103
FOS 39	60	37.719
FOS 40	24	21.918

CONSUMER CONFART (CODE)	Total consumption (kWh)
FOS 2	1.975
FOS 3	7.197
FOS 4	1.887
FOS 5	10.394
FOS 6	962
FOS 7	798
FOS 8	1.444
FOS 9	2.951
FOS 10	1.453
FOS 11	2.968
FOS 12	21.163
FOS 13	494
FOS 14	2.187
FOS 15	1.531

FOS 16	3.400
FOS 17	759
FOS 18	15.128
FOS 19	1.233
FOS 20	4.183
FOS 21	2.773
FOS 22	2.337
FOS 23	1.154
FOS 24	3.304
FOS 25	1.395
FOS 26	9.110
FOS 27	1.292
FOS 28	84.369
FOS 29	32.639
FOS 30	5.165
FOS 31	1.223
FOS 32	1.339
FOS 33	20.916
FOS 34	4.748
FOS 35	2.322
FOS 36	4.097
FOS 37	8.458
FOS 38	4.660
FOS 39	35.019
FOS 40	1.189
FOS 41	4.417
TOTALE	**314.033**
HOUSEHOLD CONSUMER	**Total consumption (kWh)**
1.674	**6.030.432**
TOTAL	**6.344.466**

Table 8: Scenario maximum power summary

Second scenario: optimized power installed.

Optimization method

The objective of the optimisation method is to ascertain the optimal plant size for each prosumer. An energy optimisation process was conducted to ascertain the optimal plant size in accordance with the consumption patterns of each prosumer. This optimisation was based on two key indices previously discussed: **SSi** (self-sufficiency index) and **SCi** (self-consumption index). The process entailed an analysis of how these indices vary with changes in plant size, with the objective of identifying the most efficient configuration. The resulting curves are presented below:

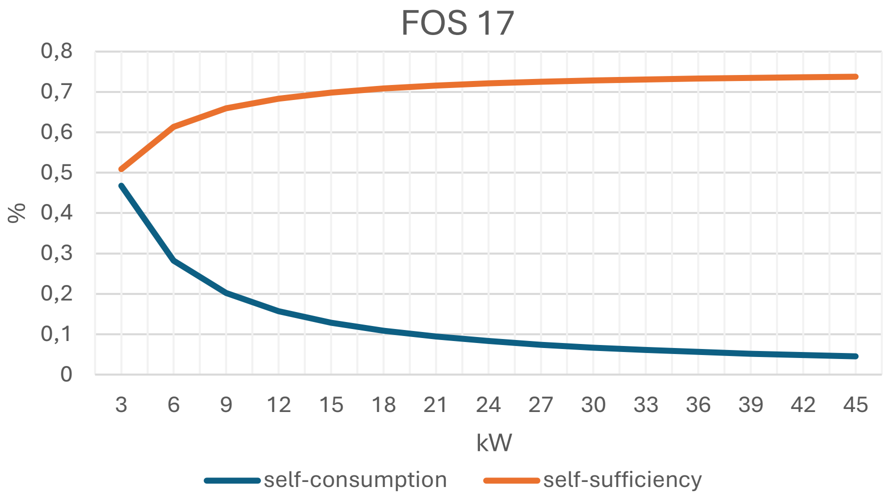


Figure 28: variation of curves self-consumption self-sufficiency with respect to plant size.

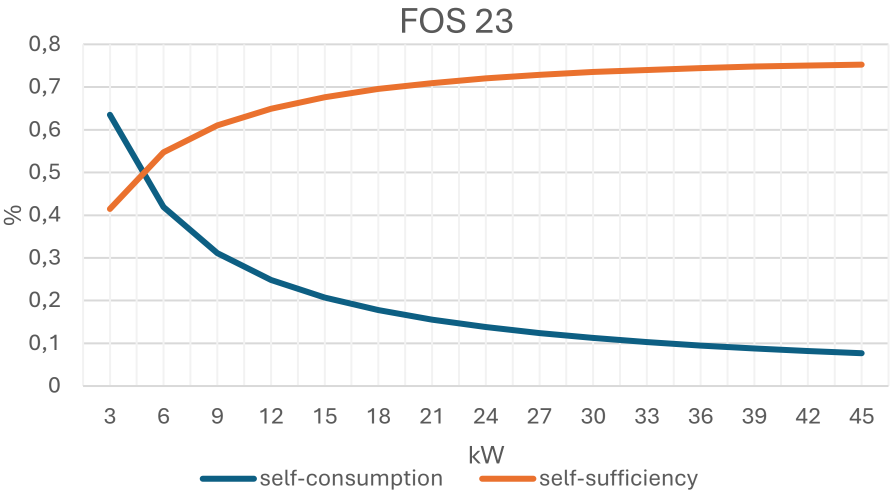


Figure 29:variation of curves self-consumption self-sufficiency with respect to plant size.

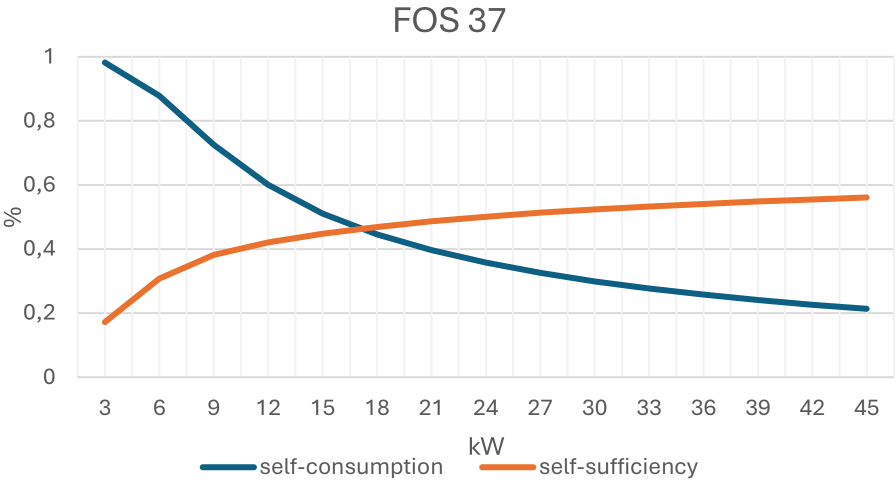


Figure 30:variation of curves self-consumption self-sufficiency with respect to plant size.

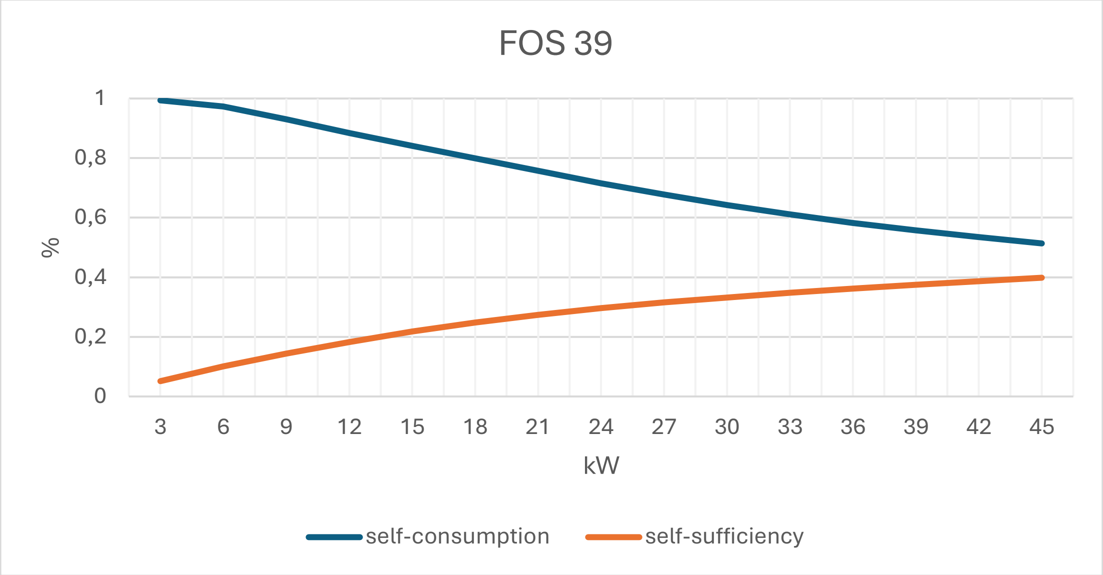


Figure 31: variation of curves self-consumption self-sufficiency with respect to plant size.

For all the possible prosumers this analysis has been performed, understanding how the behaviour of the two indices curve, the range of variation of plant size was defined by a minimum of 3 kW and a maximum equal to the maximum power installable computed in the scenario analysed before.

The optimal size for the energetic optimization is the intersection between the two curves because is the point that represent a size of the plant coherent with the real consumption of the possible prosumer. if the two curves never intersect, the optimised size is chosen:

- the maximum installable for each prosumer if the self-consumption curve always remains higher than the self-sufficiency curve.
- the minimum installable (3 kW one of the smallest sizes for PV plants) if the self-consumption curve always remains above the self-sufficiency curve.

After that analysis performed for every prosumer, the following table has been obtained.

PROSUMER							
CODE	**Power (kWp)**	**Annual consumption (kWh)**	**Annual production (kWh)**	**Energy direct self-consumed (kWh)**	**Energy injected grid (kWh)**	**Self-sufficiency %**	**Self-consumption %**
FOS 2	6	6.186	6.303	2.808	3.496	45,39%	44,54%
FOS 5	18	22.452	22.477	10.544	11.932	46,97%	46,91%

FOS 6	3	3.635	3.727	1.941	1.786	53,40%	52,08%
FOS 7	3	3.801	3.583	1.110	2.473	52,36%	30,97%
FOS 8	3	2.518	3.320	835	2.485	33,14%	25,14%
FOS 9	6	7.132	7.159	3.752	3.407	52,61%	52,41%
FOS 11	8	8.005	8.229	3.636	4.593	45,43%	44,19%
FOS 13	3	2.079	3.505	1.174	2.331	56,49%	33,50%
FOS 14	5	4.955	5.344	1.975	3.369	39,87%	36,96%
FOS 16	5	5.502	5.777	1.653	4.124	30,04%	28,61%
FOS17	3	3.001	3.265	1.527	1.738	50,89%	46,78%
FOS 18	49	53.420	53.448	29.526	23.922	55,27%	55,24%
FOS 19	3	2.232	3.267	832	2.435	37,25%	25,45%
FOS 21	6	6.286	6.377	3.021	3.356	48,06%	47,38%
FOS 23	5	5.003	5.332	2.565	2.767	51,26%	48,10%
FOS 24	3	6.267	3.606	2.725	881	43,48%	75,57%
FOS 27	4	3.801	4.088	1.959	2.130	51,53%	47,91%
FOS 28	10	95.180	10.807	10.773	34	11,32%	99,69%
FOS 29	4	37.064	4.449	4.449	0	12,00%	100,00%
FOS 31	3	2.568	3.265	1.006	2.259	39,18%	30,82%
FOS 32	3	3.557	3.537	1.662	1.875	46,73%	46,98%
FOS 36	9	10.063	10.115	4.565	5.550	45,37%	45,13%
FOS 37	17	21.149	21.250	9.800	11.450	46,34%	46,12%
FOS 39	58	63.024	63.048	270619	35.429	43,82%	43,81%
FOS 40	5	5.498	5.750	3.110	2.640	56,57%	54,08%
TOTAL	**242**	**384.378**	**271.029**	**134.566**	**136.463**		

Table 9: Scenario optimised power energetic indices

As seen in the previous Scenario, to optimise a REC configuration in which the self-consumed and incentivised energy is at least 80 per cent of the energy fed in, it is necessary to envisage other end consumers below the same primary substation joining the REC. The type of end consumer assumed in this scenario is households.

The summary tables are shown below:

FOSSANO		
Energy injected (kWh)	**Energy self-consumed (kWh)**	**Percentage energy self-consumed in REC**
136.463	**109.305**	**80.10%**
PROSUMER (CODE)	**POWER PV**	**Energy injected (kWh)**
FOS 2	6	3.496
FOS 5	18	11.932
FOS 6	3	1.786
FOS 7	3	2.473
FOS 8	3	2.485
FOS 9	6	3.407
FOS 11	8	4.593
FOS 13	3	2.331
FOS 14	5	3.369
FOS 16	5	4.124
FOS 17	3	1.738
FOS 18	49	23.922
FOS 19	3	2.435
FOS 21	6	3.356
FOS 23	5	2.767
FOS 24	3	881
FOS 27	4	2.130
FOS 28	10	34
FOS 29	4	0
FOS 31	3	2.259
FOS 32	3	1.875
FOS 36	9	5.550
FOS 37	17	11.450
FOS 39	58	35.429
FOS 40	5	2.640
CONSUMER CONFART (CODE)	**Total consumption (kWh)**	
FOS 2	3.378	
FOS 3	7.197	
FOS 4	1.887	

FOS 5	11.907
FOS 6	1.694
FOS 7	1.010
FOS 8	1.684
FOS 9	3.380
FOS 10	1.453
FOS 11	4.368
FOS 12	21.163
FOS 13	905
FOS 14	2.979
FOS 15	1.531
FOS 16	3.850
FOS 17	1.474
FOS 18	23.894
FOS 19	1.401
FOS 20	4.183
FOS 21	3.265
FOS 22	2.337
FOS 23	2.438
FOS 24	3.542
FOS 25	1.395
FOS 26	9.110
FOS 27	1.843
FOS 28	84.408
FOS 29	32.615
FOS 30	5.165
FOS 31	1.562
FOS 32	1.895
FOS 33	20.916
FOS 34	4.748
FOS 35	2.322
FOS 36	5.498
FOS 37	11.349
FOS 38	4.660
FOS 39	35.405
FOS 40	2.388
FOS 41	4.417
TOTALE	**340.614**
HOUSEHOLD CONSUMER	**Total consumer (kWh)**
100	**360.240**
TOTAL	**700.854**

Table 10:: Scenario maximum power summary

Compared to the previous scenario, the size of the installations is greatly reduced and consequently the number of domestic consumers to be included in the REC is also greatly reduced in order to reach 80% of shared energy consumed

Economic analysis

The economic analysis of a Renewable Energy Community involves the evaluation of the financial aspects, and the potential benefits associated with the adoption of renewable energy sources within a municipal or local government setting. This type of analysis considers the economic feasibility, costs, and possible benefits inside the local territory. By conducting a comprehensive economic analysis that considers multiple factors, community decision-makers can make informed choices about the integration of renewable energy, aligning environmental sustainability with economic goals and the well-being of the local community.

In this section the economic analysis is performed to check the financial sustainability of the REC.

quantification of investments (CAPEX)

To determine the cost of each photovoltaic system, the unit prices published in the draft MASE decree that is to regulate the incentive modalities for shared energy in self-consumption configurations for sharing renewable energy and the PNRR subsidies for RECs and collective self-consumption in municipalities of up to 5000 inhabitants were taken as a reference.

The unit prices considered were:

Plant size	Unit prices
P < 20 kW	1.500 €/kW
20 kW < P < 200 kW	1.200 €/kW
200 kW < P < 600 kW	1.100 €/kW
600 kW < P < 1000 kW	1.050 €/kW

Table 11:PNRR contribution

based on these unit prices, the investment cost was estimated for each prosumer member of Confartigianato Cuneo, in both scenarios (scenario 1 maximum installable power, scenario 2 optimised installable power).

FOSSANO				
	scenario 1		scenario 2	
CODE	Power (kWp)	cost (€)	Power (kWp)	cost (€)
FOS 2	98	117.504	6	9.000
FOS 5	31	36.720	18	27.000
FOS 6	101	121.608	3	4.500
FOS 7	40	47.693	3	4.500
FOS 8	20	24.192	3	4.500
FOS 9	10	14.553	6	9.000
FOS 11	71	84.672	8	12.000
FOS 13	87	104.026	3	4.500
FOS 14	99	119.232	5	7.500
FOS 16	14	21.600	5	7.500
FOS 17	121	145.152	3	4.500
FOS 18	139	166.320	49	58.800
FOS 19	47	56.678	3	4.500
FOS 21	13	18.900	6	9.000
FOS 23	161	193.536	5	7.500
FOS 24	4	5.400	3	4.500
FOS 27	97	115.776	4	6.000
FOS 28	10	14.904	10	15.000
FOS 29	4	6.000	4	6.000
FOS 31	40	48.384	3	4.500
FOS 32	25	29.549	3	4.500
FOS 36	53	63.504	9	13.500
FOS 37	79	95.040	17	25.500
FOS 39	61	72.576	58	69.600
FOS 40	24	28.426	5	7.500
TOT	**1.446**	**1.751.614**	**242**	**330.900**

Table 12: CAPEX scenario optimised power

PNRR

Mission 2, Component 2, Investment 1.2 of the PNRR provides for capital grants of up to 40% of eligible costs for the construction of renewable energy plants, also combined with energy storage systems that are part of RECs in municipalities with a population of less than 5,000 inhabitants. Within the analysed configurations, 4 plants were identified that could benefit from this contribution as they would be built in the municipality of Sant'Albano Stura. These are the results for both the scenario.

CODE	Power (kWp)	cost (€)	PNRR (€)	power (kWp)	cost (€)	PNRR (€)
FOS 9	10	14.550	5.820	6	9.000	3.600
FOS 17	121	145.200	58.080	3	4.500	1.800
FOS 29	4	6.000	2.400	4	6.000	2.400
FOS 37	79	95.040	38.016	17	25.500	10.200

Table 13: PNRR contribution REC prosumer

OPEX

To perform an economic analysis, it is necessary to estimate the management cost that occur every year to maintain the plant in condition to work properly.

The main operational expenditure costs of PV plants are cost for insurance (estimated to be about 1% per year of the CAPEX) and cost for maintenance (cleaning cost estimated to be 20 €/kWp/year)

OPEX	Unit of measure	Value
insurance	[€/year]	1% capex cost
maintenance	[€/kWp/year]	20

Table 14:OPEX

Revenues

To draw up an economic analysis, it is necessary to estimate the future revenues generated by the photovoltaic systems assumed to be installed on the roofs of buildings. Revenues may be paid directly to the prosumer or to the energy community to which these installations are contributed; in the latter case, a portion will then be returned to the prosumer itself who made the initial investment, according to the Renewable Energy Community regulations.

The following diagram describe the

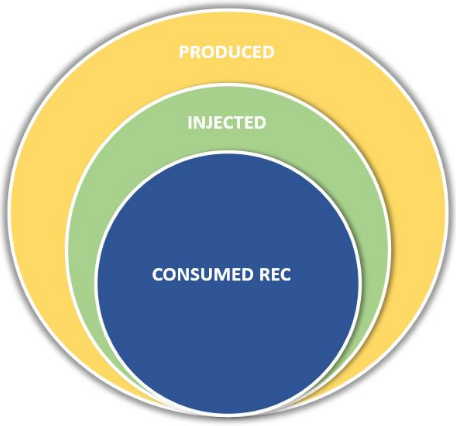


Figure 32:Energy diagram.

The main revenues valorisation is shown in the following table:

Revenues	Incentive [€/kWh]
Direct self-consumption	0,24
Premium Tariff	0,13
Dedicated withdrawal	0,104
Avoided network cost	0,0106

Table 15:Revenues

Direct self-consumption

Photovoltaic installations on the roofs of buildings allow producers to directly consume energy within the buildings themselves by covering part of the consumption of the electrical consumers there. Direct self-consumption results in a reduction of the energy bill as it reduces the withdrawal of electricity from the grid.

In the context of a business plan, this saving can be valued at the unit price of energy on the bill (including charges and taxes), which in September 2024 stands at approximately 240 €/MWh.

Direct self-consumption is the part of energy produced but not injected to the grid as shown in the following figure.

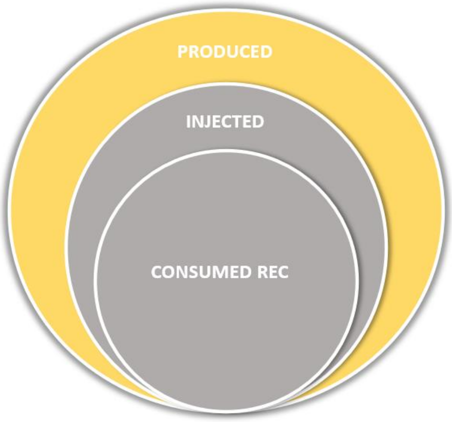


Figure 33: energy self-consumed.

Dedicated withdrawal

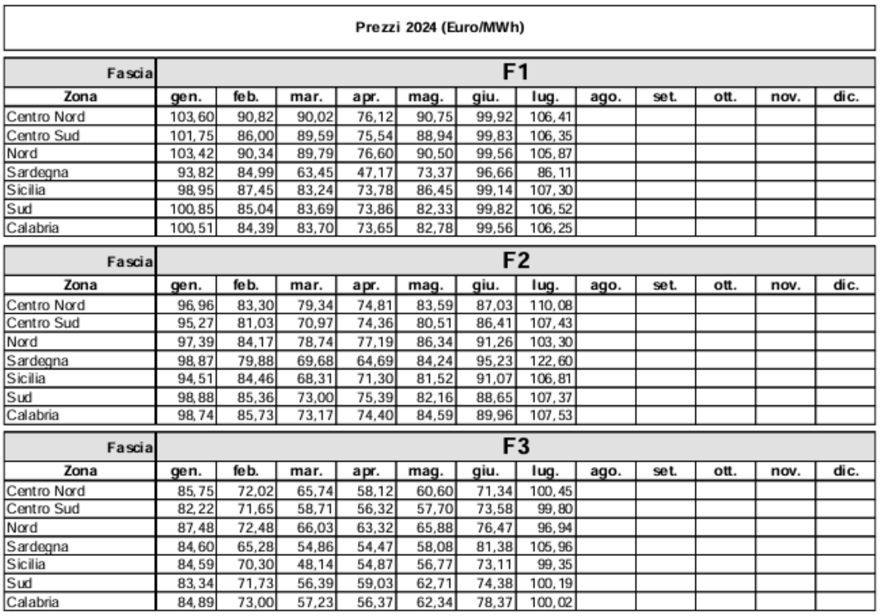
Dedicated Withdrawal is a simplified method available to producers for the marketing of electricity produced and fed into the grid, active since 1 January 2008.

It consists in the sale to the GSE of electricity fed into the grid by plants that can access it, at the request of the producer and as an alternative to the free market, according to principles of procedural simplicity and applying market economic conditions.

In fact, the GSE pays the producer a certain price for each kWh fed into the grid.

Revenues accruing to producers from the sale of electricity to the GSE are therefore added to those earned from any incentive mechanisms except where all-inclusive fixed prices, including the incentive, are applied for the withdrawal of electricity fed into the grid.

The value of the dedicated withdrawal can be associated with the Zonal Price which, today is about **104€/MWh** fed into the grid.



Prezzi 2024 (Euro/MWh)

Fascia	F1											
Zona	gen.	feb.	mar.	apr.	mag.	giu.	lug.	ago.	set.	ott.	nov.	dic.
Centro Nord	103,60	90,82	90,02	76,12	90,75	99,92	106,41					
Centro Sud	101,75	86,00	89,59	75,54	88,94	99,83	106,35					
Nord	103,42	90,34	89,79	76,60	90,50	99,56	105,87					
Sardegna	93,82	84,99	63,45	47,17	73,37	96,66	86,11					
Sicilia	98,95	87,45	83,24	73,78	86,45	99,14	107,30					
Sud	100,85	85,04	83,69	73,86	82,33	99,82	106,52					
Calabria	100,51	84,39	83,70	73,65	82,78	99,56	106,25					

Fascia	F2											
Zona	gen.	feb.	mar.	apr.	mag.	giu.	lug.	ago.	set.	ott.	nov.	dic.
Centro Nord	96,96	83,30	79,34	74,81	83,59	87,03	110,08					
Centro Sud	95,27	81,03	70,97	74,36	80,51	86,41	107,43					
Nord	97,39	84,17	78,74	77,19	86,34	91,26	103,30					
Sardegna	98,87	79,88	69,68	64,69	84,24	95,23	122,60					
Sicilia	94,51	84,46	68,31	71,30	81,52	91,07	106,81					
Sud	98,88	85,36	73,00	75,39	82,16	88,65	107,37					
Calabria	98,74	85,73	73,17	74,40	84,59	89,96	107,53					

Fascia	F3											
Zona	gen.	feb.	mar.	apr.	mag.	giu.	lug.	ago.	set.	ott.	nov.	dic.
Centro Nord	85,75	72,02	65,74	58,12	60,60	71,34	100,45					
Centro Sud	82,22	71,65	58,71	56,32	57,70	73,58	99,80					
Nord	87,48	72,48	66,03	63,32	65,88	76,47	96,94					
Sardegna	84,60	65,28	54,86	54,47	58,08	81,38	105,96					
Sicilia	84,59	70,30	48,14	54,87	56,77	73,11	99,35					
Sud	83,34	71,73	56,39	59,03	62,71	74,38	100,19					
Calabria	84,89	73,00	57,23	56,37	62,34	78,37	100,02					

Figure 34: zonal price GSE.

In the figure below the portion of energy paid with the dedicated withdrawal is shown:

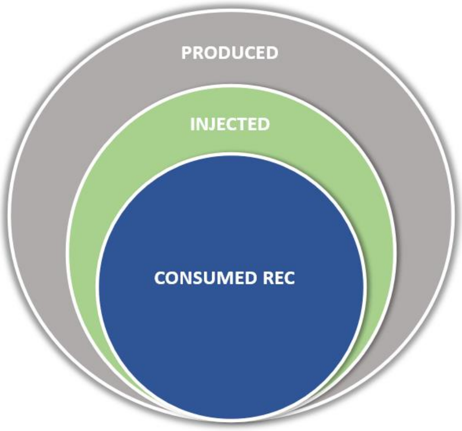


Figure 35:energy injected (remunerated with dedicated withdrawal)

Premium tariff and avoided network cost.

REC revenues concern the valorisation of shared energy through the incentive determined by the premium tariff, this tariff is determined by the MASE Ministerial Decree. (value in table premium Tariff) As seen before the medium zonal price is the price stood at an average value lower than **140 €/MWh** that allow to get the maximum of the premium tariff.

For the geographic area of Cuneo, a correction factor has been added to the premium tariff to consider the different levels of solar radiation between the various Italian regions. this correction factor amounts to approximately 10€/MWh.

The "Testo Integrato Autoconsumo Diffuso" (TIAD) published by ARERA with its resolution 727/2022/R/EEL of 27 December 2022 provides that the shared electricity pertaining only to the connection points located in the portion of the distribution network subtended by the same primary substation is valued through the restitution of the variable part of the transmission tariff, which for the year 2024 is defined as **10,57€/MWh**

Size plant [kW]	Incentive [€/MWh]	Correction factor [€/MWh]	ARERA Tariff [€/MWh]	Incentive value + correction + ARERA [€/MWh]
P < 200 kW	80 + max (0; 180 - Pz) €/MWh	10 €/MWh	8€/MWh	138€/MWh
200 kW < P < 600 kW	70 + max (0; 180 - Pz) €/MWh	10 €/MWh	8€/MWh	128 €/MWh
P > 600 kW	60 + max (0; 180 - Pz) €/MWh	10 €/MWh	8 €/MWh	118€/MWh

Table 16:premium tariff

In the figure below the part of energy incentivised is shown:

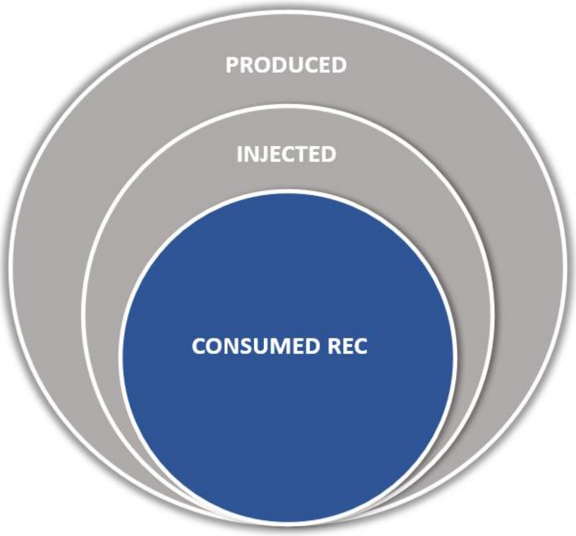


Figure 36: energy shared and consumed in REC.

Division of revenues

The CER-a Energy Community has a regulation governing revenue sharing based on the following rules:

The total revenue generated each RES plant for energy sharing will then be allocated between the following categories:

- $REC_{management}$ = share of annual revenues available for the remuneration of REC management activities
- Q_{pro} = share of annual revenues available for allocation among producer members
- Q_{con_comp} =REC's share of annual revenues available for allocation among consumer members companies
- Q_{con_NOcomp} = REC's share of annual revenues available for apportionment among consumer members other than companies
- Q_{soc} = share of the annual revenues available to the REC for activities with social purposes

If revenues are generated from the shared energy of RES plants built without the use of non-repayable incentives, they will be distributed according to the following percentages and priorities:

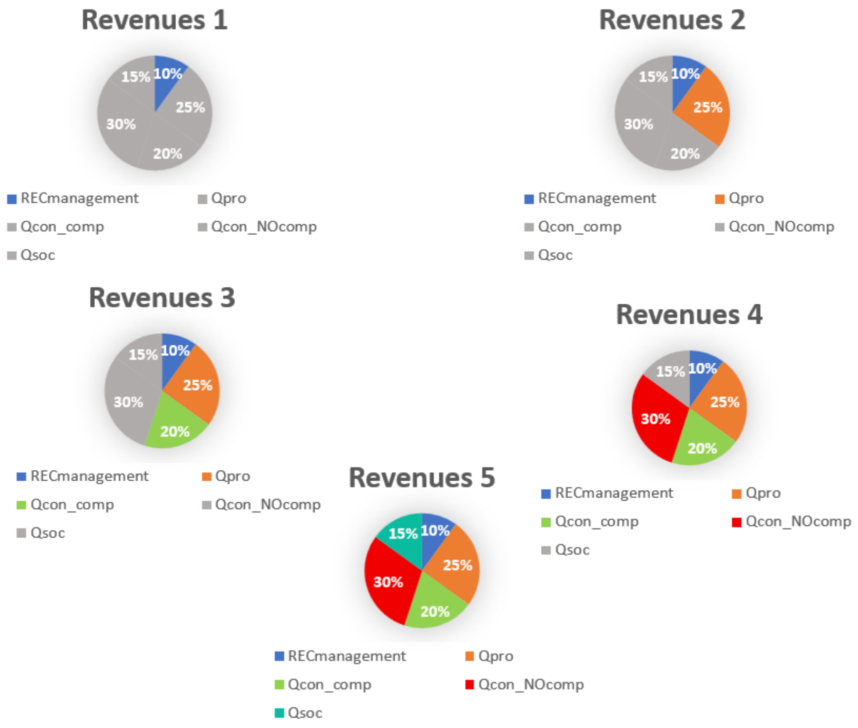


Figure 37: progressive remuneration of REC CER-a Without PNRR

- $REC_{management}$ = part of the incentive generated by 10% of the energy fed into the grid by the RES plant and shared in the REC, these costs will be the first to be remunerated thanks to the incentive tariff
- Q_{pro} = part of the incentive generated by 25% of the energy fed into the grid by the RES plant and shared in the REC, the producers will be the second to be remunerated until the established percentage is reached and on the basis of the available resources

- Q_{con_comp} = part of the incentive generated by 20% of the energy fed into the grid by the RES plant and shared in the REC, the corporate consumers will be the third to be remunerated until the established percentage is reached and on the basis of available resources
- Q_{con_NOcomp} = 30% of the energy fed into the grid by the RES plant and shared in the REC, non-corporate consumers will be the fourth to be remunerated until the set percentage is reached and based on available resources
- Q_{soc} = 15% of the energy fed into the grid by the RES plant and shared in the REC, initiatives with social purposes will be the quarter at the same level as corporate consumers to be remunerated up to the established percentage and based on available resources

If revenues are generated from the shared energy of RES plants built using non-repayable incentives, they will be distributed according to the percentages and priorities listed below:

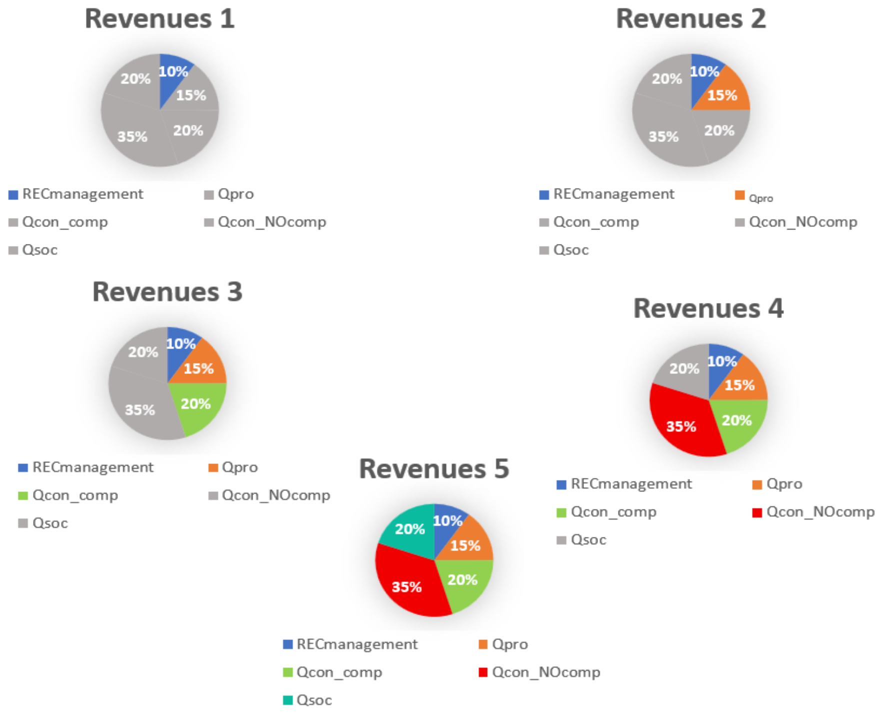


Figure 38: progressive remuneration of REC CER-a with PNRR

- $REC_{management}$ = part of the incentive generated by 10% of the energy fed into the grid by the RES plant and shared in the REC, these costs will be the first to be remunerated thanks to the incentive tariff
- Q_{pro} = part of the incentive generated by 15% of the energy fed into the grid by the RES plant and shared in the REC, the producers will be the second to be remunerated until the established percentage is reached and on the basis of the available resources

- Q_{con_comp} = part of the incentive generated by 20% of the energy fed into the grid by the RES plant and shared in the REC, the corporate consumers will be the third to be remunerated until the established percentage is reached and on the basis of available resources
- Q_{con_NOcomp} = 35% of the energy fed into the grid by the RES plant and shared in the REC, non-corporate consumers will be the fourth to be remunerated until the set percentage is reached and based on available resources
- Q_{soc} = 20% of the energy fed into the grid by the RES plant and shared in the REC, initiatives with social purposes will be the quarter at the same level as corporate consumers to be remunerated up to the established percentage and based on available resources

Cash flows and Net Present Value

For every potential prosumer has been performed a cash flows analysis to analyse the economic performance of the PV plants.

The main revenue for a prosumer comes from:

Revenues	Incentive [€/kWh]	Energy	Percentage distribution	Revenue [€/kWh]
Direct self-consumption	0,24	E_{sc}	100%	0,24
Premium Tariff	0,13	E_{inj}	25-15%	0,032
Dedicated withdrawal	0,104	E_{inj}	100%	0,104
Avoided network cost	0,0106	E_{inj}	25%	0,0025

Table 17:Revenues distribution for prosumer

Direct self-consumption:

Direct self-consumption is the most profitable item for a prosumer. The energy produced and immediately consumed on site reduces the electricity bill by avoiding buying electricity from the grid at higher prices. The value of 0,24€/kWh corresponds to the average kWh cost in August 2024, so for each kWh self-consumed, the prosumer saves 0,24€. Direct self-consumption also reduces exposure to energy transport and distribution costs, representing a higher net gain than selling energy to the grid. The higher the self-consumption, the higher the economic return for the prosumer and thus the payback time of the investment.

Dedicated withdrawal:

Dedicated withdrawal provides that all energy produced and fed into the grid is paid to the producer based on the average zonal price, which in August 2024 was €0,104/kWh. This method of remuneration depends on the market and local energy demand, which can bring some variability in the prosumer's revenue. However, it is a stable source of revenue for excess energy that cannot be self-consumed, allowing the prosumer to optimise its earnings, even if at a lower rate of remuneration than direct self-consumption.

Premium Tariff and Avoided network cost (ARERA contribution):

The premium tariff and ARERA contribution pay the prosumer that contribute to the REC sustainability, if the energy fed into the grid and consumed within the REC exceeds 35%, the prosumer is paid 25% of the premium tariff + ARERA contribution (if the PNRR capital contribution has been used, the tariff +ARERA paid to prosumers becomes 15% of the energy fed into the grid)

Cash flow

The cash flow analysis for a prosumer allows to understand the return on investment over time by considering revenues and expenses for every prosumer a simple cash flows have been calculated as follows:

$$CF = \begin{cases} -CAPEX \ at \ t = 0 \\ Revenue_t - OPEX_t \quad t = 1,2, \dots 20 \end{cases}$$

Where:

CAPEX: is the total cost of the plant

OPEX: is O&M cost.

Revenue: is the sum of annual income generated by the installation for the prosumer

Net present value

The Net Present Value (NPV) for a prosumer is a financial metric used to evaluate the profitability of an investment over time. NPV calculates the present value of all the future cash flows generated by the project, discounted by their current value, and subtracted to the initial investment cost (CAPEX). The result is a graph where is indicated the net value of the investment year by year. A positive NPV would indicate recouping the investment and making some profit.

In the context of a renewable energy plant, the NPV would consider the costs and benefits associated with operation of renewable energy infrastructure, such as solar panels, inverter, cables, and related facilities. The NPV analysis considers factors such as initial capital expenditures (CAPEX), operating expenses (OPEX), energy production, revenue generation, and discount rates. A positive NPV would indicate that the renewable energy project is expected to yield a return on investment, making it financially viable.

In the context of renewable energy plant, the NPV would consider all the revenues that came from the energy produced as previously explained revenues for a prosumer are:

$$Revenue = E_{sc}[kWh] * 0{,}24[€/kWh] + E_{inj}[kWh] * (0{,}0025 + 0{,}0325)[€/kWh] + E_{inj}[kWh] * 0{,}104[€/kWh]$$

The net present value analysis considers both the revenues and OPEX with an interest rate (i) [23] equal to 4% so it become as follows.

$$CF = \begin{cases} -CAPEX \; at \; t = 0 \\ (Revenue_t - OPEX_t) * 1/(1+i)\hat{}t \quad t = 1,2, \dots 20 \end{cases}$$

The following table resume all the benefit and cost for a prosumer taken as example:

Capital Expenditure (CAPEX)			
PV Plants			**27.305 €**
Revenues for prosumer			
	Energy [kWh]	Unit price [€/kWh]	Total [€/y]
Direct Self-consumption	10.544	0,24	**2.530€/y**
Dedicated withdrawal	11.932	0,104	**1.240 €/y**
Premium tariff plants < $200kW_p$	11.932	0,032	**418€/y**
TOTAL			**4.188€/y**
Operational Expenditure (OPEX)			
Plants insurance	Tariff [%]	CAPEX	Total [€]
	1%	27.305€	**273€/y**
Maintenance	Tariff [€/kW_p]	Installed power	
	20	18	**360 €/y**
TOTAL			**633€**

Table 18:economic analysis FOS 5

Considering these revenues, OPEX, initial investment costs and a discount rate of 4%, the net present value analysis was carried out.

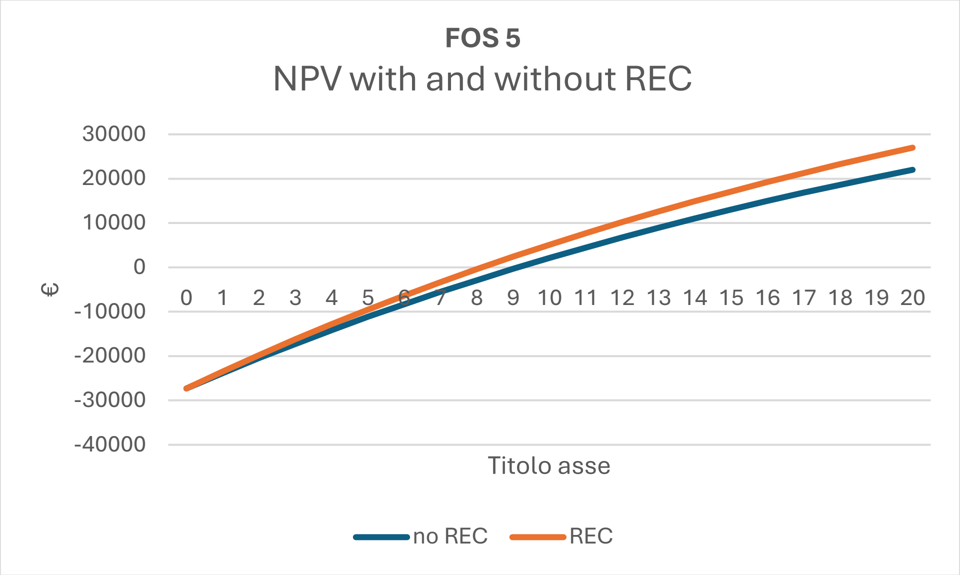


Figure 39: NPV with and without REC

In conclusion, the analysis utilising the Net Present Value (NPV) method demonstrates that the joining a Renewable Energy Community (REC) can make the investments in renewable plants significantly more profitable. The results demonstrate that the payback period for projects within a REC can be reduced by up to two to three years in comparison to similar plants outside the community. This competitive advantage derives from the sharing of the energy produced and the associated economic benefits, making RECs a strategic tool for accelerating the energy transition and maximising the return on investment in renewable energy.

Chapter 4: REC Fossano: local flexibility service potential

Introduction to grid flexibility services

In recent years, the global energy sector is experiencing a radical change to reduce greenhouse gas and move to a more sustainable production. In this context, the spread of renewable energy sources (RES) such as solar, wind, and biomass is playing a crucial role. However, while these sources offer considerable environmental advantages, they also present several challenges related to their unpredictability and inconstant production.

RES, particularly those based on wind and solar resources, are subject to fluctuations in output due to variations in weather conditions, which occur on a seasonal, daily and hourly basis. This implies that energy generation from these sources is discontinuous and challenging to anticipate with precision. The irregularity of energy production can result in significant imbalances between supply and demand, necessitating adaptations to the electricity system.

Furthermore, maintaining grid frequency stability is a significant challenge, as rapid variations in energy production and consumption can easily compromise this stability. Furthermore, the traditional electricity grid was designed to accommodate centralized production plants, predominantly based on fossil sources, which can be easily regulated. The transition to a system with a higher share of renewables therefore requires a radical change in grid management, which in turn gives rise to the necessity for flexibility services.

In response to the problems described, **grid flexibility services** are emerging as one of the most innovative solutions for balancing energy supply and demand in a system increasingly dependent on RES. Flexibility refers to the ability of the grid to adapt to variations in both energy demand and production, reducing consumption peaks and managing overproduction situations efficiently.

Flexibility services can be provided by several resources, including:

- **Flexible demand**: The use of demand management technologies, which allow consumers to adapt their consumption according to grid conditions.
- **Generation units**: Conventional power plants that can rapidly change their production to compensate for variations in renewable generation.
- **Energy storage systems**: Storage systems, such as batteries (electro chemical, hydroelectric, etc….), that store excess energy produced during periods of high production and release it when production decreases.

- **Electric vehicles**: In the future, electric vehicle batteries could become an integral part of the grid, supplying energy during peak demand and recharging when there is an abundance of production (V2G & G2V).

One of the most innovative and revolutionary aspects of the ongoing energy transition is the move from a centralized production system to a distributed production system. Traditionally, electricity was generated in large power plants located in a few strategic areas, and then distributed through a capillary network to end consumers. This model (Figure 30), however, is no longer sustainable in a world where an increasing share of energy production comes from small distributed renewable plants, such as solar panels installed on the roofs of houses or wind farms spread across the country.

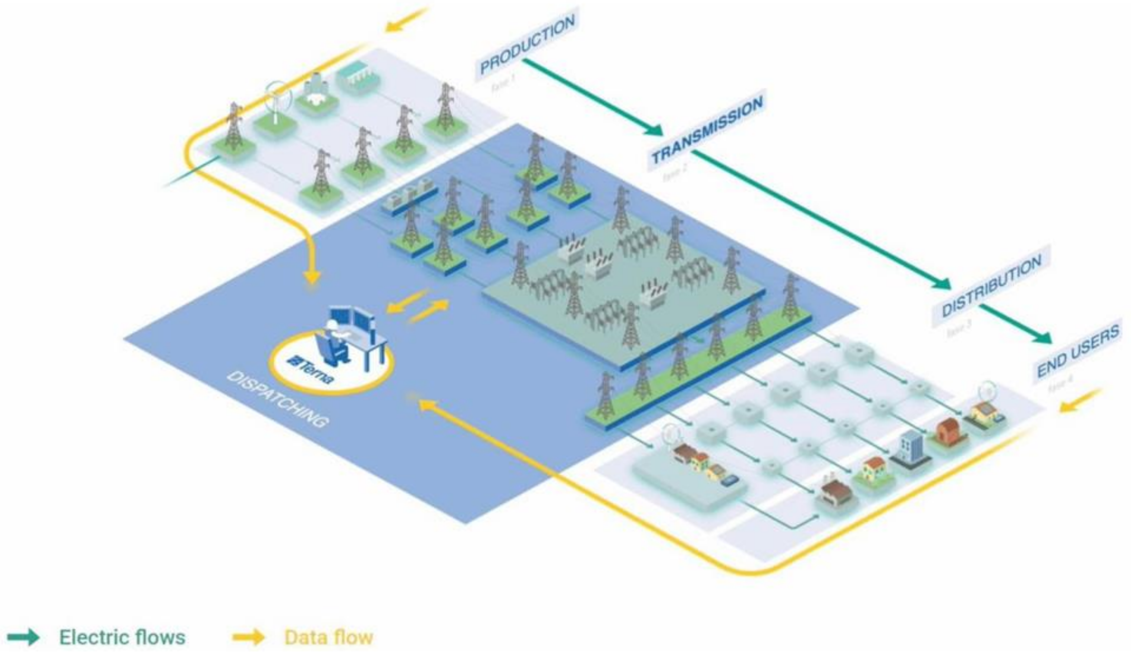


Figure 40: centralised energy system.

The concept of **distributed generation** involves energy generated locally, close to the places of consumption, thus reducing transmission losses and increasing the overall efficiency of the system. This new model introduces greater complexity in grid management, as generation diffused and no longer concentrated in a few large units. However, it also represents a huge opportunity to improve grid resilience and to actively involve consumers in the energy process.

Finally, these services open the way to new business models and market opportunities, in this context the thesis aims to understand how a REC can participate in the provision of flexibility also known as ancillary services.

Project EDGE

EDGE [24] is an experimental project conducted by "e-distribuzione" (one of the main Distribution System Operators in Italy) that opens the possibility to medium or small producers/consumers to participate in the market of national grid flexibility services. This project is being conducted under the supervision and authorization of ARERA (Autorità di Regolazione per Energia, Reti e Ambiente) Italy's regulatory for energy network.

Objective of the project:

The main objective of the project is to explore the "flexibility services "that allow users (both consumers and producers of energy) to actively participate in balancing the energy grid. By doing so, they help to mitigate the imbalances between production and demand increasing the stability of the power systems.

Participants in this market can modulate the amount of energy they take from or feed into the grid at certain times. This modulation helps to reduce fluctuations in the energy grid, especially during peak periods of renewable energy production.

Participant:

Consumers: users who only consume energy and can modulate their consumption, and so the energy withdrawn.

Producers: users who only produce energy and who can modulate the energy they feed into the grid.

Prosumer: users who are able to both produce and consume energy and who are able to modulate the energy they supply and take from the grid.

Users can participate:

Individually: users able to satisfy the demand for flexibility individually for the period requested.

Aggregation of resources: users can aggregate resources to increase the power for the period of time required for flexibility.

Users during registration on the portal must satisfy a lot of technical parameters and must do some technical simulation of quick reaction and simulation that all systems work properly.

Test area:E-distribuzione has selected four test areas that are characterized by structural criticalities in the electricity network; these experimental areas are in the province of:

- **Foggia**
- **Benevento**
- **Venezia**
- **Cuneo**

In each province, several smaller areas were chosen with varying demands for flexibility, every flexibility demand has different request in:

- **Power:** different amounts of power drawn or fed into the grid is required for each area to participate in the provision of flexibility services.
- **Period:** Depending on the length of time required to provide the service, experimentation usually requires a minimum of 2/3 months of service provision for a variable number of days per week, for specific critical hours of the day.
- **Duration of service**: Each flexibility request has a different duration requirement.

Remuneration:

The remuneration systems are divided in two main components:

Availability Remuneration: This is a guaranteed payment that participants receive simply for their willingness to provide flexibility at the pre-determined times. Whether the flexibility service is requested or not, the user is paid for his availability.

Service Remuneration: This payment is only made if the flexibility service is requested by the system operator. If a user is asked to change the amount of energy taken or injected at a certain time, he will receive this additional payment for the service provided.

Public tenders:

E-Distribuzione, in collaboration with **Piclo**, has developed a portal (Piclo Flex) [25] to facilitate dialogue between distribution system operators and flexibility service providers.

This platform presents the areas of interest for flexibility services, indicating the power required, the hours of availability, and the period of interest for the provision of these services.

Furthermore, the remuneration for these services is indicated. The platform allows flexibility service providers to register and participate in public tenders.

For each public tender, an auction is held between the users. Each participant can offer a different amount of Powe, a different time of service or a lower remuneration for the service to win the downward auction of the public tender.

At the end of the auction end date Piclo communicates the outcome of the tender to the winners, conducting further tests.

Case of study Fossano

Fossano, the place where the REC feasibility study has been performed, corresponds to one of the areas selected for the experimental project EDGE. The following figure describes the characteristics of public tenders.

Gara

CUNEO_1

FASE DI REGISTRAZIONE Carica le risorse
Apertura / 6 dic 2023 07:00 Chiusura / 1 mar 2024 16:00

FASE DI GARA
Apertura / 22 apr 2024 08:00 Chiusura / 26 apr 2024 17:00

Identificativo della gara	CN_BUSCA_DY204908 2
Tipo di potenza	Potenza attiva
Tipo di servizio	Altro
Prodotto di flessibilità	-
Direzione di fornitura richiesta	Riduzione della generazione / Aumento del consumo
Tensione al punto di connessione	0,23 kV - 20 kV
Acquirente	E-distribuzione
Tipo di gara	Disponibilità e utilizzo
Validazione fornitore	

45.000,00 €
Budget annuo massimo

750,00 €/MW/h
Prezzo per Disponibilità

500,00 €/MWh
Prezzo per Utilizzo

Finestra di flessibilità

CN_Estate24 - CN_pom_fer
0,15 MW, 192 ore disponibili

1 giugno 2024
Inizio Finestra di disponibilità

31 agosto 2024
Fine Finestra di disponibilità

12:00 - 15:00
Fascia di disponibilità

● ● ● ● ● ○ ○
Lun Mar Mer Gio Ven Sab Dom
Giorni richiesti

20
Stima attivazioni

3 ore
Stima tempo attivazione

60
Stima ore di utilizzo

0,15 MW
Quantità richiesta nel perimetro di flessibilità

0,1 MW
Quantità richiesta per la fornitura

2 ore
Durata richiesta per la fornitura

3 ore
Durata richiesta nel perimetro di flessibilità

Figure 41: specific of CUNEO 1 experimental area.

Details:

Area of CUNEO 1:

Looking on the web platform developed by Piclo it has been seen that in the area of Fossano have been planned several public tenders, unfortunately the data of these public tenders are secreted by E-distribuzione and the only data available are those of CUNEO 1 which correspond to another area, but since these are the only data available, for the calculation has been simulated that these were the request also for the tenders in Fossano. (Even though all these public tenders have expired, as they were only active until the summer of 2024)

Period of the service:

The period of request of the availability service is during all weekdays for the months of June, July and August. Between 12:00 and 15:00 service must be guaranteed for a minimum of 2 hours, and the distributor also estimates that the service could be activated 20 times.

Power required:

This public tender requires an increase in consumption or decrease in production of at least 100kW and no more than 150kW.

Remuneration prices:

This public tender has set a maximum remuneration for availability to €750/MWh and for utilisation at €500/MWh, which are the economic auction bases for the public tender at a discount.

These are the fixed data required by the distributor (**E-distribuzione**), and in the following chapter the possibility of "CER-a" participating in the provision of these services has been analysed through two different scenarios.

In the next chapter, the participation of CER-a has been simulated with two different scenarios.

Scenario 1: distributed BESS

Electrochemical battery analysis

In this chapter has been simulated the participation to the flexibility service particularly at the public tender (CUNEO 1) with an aggregate of resources, in this case some electrochemical batteries.

Starting from the data obtained in the simulation of optimized REC has been simulated the presence of PV-connected electrochemical batteries in every prosumer building (previously analysed in the feasibility studio).

The aim of this simulation is to verify if the flexibility service delivered by a multiple number of electrochemical batteries grid/PV connected could be technically and economically feasible. The following figure describe the functional diagram:

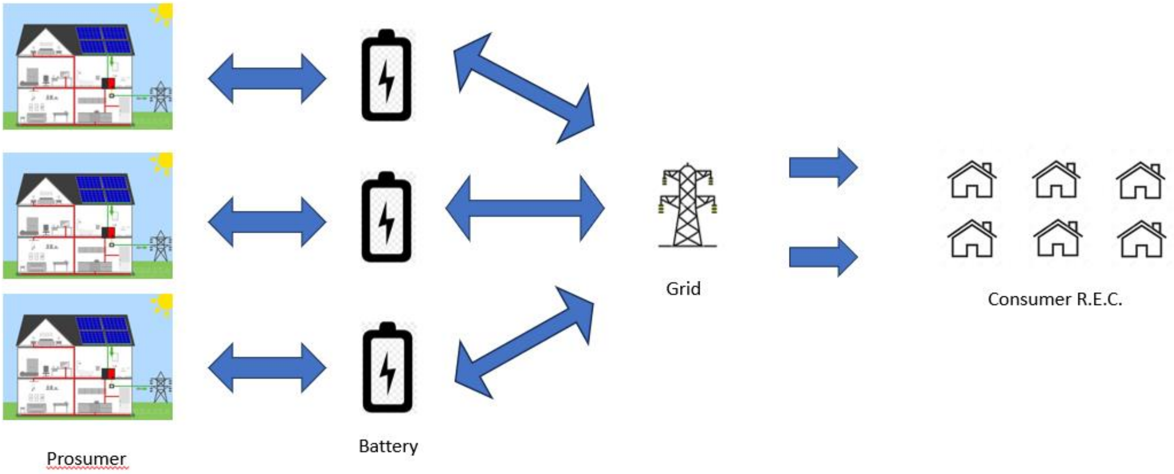


Figure 42: functional diagram flexibility service by aggregate of resources.

Key Logical Steps:

Normal battery usage: electrochemical battery PV-connected are useful for the night use of energy generated during the day by the renewable plant.

Behaviour During Flexibility Period: In the period of flexibility the normal behaviour changes a bit. In the hours of flexibility, the distributor requires, that an aggregate of resources become able to absorb at least **100kW** by the grid for at least **2** consecutive hours, this absorption could be made by the electrochemical batteries taking energy from the grid.

So, the minimum energy that must be absorbed by the batteries is **200 kWh**.

This data was used to select the correct battery size for each prosumer:

Battery Sizing: for each prosumer, the battery size was chosen to be 12kWh, a common capacity for household batteries (also able to store more than the minimum energy request by flexibility as an aggregate). To maintain long-term battery performance, a depth of discharge (DoD) of at least 10% is required, so the actual capacity is 90% of the total.

Maximum storable energy:

$$E_{withdrawal,MAX} = 90\% * battery_{capacity}[kWh] * Number_{prosumer}[-]$$

The maximum energy that can be stored as an aggregate of resources is **270kWh** allowing the REC to participate in the public tender CUNEO 1

Where:

Number of prosumers is the number of prosumers in the REC

Minimum power to be withdrawn by each battery:

$$P_{withdrawal,MIN} = \frac{100\ [kW]}{(Number_{prosumer}[-])} = 4\ [kW]$$

The minimum power absorbed by every battery is **4kW**. To reach the minimum absorbed power ok 100 kW.

Maximum power withdrawable:

Taking into account that the service must be provided for at least 2 hours.

$$.P_{withdrawal,MAX} = \frac{270\ [kWh]}{(hour_{minimum}[h]) * (Number_{prosumer}[-])} = 5{,}4\ [kW]$$

The maximum power that each battery can withdraw is **5,4 KW** ensuring that the flexibility service is provided for at least 2 consecutive hours.

Operation:

Normal battery usage:

The battery connected to a PV system ensures some benefits as it increases the self-consumed energy, which ensures extra economic (self-consumed energy is the most remunerated part of energy) and increases the self-sufficiency. It reduces the dependence from the electricity market and from price fluctuations.

In the following graph is analysed the behaviour of a prosumer (FOS 36 of the REC) with 9kWp of PV installed (optimized size) and a battery of 12 kWh useful to maximize the self-consumption and self-sufficiency of the prosumer

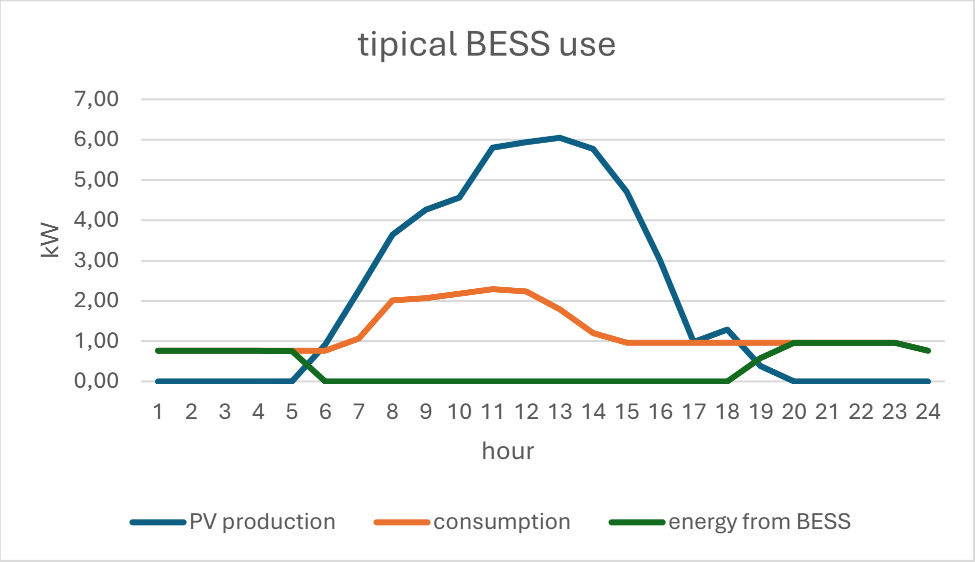


Figure 43: FOS 36 consumption PV production and BESS curve (day 30/05)

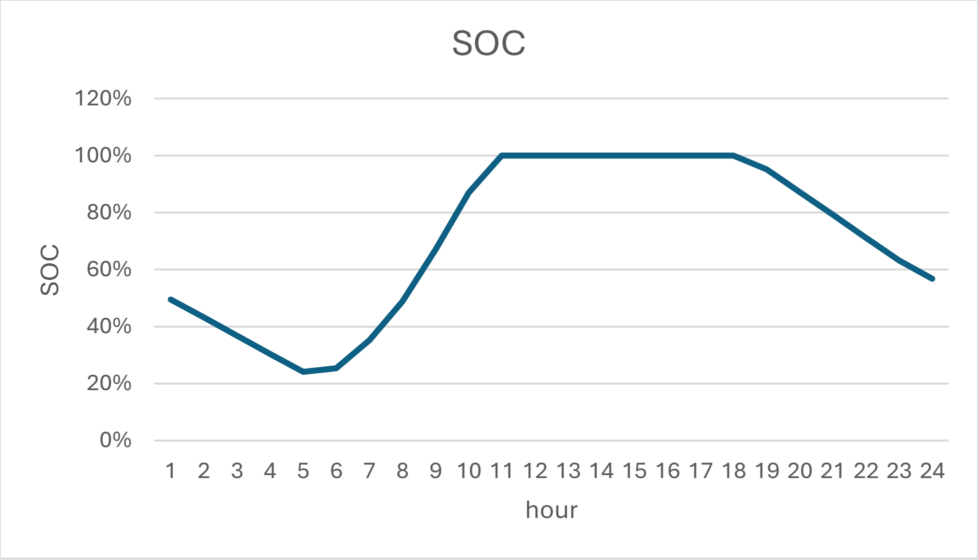


Figure 44:SOC of the battery FOS 36 (day 30/05)

As shown in the previous figures, on sunny days, the battery manages to completely fill itself during the middle hours of the day thanks to the overproduction of the PV systems with respect to the consumption of the user. During the night, the battery supplies energy to the user, maximising the user's own consumption.

Behaviour During Flexibility Period:

During the aforementioned flexibility period, the battery's behaviour undergoes a notable alteration. In order to participate in the flexibility service, it is necessary to absorb energy from the grid (5kW for a minimum of two hours). In order to fulfil the aforementioned requirements, it is necessary to discharge the battery completely in order to maintain an adequate level of capacity within the storage system, thereby ensuring the ability to absorb 10kWh. During the two-hour period preceding the flexibility period (10:00-12:00), the battery will inject 5kW into the grid, and subsequently absorb the same amount of energy from the grid for the following two hours (12:00-14:00). This process guarantees the provision of the flexibility service.

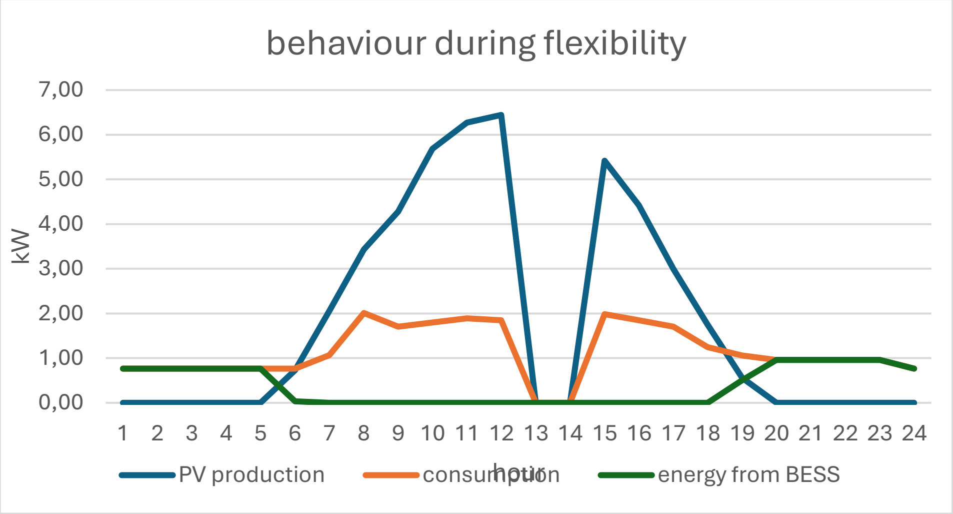


Figure 45: User 36 consumption PV production and BESS curve (flexibility day 16/06)

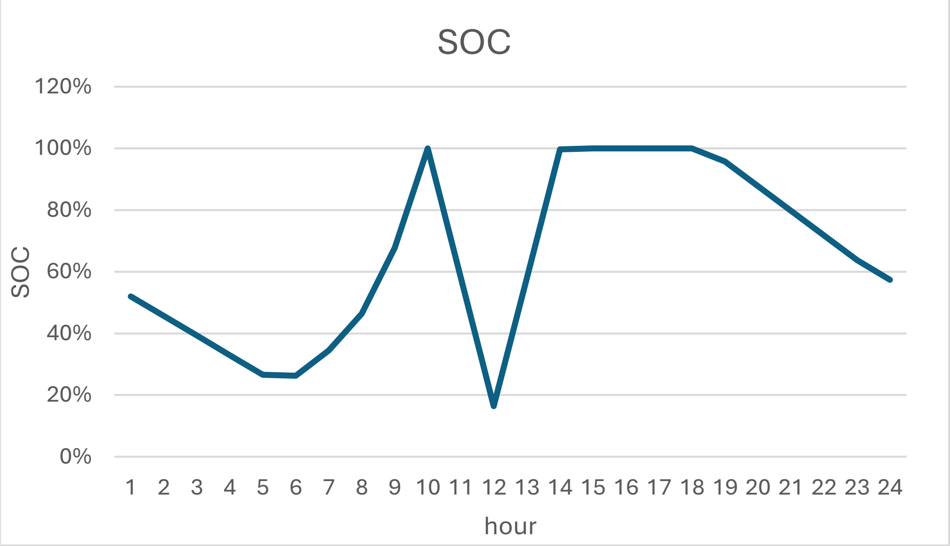


Figure 46: SOC of the battery user 36 (flexibility day 16/06)

In this analysis, in order to simplify the algorithm, some assumptions have been made: every time that the user guarantee the availability it is also requested the service. During the 2 hours before the flexibility service (10:00-12:00), the battery discharges its stored energy into the grid and also, if present, the excess production of the PV with respect to the consumption of the user is sent to the grid. During the flexibility hours, the PV panels are disconnected from the systems and therefore don't produce any energy (it is necessary to increase the total withdrawal of the POD compared to the usual behaviour) in order to ensure an increase of the withdrawal of at least 5kW. To further simplify the algorithm, consumption during flexibility hours is set to zero, this assumption has been made to be precautionary, because any consumption during the flexibility period would help to discharge the battery, would have a positive impact on the system's overall performance. By setting consumption to zero, the focus remains only on matching the flexibility requirement through battery discharge and grid energy absorption.

Economic analysis

The electrochemical battery is an extremely useful device for new prosumers for the advantages previously discussed (self-consumption, self-sufficiency, etc…). However, despite these benefits, the high upfront cost of such batteries remains a significant barrier (CAPEX). While there are some economic returns from standard usage, these returns are often too modest to justify the investment. In this section is explored if the additional revenues coming from the flexibility service could make this device becoming more cost-effective.

CAPEX:

The cost of this device is function of its capacity. Nowadays the cost is around **800 €/kWh** for small scale, so the cost of this device is described by the following formula:

$$CAPEX = \ unit\ cost\ [€/kWh] * Capacity\ [kWh] = 9600\ €$$

The battery as an average life of about 10 years with almost no maintenance cost.

Cost:

There are two main costs associated with the energy that enters the battery:

Cost of Energy from the Grid: This refers to the price paid for energy drawn from the grid to charge the battery, during the flexibility service. The cost of this energy is equal to the cost of kWh in the electricity invoice.

$$Cost\ \ Energy\ absorbed = Energy\ absorbed\ for\ the\ service\ [kWh]\ *\ number\ activation\ [-] * cost\ electricity\ [€/kWh] = \mathbf{163}€$$

Where:

Energy absorbed for flexibility is the energy withdrawn from the grid during the flexibility service absorbed by the battery. (10 kWh/activation)

Number of activations: number of times the flexibility service is requested for the assumption made this is equal to 68 (weekdays in the flexibility moths)

Cost electricity: is the cost of the kWh in the electricity invoice (0.24 €/kWh)

Loss of earning share R.E.C.: this refers to the energy that during the normal usage goes in the battery instead of finishing into the grid.

$$Loss\ R.E.C. = energy\ in\ battery\ [kWh]\ * remuneration\ prosumer\ [€/kWh]$$

Where:

Energy in battery: the total amount of energy that is stored in the battery during a year, instead of being shared in the REC (FOS 36 :2.113kWh)

Remuneration prosumer: is the remuneration that all producers get for the energy shared in the community (0.125€/kWh=dedicated withdrawn + 25% of premium tariff+ ARERA contribution)

REVENUES:

Valorisation self-consumption due to the battery: this is the revenue that comes from the self-consumption increased by the presence of the battery (normal usage), the energy stored in the battery during the day, and it is used during the night translates into a reduction of the electric invoice.

$$\boldsymbol{Valorisation\ battery} = energy\ in\ battery\ [kWh]\ * cost\ electricity\ [€/kWh]$$

Where:

Energy in battery: the total amount of energy that is stored in the battery over a year, instead of being shared in the REC (user 36 :2.113kWh).

Cost electricity: is the cost of the kWh in the electricity invoice (0.24 €/kWh).

Revenues energy fed pre flexibility: this is the energy fed into the grid before the hours before flexibility that is remunerated as dedicated withdrawal.

$$\boldsymbol{Revenues\ energy\ fed}\ = energy\ discharged\ \ [kWh]\ * dedicated\ withdrawal\ [€/kWh]$$

Where:

Energy discharged: is the energy discharged into the grid in the hour before the flexibility.

Dedicated withdrawal: is the remuneration for the energy injected into the grid to the producers (0,09 €/kWh)

Flexibility service: The aim of this simulation is to assess the economic viability of the battery, especially focusing on the remuneration of flexibility, to make this economic simulation the price for service and availability have been set at the maximum value of the public tender (availability at €750/MWh and 500€/MWh for the service)

$$\textit{Flexibility service} = Energyabsorbedfortheservice[kWh] * numberactivation[-] * (availability + service)[€/kWh] = \mathbf{850€}$$

Where:

Energy absorbed for the service is the energy withdrawn from the grid during the flexibility service absorbed by the battery. (680 kWh/year).

Number of activations: number of times the flexibility service is requested for the assumption made this is equal to 68 (weekdays in the flexibility months).

Availability service: These are the remunerations for the flexibility service, which, based on the assumptions made, amount to 1.25€/kWh (0.50€/kWh for the service and 0.75€/kWh for availability). This is because the hours of service are equal to the hours of availability.

Cash flow analysis:

For each prosumer, a cash flow analysis has been conducted, taking into account the initial investment cost of the battery and all the revenues and costs previously described. The valuation of flexibility service is considered to recur annually (that's has been made to analyse the economic impact that this service could have in the affordability of the battery) even though, this is only an experimentation and last for only one year Although this service is currently in its trial phase, many future scenarios suggest that flexibility could increasingly become a valuable resource.

The following table summarises the cash flow for the example user 36:

FOS 36	Battery 12 kWh
CAPEX	9.600 €
Cost of Energy from the Grid:	-163€
Loss of earning share R.E.	-264€
Flexibility service	850 €
Revenues energy fed pre flexibility	52 €
Valorisation self-consumption thanks to the battery	507 €
simple payback time [years]	9,8

Table 19: Cash flow battery FOS 36

The table clearly illustrate the significance of the revenues generated from flexibility services flexibility that account more than a half of the total revenues coming from the storage.

The analysis performed for each prosumer resulted in varying simple payback times. To assess the economic impact of the flexibility service, a comparison was made between the simple payback time with and without the annual remuneration of the flexibility service.

This comparison allows a clear understanding of how significant the role of flexibility services can be in improving the affordability and economic attractiveness of energy storage systems for prosumers.

prosumer	**2**	**5**	**6**	**7**	**8**	**9**	**11**
simple payback time with flexibility	9,5	9,4	9,4	9,4	9,5	9,3	9,5
simple payback time without flexibility	29,6	29,0	29,0	29,6	29,2	27,9	29,3
prosumer	**13**	**14**	**16**	**17**	**18**	**19**	**21**
simple payback time with flexibility	9,5	9,5	9,4	9,5	9,4	9,5	9,2
simple payback time without flexibility	29,6	29,4	29,1	29,4	29,0	29,5	26,6
prosumer	**23**	**24**	**27**	**28**	**29**	**31**	**32**
simple payback time with flexibility	9,4	8,9	9,3	8,6	8,6	9,5	9,4
simple payback time without flexibility	29,1	24,4	27,6	22,6	22,6	29,6	29,0
prosumer	**36**	**37**	**39**	**40**			
simple payback time with flexibility	9,8	9,4	9,4	9,4			
simple payback time without flexibility	32,5	28,8	29,0	28,7			

Table 20: simple payback time with and without flexibility

The table clearly demonstrates the crucial role of revenues from flexibility services, which can significantly reduce the payback time to approximately 10 years. Without these revenues, the investment in the storage system may never become profitable. This highlights how flexibility services can transform an otherwise unprofitable investment into a possible solution by providing a consistent cash flow that accelerates the return on investment.

Scenario 2: Concentrated BESS

The second scenario analyses the possibility of participating in flexibility services through centralised storage with connected charging infrastructure for electric vehicles. To make these calculations, it is necessary to estimate the spread of electric vehicles and quantify their impact on the electricity grid in relation to the number of charging infrastructures.

Evolution of EV in Italy and Fossano

The evolution in the spread of electric vehicles has increased significantly with the spread of incentives in recent years.

The ACI “Automobile Club d'Italia” [26] website every year makes a self-portrait of the national car fleet for all registered vehicles by region and province [27], thanks to this data the following table for the geographical area of interest has been obtained:

Year	Italy	Piemonte	Cuneo	Fossano
2019	22.728	1.374	179	6
2020	69.754	3.886	473	18
2021	136.754	8.652	1.122	36
2022	158.131	10.360	1.443	43
2023	219.540	14.582	2.004	63

Table 21: Numbers of EV

This trend of growth is strongly influenced by the decrease of the price for EV and the creation of new incentives.

The diffusion of charging infrastructure in public areas is also a key parameter to understand the use of this device. This analysis is carried out by motus-E [28], which every year produces a report analysing the diffusion of charging infrastructure in each region [29]:

Year	Italy	Piemonte	Cuneo	Fossano
2019	13.721	1.330		
2020	19.324	2.048		
2021	26.024	2.602		
2022	36.772	3.848		
2023	50.678	5.169	283	14

Table 22: Number of recharging infrastructures

The only data available on the recharging infrastructure are at the regional level, the information for Cuneo and Fossano represent the current situation.

The ratio between EV and recharging infrastructure could give an idea of the utilization of the device.

Year	Italy	piemonte	Cuneo	Fossano
2019	2	1		
2020	4	2		
2021	5	3		
2022	4	3		
2023	4	3	7	5

Table 23: ratio between EV /recharging infrastructure

The table evidence that the average ratio is that for every 5 cars there is a column available in a public area.

Consumption EV

Another important parameter for understanding the impact of electric vehicles (EVs) on the national grid is their average energy consumption. In recent months, an interesting experiment was conducted by the GSE, in collaboration with ARERA, allowing EV users with recharging infrastructure to temporarily increase the maximum power of their Point of Delivery (POD) during nighttime hours or holidays. This experiment yielded several valuable results:

- The impact of EV charging on the national grid when concentrated during nighttime hours.
- The amount of energy withdrawn during these periods, provide a clearer idea of the monthly consumption of EVs.

All this information has been reported in the [30]

The following figure represents the monthly energy consumed by EVs.

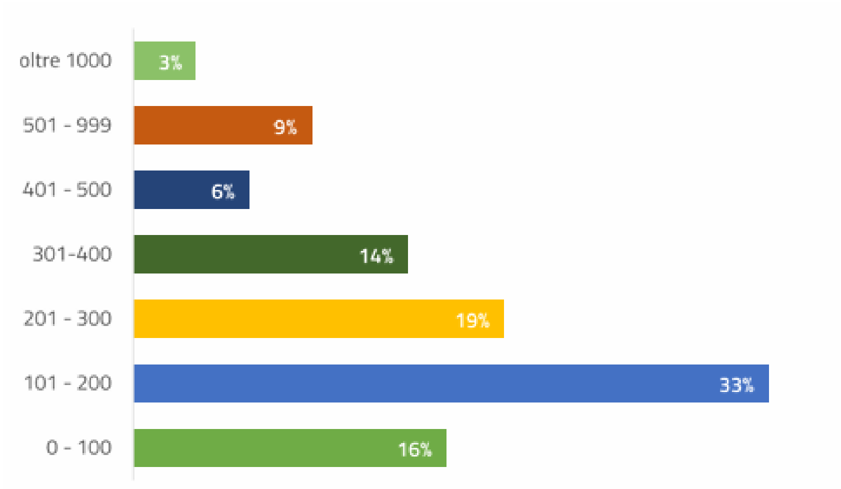


Figure 47: Monthly kWh consumed by EVs.

Based on this information, the average consumption of EVs is estimated to be **280kWh/month**

These analyses are crucial for understanding the consumption of EVs and to predict the potential future trends of diffusion and consumption patterns.

Analysis concentrated BESS

In this scenario has been analysed the possibility to participate in the provision of flexibility services with a big stack of electrochemical battery grid connected and that provides a charging service for electric vehicles. In this chapter has been simulated the participation to the flexibility service particularly at the public tender (CUNEO 1)

The aim of this simulation is to verify if the flexibility service delivered by a big stack of electrochemical battery grid connected could be technically and economically feasible. The following figure describe the functional diagram:

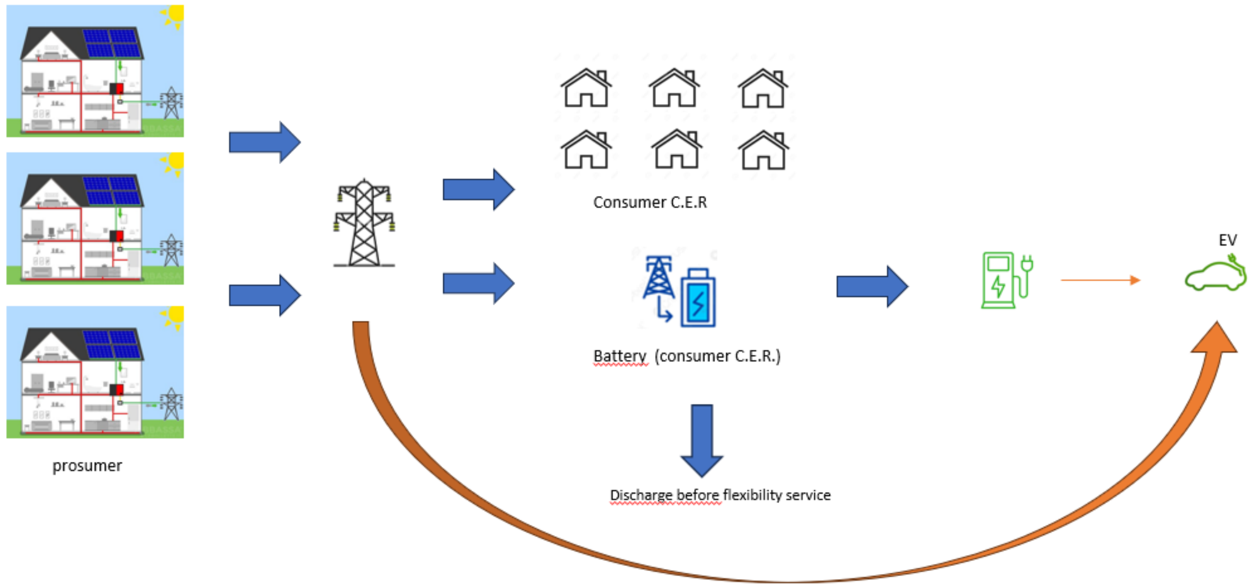


Figure 48:Functional diagram flexibility service by concentrated BESS.

Key Logical Steps:

Operating battery and charging station: electrochemical battery grid-connected, located in the primary cabin of the REC and in the area of flexibility, useful to maximize the self-consumption energy in the REC having economical and technical benefit. The battery is then discharged by the EVs recharging infrastructure directly connected to the battery.

EVs charging station: charging stations for electric vehicles are connected to the battery and the grid, drawing energy from one and the other depending on power, energy needs and current SOC of the battery.

Behaviour During Flexibility Period: In the period of flexibility the normal behaviour changes a bit. In the hour of flexibility, the distributor requires, that the resource become able to absorb at least **100kW** by the grid for at least **2;** consecutive hours, this absorption could be made by the electrochemical batteries taking energy from the grid.

So, the minimum energy that must be absorbed by the batteries is **200 kWh**.

Utilizing this data it has been chosen a proper size of the battery for each prosumer:

Battery Sizing: The minimum energy that need to be stored is **200kWh** to maintain long-term battery performance; a depth of discharge (DoD) of at least 10% is required, so the actual capacity is 90% of the total. So, the minimum capacity of the storage is **230kWh.**

Maximum storable energy:

$$E_{withdrawal,MAX} = 90\% * battery_{capacity}$$

The maximum energy that can be stored by the storage of resources is **207kWh** allowing the REC to participate in the public tender CUNEO 1

withdrawn power:

The minimum energy that needs to be withdrawn during flexibility for the public tender CUNEO 1 is 100kW.

Standard operation battery and charging station: the grid-connected battery plays a crucial role in optimising the use of renewable energy within a Renewable Energy Community (REC). Below is explained the charging and discharging mechanism of the charging station and battery.

Battery discharging phase-charging station:

The charging station is connected to the battery and to the national grid, and its operation is based on an optimised management of the renewable energy produced within the Renewable Energy Community (REC).

When there is a surplus of production from renewable energy sources (RES), both the charging stations and the battery become consumers of the REC, developing the premium tariff for self-consumed energy. Priority is given first to electric vehicles connected to the columns: if the surplus of energy produced by RES is greater than that consumed by the REC consumer and EVs, the excess energy is stored in the battery.

When there are no electric vehicles charging, the energy produced by the RES surplus is fully absorbed by the battery.

If, on the other hand, there is no production from RES and there are electric cars charging, the battery, if it has energy stored, will supply it to the vehicles. If the battery is empty, the cars will draw energy directly from the national grid.

This system maximises the use of renewable energy, reducing the withdrawal from the grid and maximising the economic benefits for the community.

Different scenarios have been analysed to carry out an energetic and an economic simulation of the behaviour of the system; the main thing changing is the energy withdrawn by each car daily and the number of cars daily charging in the station:

- 1) 5 cars withdrawing 280 kWh/month, equal to 1 car withdrawing 50kWh everyday (current scenario based on the analysis of GSE experimentation)
- 2) 5 cars are charged per day, each one requiring 50 kWh.
- 3) 10 cars are charged per day, each one requiring 50 kWh.
- 4) 15 cars are charged per day, each one requiring 50 kWh.

The normalised curve for charging infrastructure used for the simulation is the one described in chapter 2 (profile available on the GSE website):

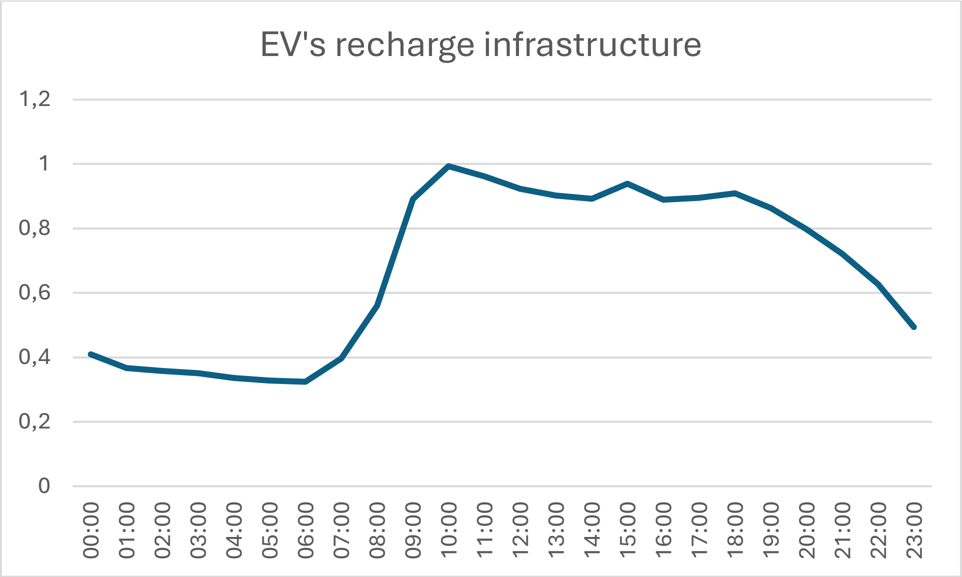


Figure 49:EVs recharge infrastructure normalised curve.

The analysis performed starts from the feasibility studio, optimized plant, analysing the energy hourly injected into the grid and then the consumption made by the REC consumer:

The residual energy not consumed by member of REC has this distribution path:

- If there are cars in charging station, the energy is sent to the cars, if a further excess remains, it is sent to the battery.
- If there are no cars charging all energy is sent to the battery or not consumed.

This procedure is repeated for each hour of the year, providing a comprehensive view of energy production, consumption, and distribution across the community. The main results are summarized in the following table.

	scenario 1	scenario 2	scenario 3	scenario 4
energy absorbed by EVs [kWh/year]	16.800	90.000	180.000	270.000
energy directly in cars [kWh/year]	4.230	19.560	35.833	49.120
energy through battery [kWh/year]	10.089	26.340	28.527	21.965
energy injected by prosumer [kWh/year]	77.580	77.580	77.580	77.580
Self-consumption [%]	43,15%	43,15%	43,15%	43,15%
self consumption with Evs [%]	46,25%	57,48%	69,41%	79,14%
Self-consumption with Evs+ battery [%]	53,68%	76,78%	90,31%	95,24%

Table 24: Energy value and indices different scenario

The first row represents the annual energy consumption of the cars in the different scenarios analysed.

The second row represents the energy that is fed directly into the EVs from the grid (in contemporaneity with the overproduction of RES).

The third row represents the energy absorbed annually by the battery and then consumed by the EVs.

The fourth row represents the energy injected into the grid by the REC prosumer (net of consumption by REC members).

And the last three rows represent the self-consumption indices with and without the battery and charging station.

The following graph shows the behaviour of the consumption, production and balance curve of BESS for three summer days:

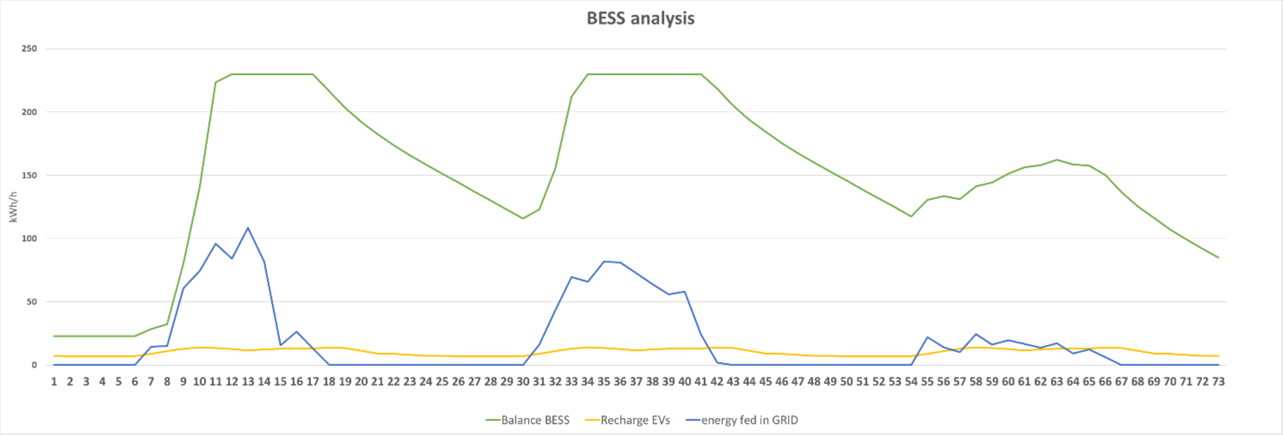


Figure 50: behaviour of the battery in summer day with no flexibility (second scenario)

Behaviour During Flexibility Period:

During the flexibility the behaviour of the battery changes significantly, in order to participate in the flexibility service, we need to absorb energy from the grid (100kW for at least 2 hours) to do this we need to discharge the battery completely to keep enough capacity in the storage to absorb 200kWh. In the 2 hours before the flexibility (10:00-12:00), the battery will inject 100kW into the grid and then absorb the same amount of energy from the grid for the two following hours (12:00-14:00), guaranteeing the flexibility service.

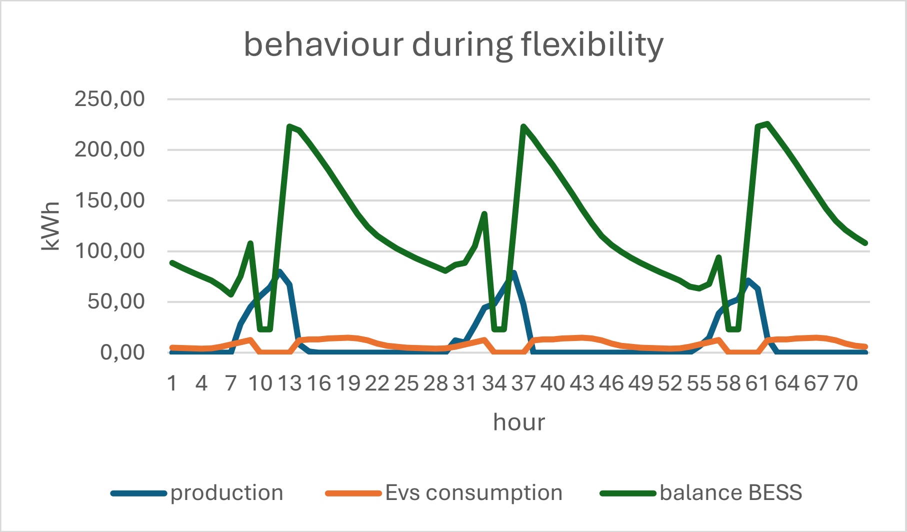


Figure 51: Behaviour of the BESS in flexibility day (second scenario)

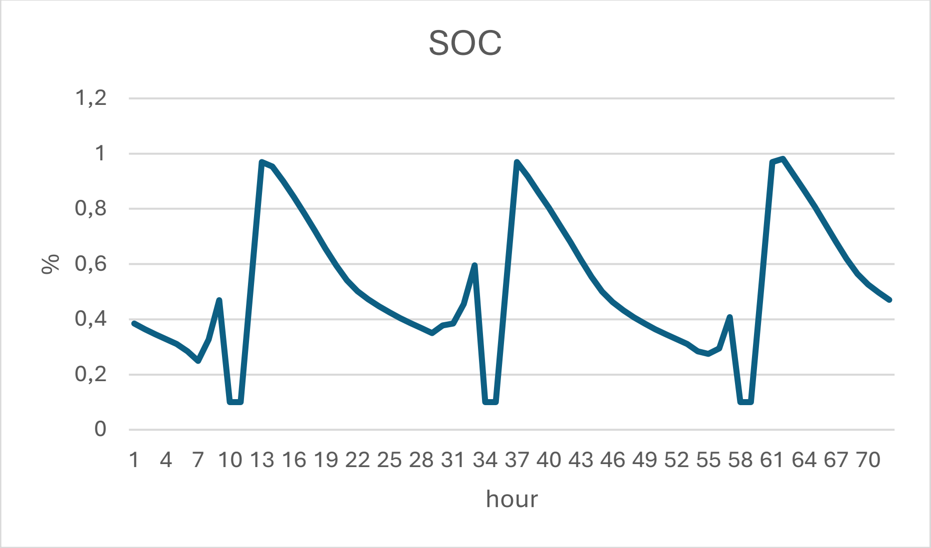


Figure 52: Behaviour SOC of the BESS in flexibility day (second scenario)

The graphs represent the behaviour of the Battery Energy Storage System (BESS) during flexibility days, with certain assumptions made to simplify the algorithm. During the designated flexibility hours, the recharging service is stopped, and the battery is utilized only for flexibility operations, which include both charging and discharging phases (if necessary).

In this scenario, the Renewable Energy Community (REC) is able to participate in the flexibility service through this device, while at the same time creating an EV charging station.

Economic analysis:

The electrochemical battery is an extremely useful device for optimising a REC. However, despite this advantage, the high initial cost of such batteries remains a significant barrier (CAPEX). While there are some economic returns from standard use, these returns really depend on the number of recharges. This section explores whether the additional revenue from the flexibility service could make this device more cost effective.

CAPEX:

The cost of this device is a function of its capacity, nowadays the cost is around 600€/kWh for medium/large scale. To include the cost of installation and connection costs the price is considered **800€/kWh**, so the cost of this device is described by the following formula:

$$CAPEX = unit\ cost\ [€/kWh] * Capacity\ [kWh] = 184.000\ €$$

The battery as an average life of about 10 years with almost no maintenance cost.

Cost:

There is just one cost associated with the energy that enters in the battery:

Recharge Cost: This refers to the price paid for energy drawn from the grid to charge the battery, during his normal use and during the flexibility hours. The cost of this energy is equal to the cost of kWh in electricity bill.

$$Recharge\ cost = Energy\ absorbed\ [kWh] * cost\ electricity\ [€/kWh]$$

Where:

Energy absorbed is the energy withdrawn from the grid during the flexibility service and during the normal usage by the battery. (in this scenario, unlike before, the energy is always recharged from the grid)

Cost electricity: is the cost of the kWh in the electricity bill (0.24 €/kWh)

REVENUES:

Revenues energy fed pre flexibility: In this scenario, energy fed into the grid in the hours before flexibility is available is considered a waste and therefore not remunerated**.**

Flexibility service: The aim of this simulation is to assess the economic viability of the battery, especially focusing on the remuneration of flexibility, to make this economic simulation the price for service and availability have been set at the maximum value of the public tender (availability at €750/MWh and 500€/MWh for the service)

$$Flexibility\ service = Energy\ absorbed\ for\ the\ service\ [kWh]\ *\ number\ activation\ [-] * (availability + service)[€/kWh] = \mathbf{17.000€}$$

Where:

Energy absorbed for the service is the energy withdrawn from the grid during the flexibility service absorbed by the battery. (200kWh/activation).

Number of activations: number of times the flexibility service is requested for the assumption made this is equal to 68 (weekdays in the flexibility months).

Availability service: These are the remunerations for the flexibility service, which, based on the assumptions made, amount to 1.25€/kWh (0.50€/kWh for the service and 0.75€/kWh for availability). This is because the hours of service are equal to the hours of availability.

Extra revenues for increase self-consumption (BESS): This represents the revenue generated by the BESS, which ensures the benefits associated with the role of a smart consumer in the REC. The BESS is a smart consumer because it only charges when it is able to generate the premium tariff.

$$\textit{Premium tariff generated} = \textit{Energy absorbed by BESS}\ [kWh] * \textit{premium tariff}\ [€/kWh]$$

Where:

Energy absorbed by BESS: The energy absorbed by the battery energy storage system (BESS) represents the energy withdrawn from the grid during periods of excess renewable energy generation in normal usage.

Premium tariff: the premium tariff is the valorisation of the kWh in the REC (0.14 €/kWh)

Extra revenues for increase self-consumption (EV): This represents the revenue generated by the EVs in recharging infrastructure, which ensures the benefits associated with the role of a consumer in the REC, ensuring the development of the premium tariff.

$$\textit{Premium tariff generated}\,(2) = \textit{Energy absorbed by EV}\ [kWh] * \textit{premium tariff}\ [€/kWh]$$

Energy absorbed by EV: The energy absorbed by the electric vehicles (EVs) represents the energy withdrawn from the grid during periods of excess renewable energy generation in normal usage.

Premium tariff: the premium tariff is the valorisation of the kWh in the REC (0.14 €/kWh)

Revenues from the recharge EV: The revenues generated by the energy supplied to electric vehicles (EVs) are derived from two distinct energy sources: direct grid supply and battery energy storage system (BESS) integration.

$$\textit{Revenues Energy sold EVs} = (\textit{Energy from BESS to EVs}\ [kWh] + \textit{Energy from grid to EVs}\ [kWh]) * \textit{recharge price}\ [€/kWh]$$

Where:

Energy from BESS to EVs: This represents the quantity of energy that is extracted from the battery energy storage system (BESS) and subsequently injected into the electric vehicle (EV).

Energy from grid to EVs: This represents the quantity of energy that is extracted from the grid and subsequently injected into the electric vehicle (EV).

Recharge price: that is the mean expenditure incurred by electric vehicles (EVs) for energy at fast recharging stations. (0,55 €/kWh).

Scenario of an external electric charge provider:

In this scenario, the charging station is operated by an external provider, and thus the point of delivery (POD) of the charger is not a member of the renewable energy community (REC). Consequently, the premium tariff is not developed (only the POD of the BESS is in the REC). In this scenario, the energy is sold by BESS to the external provider at the cost of procurement (€0.24/kWh). The primary sources of revenue are as follows:

- Flexibility services
- premium tariff development during charging (simultaneous PV feed-in and storage charging)

- Revenues from EV charging (sale of energy to the charging provider)

Investment (€)	**Numbers of cars**			
	1	5	10	15
CAPEX BESS (230 kWh)	184.000 €	184.000 €	184.000 €	184.000 €
Annual cost (€/year)				
Recharge BESS (0,24 €/kWh)	-5.725 €	-8.500€	-8.200 €	-7.000 €
Annual revenues (€/year)				
flexibility	17.000 €	17.000 €	17.000 €	17.000 €
sharing REC. (0,14€/kWh)	1.400 €	3.850 €	4.380 €	3.850 €
Charge EV (0,24€/kWh)	2.400 €	6.590€	7.500 €	6.611 €
Payback time (year)	**12,2**	**9,7**	**8,9**	**9,0**

Table 25:Economic analysis different scenario

The only annual cost is "Recharge BESS" and refers to the energy taken from the grid to recharge BESS during the period of simultaneous RES injection and flexibility. As the number of cars increases, the energy stored in the BESS decreases since priority is given to charging vehicles, directing energy to them instead of storage system.

In this scenario, it is clear that if the number of cars is too low, the revenue from REC sharing remains minimal, making the unit economically dependent on the flexibility service. Vice versa, if the energy demand of the cars is too high, the battery energy storage system (BESS) is rarely charged, as electric vehicles (EVs) take priority over BESS charging. This reduces both the availability of BESS and the revenue from sharing.

Scenario electric charging station belong to the REC.

In this scenario, the charging station is operated by the REC, and thus the point of delivery (POD) of the charger is a member of the renewable energy community (REC). Consequently, the premium tariff is developed. In this scenario, the energy is sold to the electric vehicle at a cost-effective solution for fast charging station(0,55€/kWh).

In this scenario, the initial investment cost (CAPEX) includes the BESS and a charging column for the number of cars of in the scenario (the cost of each charging column is estimated to be 25.000€). When the charging station is included in our control volume, cash flows increase, and the payback time is reduced.

The only annual cost is "BESS charging + charging station" and refers to the energy taken from the grid to charge the EV and the BESS during the period of simultaneous RES injection and flexibility. As the number of vehicles increases, the energy stored in the BESS decreases as priority is given to charging vehicles and energy is directed to them rather than to the storage system.

The primary sources of revenue are as follows:

- Flexibility service
- Additional REC revenues (tariff developed directly from the column, and BESS for self-consumption of PV energy fed into the grid)
- Charge EV, Energy from the grid or BESS to cars (sale of energy via the charging station at 0,55 €/kWh)

Investment (€)		**Numbers of cars**		
	1	5	10	15
CAPEX COLUMN.EV+ BESS (230 kWh)	209.000 €	309.000 €	434.000 €	559.000 €
Annual cost (€/year)				
Recharge BESS + charging station (0,24 €/kWh)	-4.150 €	-23.720 €	-41.500 €	-62.300€
Annual revenues (€/year)				
flexibility	17.000 €	17.000 €	17.000 €	17.000 €
sharing REC. (0,14€/kWh)	1.900 €	6.100 €	8.500 €	9.400 €
Charge EV (0,55€/kWh)	9.500 €	47.600 €	95.200 €	142.800€
Incidence of FLEX/Revenues	60%	24%	14%	10%
Payback time (year)	**8,6**	**6,6**	**5,5**	**5,2**

Table 26:Economic analysis different scenario

In this simulation, the increase in daily EV charging can significantly reduce the payback time, making the flexibility services almost negligible as a source of revenue compared to the revenues generated by EV charging services. By including the charging stations in the control volume and increasing the number of charging vehicles, we can maximize the self-consumption of energy within the Renewable Energy Community (REC) maximizing also this revenue.

Current technologies:

The main manufacturers of this device are Tesla and Atlante, two leading companies in the field of energy solutions and charging infrastructure for electric vehicles. Tesla, known worldwide for its pioneering role in electric mobility and energy storage technologies, offers a wide range of products, including storage systems such as the Tesla Powerwall (domestic size), Megapack [31] (industrial size) and fast charging infrastructure for vehicles. These products not only support greater integration of renewable energy sources and energy self-sufficiency.

On the other hand, Atlante [31] is an emerging and equally relevant player in the European electric mobility infrastructure landscape, with a particular focus on the implementation of high-power charging networks, especially in the public and commercial sectors. Atlante is contributing to the diffusion of charging infrastructures that will accelerate the transition to a low-emission future.

Although operating at different scales and in different markets, the two companies offer complementary solutions in the fields of renewable energy and transport electrification, contributing to the development of a more sustainable and interconnected energy ecosystem.

Tesla BESS (Megapack)

The TESLA device is a substantial accumulation of energy storage, with a capacity on the order of megawatt-hours (MWh). It has been designed to address the challenges posed by the intermittent nature of large-scale renewable energy sources. Its capabilities extend beyond this specific application, and it could potentially contribute to the balancing of larger electricity grids as well.

Figure 53: TESLA Megapack

Atlante BESS

The Atlante BESS is a medium/small-scale battery energy storage system (BESS) with a capacity of 300 kWh. It has been designed with some electric columns integrated to provide fast charging services for electric vehicles (EVs), thereby circumventing the high connection costs typically associated with fast charging services. In this configuration, a portion of the power is drawn from the grid, while another portion is sourced from the BESS.

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Figure 54: Atlante storage with connected EVs charging infrastructure.

The device, situated in Milan, exhibits analogous characteristics (dimensions, functionality, etc.) to those of the BESS examined in this thesis and may be appropriate for all simulations generated by the algorithm developed in this thesis.

Chapter 5: Conclusion

This thesis started exploring the technical and economic feasibility of the renewable energy community of Fossano focused on the installation of photovoltaic systems on the roofs of Confartigianato Cuneo members. Initially, a detailed analysis was conducted to optimise the size of the systems, with the aim of maximising local self-consumption and reducing energy costs. This optimisation highlighted the importance of correctly sizing photovoltaic systems according to members' energy demand, demonstrating that the right configuration can improve both the economic and environmental sustainability of the project.

A crucial aspect of the thesis concerned the simulation of participation in network flexibility through two scenarios. In the first scenario, a centralised storage system was evaluated, linked with electric vehicle (EV) charging stations. In this context, storage acts as a key element to manage excess energy, improving grid resilience, optimization of the Renewable Energy Community and optimising EV charging. In the second scenario, a distributed storage solution was considered, with PV-grid-connected batteries directly connected to photovoltaic systems. This approach showed a high potential for energy flexibility, enabling more efficient energy management at the local level and reducing dependence on external sources.

The results clearly demonstrate that energy communities, supported by flexible storage and management systems, are a key component in the energy transition towards a more sustainable and decentralised model. The interplay between distributed generation, energy storage and active participation in grid flexibility not only improves overall energy efficiency, but also helps to reduce environmental impacts and promote greater energy independence. Furthermore, energy communities offer significant social and economic benefits, creating new opportunities for consumers and stimulating the adoption of innovative technologies.

In conclusion, this thesis not only confirms the feasibility of renewable energy communities, but also emphasises the importance of an integrated approach that includes renewables, energy storage and grid flexibility management. The proposed model represents a concrete solution to address the challenges of the energy transition and promote a more sustainable future, in line with global decarbonisation goals.

List of figures

List of tables

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