POLITECNICO DI TORINO

Energy and Nuclear Engineering: Renewable Energy Systems

Master of Science Thesis

Technical-Economical Feasibility Study for a Renewable Energy Community: The Case Study "Dora 5 Laghi"

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NOMENCLATURE

ARERA Autorità di Regolazione per Energia Reti e Ambiente
CEC Citizens Energy Community
CEP Clean Energy Package
CSC Collective Self-Consumption
CSR Corporate Social Responsibility
ENEA Ente per le Nuove tecnologie, l'Energia e l'Ambiente
ETS Ente Terzo Settore
FiT Feed in Tariff
GHGs Green House Gases
GME Gestore dei Mercati Energetici
GSA Global Solar Atlas
GSE Gestore dei Servizi Energetici
IEM Internal Electricity Market
IRR Internal Rate of Return
ISPRA Istituto Superiore per la Protezione e la Ricerca Ambientale
MASE Ministero dell’ambiente e dello sviluppo economico
MGP Mercato del Giorno Prima
MiSE Ministero dello Sviluppo Economico
NDCs Nationally Determined Contributions
NPV Net Present Value
O&M Operation and Maintenance
PA Public Administration
PBT Pay Back Time
PNIEC Piano Nazionale Integrato per l’Energia ed il Clima
PNRR Piano Nazionale di Ripresa e Resilienza
POD Point of Delivery
PPA Power Purchase Agreement
PUN Prezzo Unico Nazionale
REC Renewable Energy Community
RED Renewable Energy Directive
RES Renewable Energy Sources
RID Ritiro Dedicato
RSE Ricerca sul Sistema Energetico
SDGs Sustainable Development Goals
SEU Sistema Efficiente di Utenza
SME Small and Medium Enterprise
UN United Nations

ABSTRACT

In recent years, there has been a growing recognition of the need to transition to more sustainable and environmentally friendly sources of energy. The finite nature of fossil fuels and the urgent global challenge of climate change have spurred the development and adoption of renewable energy technologies. Among the emerging trends in this field is the concept of Renewable Energy Communities (REC), which are revolutionizing the way we generate, distribute, and consume energy.

Renewable energy communities are localized networks that harness and distribute renewable energy resources within a specific area, such as a neighbourhood, village, or town. These communities are driven by a shared vision of sustainability, self-sufficiency, and the reduction of greenhouse gas emissions. They empower individuals, households, and businesses to actively participate in the production and consumption of renewable energy, transforming them from mere consumers into active prosumers to the clean energy transition. Nowadays REC’s projects are developed mainly by Public Administrations in small municipalities.

The thesis starts with an overview of the current regulatory framework of RECs and then it is dedicated to analysing a real Case Study, the REC *Dora5laghi*, made up of six small municipalities in Piedmont. It will be built in 2024 through a partnership with Environment Park, the company that realized the feasibility study of the REC and where I did the internship. During the internship I had the opportunity to follow the development of REC’s projects and through the Case Study it was possible to define a methodology to assess its technical-economic feasibility and to highlight the advantages that such projects bring in a community, as well as current weaknesses and obstacles faced when approaching them.

The hourly energy consumption is assessed considering municipalities’ end users and obtaining data from their electricity bills. The solar PV production is computed through the use of GIS tools and the PVGIS portal. The REC's energy performance is assessed through the shared energy, the self-consumption, and the self-sufficiency indexes. Besides, a cost-optimal analysis evaluates its economic feasibility, considering investment cost and economic incentives. A sensitivity analysis was carried out in order to consider a variable electricity price and a fluctuating discount rate. In the end, benefits of different nature are considered to evaluate the positive impact on the territory.

Keywords: Renewable Energy Communities, Sustainability, Energy Transition, Public Administrations, Self-sufficiency, Photovoltaic system, Cost-optimal analysis

INTRODUCTION

Renewable Energy Communities (RECs) have emerged as a promising and innovative approach to accelerate the transition towards sustainable and decentralized energy systems. This introduction explores the concept, characteristics, benefits, and challenges associated with Renewable Energy Communities.

A Renewable Energy Community refers to a group of individuals, businesses, or organizations who collaboratively participate in generating, consuming, and managing renewable energy resources within a localized area. These communities strive to foster energy self-sufficiency, reduce greenhouse gas emissions, and promote social, economic, and environmental sustainability. The key characteristic of renewable energy communities is their reliance on a diverse range of renewable energy sources. These can include solar power, wind energy, hydroelectricity, geothermal energy, biomass, and more. By harnessing the power of these clean sources, these communities aim to minimize dependence on fossil fuels and promote a more decentralized and resilient energy system.

This introduction delves into the key characteristics of RECs, which involve a strong focus on renewable energy technologies such as solar photovoltaics, wind turbines, biomass, and micro-hydro systems. Community ownership and governance play a vital role, empowering local stakeholders to make collective decisions on energy projects, resource allocation, and revenue distribution. One of the core principles of renewable energy communities is community ownership and participation. Unlike traditional energy models, where large corporations monopolize the generation and distribution of energy, renewable energy communities are often organized as cooperative or community-led initiatives. Members of these communities have a stake in the decision-making process and the benefits derived from the energy produced. This democratic and inclusive approach, not only fosters a sense of ownership and pride, but also ensures that the benefits of renewable energy are shared equitably among the community members.

Renewable energy communities offer numerous advantages beyond environmental sustainability. By generating energy locally, these communities reduce transmission losses and increase energy efficiency. They also provide greater energy security, as they are less vulnerable to disruptions in centralized power grids. Furthermore, RECs also promote the possibility to couple the renewable plant with a charging station, thus optimizing possible delays between the production time and the consumption time. Moreover, renewable energy communities contribute to local economic development by creating green jobs, stimulating investments, and retaining energy-related revenues within the community.

RECs are also powerful enablers of a sustainable energy transition tackling a significant number of Sustainable Development Goals, such as number 7 “Affordable and clean energy”, number 10 “Reduce inequalities”, number 11 “Sustainable cities and communities” and number 12 “Responsible consumption and production” [1].

Despite the numerous advantages, Renewable Energy Communities also face challenges. These include navigating regulatory frameworks, accessing financing and funding, addressing technical and infrastructural barriers, and ensuring equitable participation and benefits for all community members. Community-based renewable energy projects are typically smaller in scale compared to utility projects. This limited scalability may not significantly impact broader energy needs. Besides, accessing to renewable energy benefits might not be equitable within the community, with certain groups potentially being excluded due to economic constraints or lack of participation. Dependency on Weather Patterns should also be considered: extended periods of cloudy days or low wind can drastically reduce energy generation, impacting the reliability of the energy supply. The availability of renewable resources varies geographically since not all communities have access to consistent sunlight or strong wind, making certain types of renewable energy less viable in some regions.

Storing excess energy for later use, especially in areas with limited access to energy storage technologies, can also be a challenge. This limits the ability to use renewable energy during non-optimal generation times. Besides, rapid advancements in renewable energy technology can render existing systems obsolete, requiring communities to continuously invest in upgrades to stay efficient and competitive. Concerning instead Market volatility, fluctuations in energy prices and government incentives, can impact the economic viability of renewable energy projects, affecting the financial sustainability of community initiatives.

Addressing these challenges and drawbacks requires careful planning, community engagement, supportive policies, and ongoing investment in research and development to make renewable energy communities more sustainable and accessible in the long run.

With RECs development the paradigm based on centralized generation is being abandoned in favour of a system based more and more on distributed generation. According to the Directive of the European Union 2018/2001 deliberated by the European Parliament and by the 11 December 2018 Council on the Promotion of the Use of Energy from Renewable Sources: Available online [2]:
"The move towards decentralized energy production has many benefits, including the utilization of local energy sources, increased local security of energy supply, shorter transport distances and reduced energy transmission losses. Such decentralization also fosters community development and cohesion by providing an economical income source and creating jobs locally".

Focusing on the aforementioned elements, decentralized energy production has to deal with four fundamental aspects:

- exploitation of local energy sources;
- local security of energy supply;
- shorter transport distances;
- reduced energy transmission losses and community development and cohesion.

CHAPTER 1 Renewable Energy Communities

1.1 Regulatory framework

An energy community is an association of users who collaborate to produce, consume, share, and manage energy produced from renewable sources through one or more energy plants installed in their area. The community is formed as a legal entity based on the open and voluntary participation of members and can be made up of local public bodies, companies, commercial activities and/or private citizens. It is therefore a collaborative form of energy, centred on a system of local exchange, which aims to encourage the active participation of citizens in the energy system. It promotes distributed generation and facilitate the transition to renewable sources, reducing users' dependence on the national electricity system.

What are the main forms of community in Italy?

The first is **Collective Self-Consumption (CSC)**, a group of at least two or more end customers acting collectively and being in the same condominium, they produce renewable electricity for their own consumption, storage, and resale.

The second form is the **Renewable Energy Community (REC)**, an aggregation of users who collaborate to produce, consume, and manage energy produced from renewable sources through one or more energy plants in their area and which constitute a legal entity based on an open and voluntary participation of members.

In 2019 the European Commission introduced the Clean Energy for All Europeans Package [3] and two directives with which the regulatory framework was defined for energy communities in the EU: Renewable Energy Directive [4], or RED II, and Internal Electricity Market (IEM) Directive [5].

RED II regulates e promotes collective self-consumption (CSC) and renewable energy community (REC) configurations. Its implementation represents a strong push to the development of renewables to achieve the objective of 42.5% of energy consumption from renewable sources by 2030 [6]. Although they represent an opportunity to contribute to accelerate the energy transition, thus facing climate change, RECs represent still a niche in most national energy markets, with an estimate of around 9.000 communities currently in operation across the EU. European countries have different degrees of development, in particular:

- Germany and Denmark, which immediately recognized the advantages of RECs, are considered pioneers and examples of best practices in identifying and implementing successful energy community models.
- France and Spain, which, in terms of the number of energy communities developed to date and the speed with which they are trying to adapt to this new reality, appear to have similar characteristics to Italy.

An overview of the European and Italian context in which REC initiatives are developed is proposed in this section. Basic knowledge of the history of such aggregative forms is necessary for a deeper understanding of their proper development. Furthermore, to comprehend the evolution of the Italian context is fundamental to anticipate possible problems and future challenges related to the integration and implementation RECs.

1.2 RECs in the European regulatory context

On November 30th, 2016, the European Commission, publishing the Clean Energy Package for all Europeans, introduced the concept of Energy Community, providing two different models: the Citizen Energy Community (CEC) or the community of citizens and the Renewable Energy Community (REC), the renewable communities. Both provide the possibility for community members to collectively carry out activities of production, distribution, supply, consumption, sharing, accumulation, and sale of self-produced energy. More generally they intend to promote the development and acceptance of Renewable Energy Sources (RES) at a local level, fostering participation in the end-user market and facilitating the supply of energy at affordable prices to combat vulnerability and energy poverty with positive repercussions also at an environmental, economic, and social level.

Before the European Directives, some European countries had already formalised the RECs) in their regulatory framework, mostly in energy cooperatives, to actively involve the end customers. Figure 1 reports the trend of energy cooperatives in Austria, Germany, GBR, and Denmark.

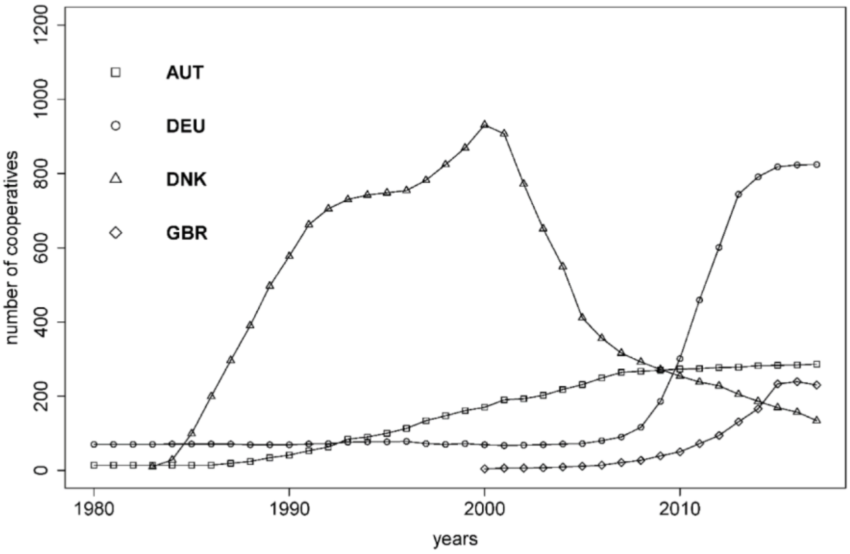


Figure 1: Number of energy cooperatives in Austria, Germany, Great Britain, and Denmark [7].

The framework of the Italian regulatory context relating to the development of Renewable Energy Communities, necessarily starts from the analysis of the development of these new entities within European legislation. The starting point can be identified in the presentation of the Renewable Energy Directive (RED) in 2018, which came into force as part of the Clean Energy Package in 2019. Both plans are developed by the European Union Commission to follow the commitments signed during the Paris Agreement, with the aim of reducing greenhouse gas emissions. Among the various initiatives proposed to achieve the set objectives, the directives present the development of RECs and self-consumption as fundamental. More in detail, the plans define the need to implement the various Member States legislations to guarantee energy consumers and producers a more flexible system, that can protect them, and that guarantees them the possibility of choosing how to produce, store, sell or share their energy [3]. The users are no longer bound to undergo only one or bilateral exchanges with the network, but they acquire the ability to interact, through energy exchanges, also with other users.

Eight legislative acts form the Clean Energy Package, among which two are of key importance such as the RED II Directive (2018/2001) [2] and the IEM Directive (2019/944) [8]. In the RED II Directive, an ambitious target is set: **by 2030, renewable sources must meet 32% of total European energy consumption**. The concept of self-consumption and renewable energy communities is defined for the first time in Articles 2.14 and 2.16, respectively. The IEM Directive, on the other hand, discusses the energy market and lays down rules for the generation, transmission, supply, and storage of electricity, as well as consumer protection aspects, to create an integrated, competitive, consumer-oriented, flexible, and fair energy market.

1.3 RECs in the Italian regulatory context

Figure 2 reports the stages of the energy supply chain according to the operator of the Italian transmission network. RECs introduce new elements of complexity in the management of the electric grid, namely Distributed Energy Sources (DERs), such as photovoltaic systems.

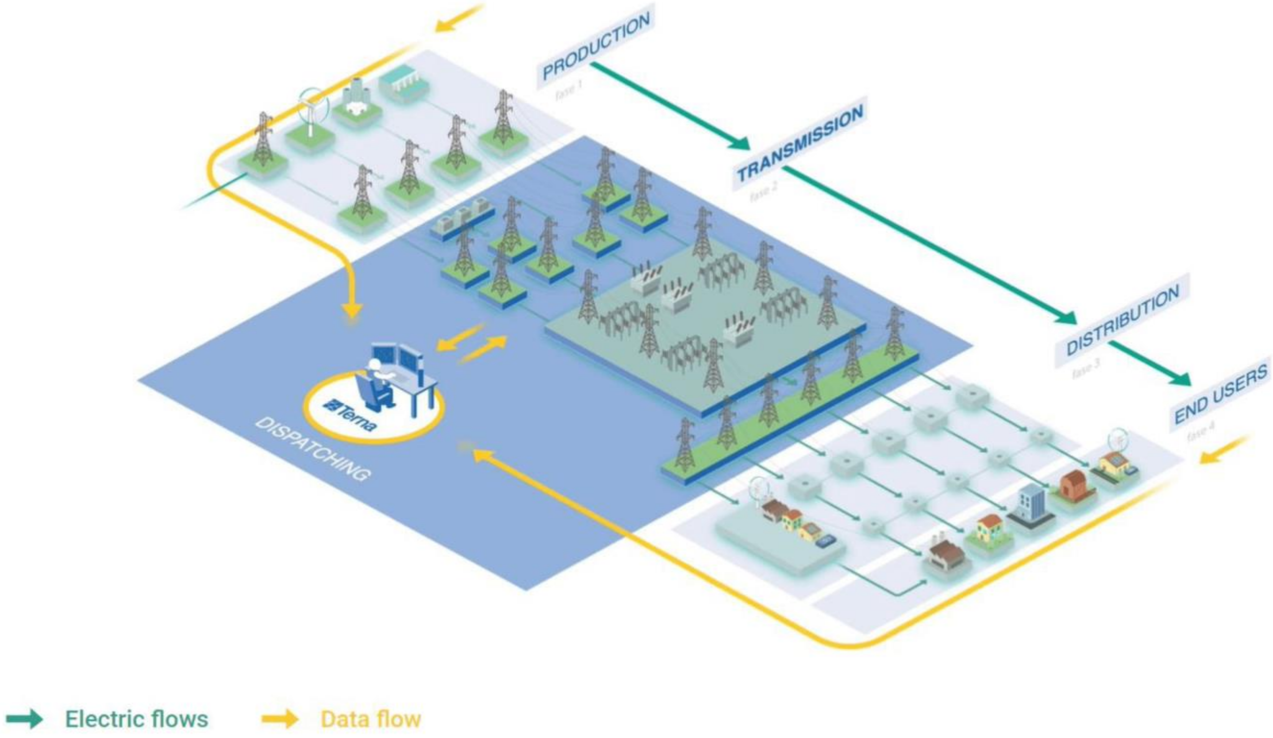


Figure 2:Graphical representation of the Italian energy supply chain [8]

In a system that will have to consider a rising number of decentralised resources, the role of active consumers becomes crucial. They are expected to modify their behavioural attitude from a purely passive one (consumer) to a proactive one (prosumer) by adapting their consumption and production profiles in response to changes in market prices and to provide grid services, if the appropriate conditions are in place to do so. The end-user's role will thus no longer be limited to the choice of the supplier, being able to rely on self-generated or locally produced energy within the energy community equipped with storage systems and energy-sharing policies among users.

Italy is adapting to the European context to encourage renewable energy communities' development and collective self-consumption. During the first half of 2023, Italy was expected to undertake the final steps to complete the transposition process that started with the Decree named*"Milleproroghe"*.

In February 2020, the art. 42-bis (attach number 8) of the Decree "*Milleproroghe*" [9] implements the European Directive RED II and consents CSC activation and REC's implementation allowing the electric energy consumers to join with the purpose of promoting the use of energy from renewable sources. The CER must have the following requirements [10]:

- shareholders or members are people, SMEs, territorial bodies, or local authorities, including municipal administrations;
- participation in the REC cannot constitute the main commercial and industrial activity;
- the main target of the association is to provide environmental, economic or social benefits at the level of community to its shareholders or members or to the local areas in which the community operates, rather than financial profits;
- participation is open to all consumers underlying the same medium/low voltage transformation cabin, including those from low-income or vulnerable families;
- the associated end customers:
  a) retain their rights as end customers, including the right to choose their own seller;
  b) can withdraw at any time without prejudice to any agreed fees in case of early withdrawal for the sharing of investments incurred, which must in any case be fair and proportionate;
  c) regulate relationships through a private law contract that uniquely identifies a subject delegate, responsible for the distribution of shared energy. Participating end customers can, furthermore, delegate to this person the management of payment and collection items towards the sellers and the GSE.

Being an innovation in the regulatory framework, laws regarding renewable energy communities are constantly evolving and changing, thus allowing this configuration to spread in the market. Initially, during a "pilot phase", members that belong to the same community had to be located under the same secondary cabin and had to be connected to the same distribution grid and each plant had to have a maximum installed power of 200 kW. The 199/2021 Decree [11], entered into force on December 15th, 2021, allowed to build larger scale communities, because of softer constraints in respect to the ones set for the pilot phase, mentioned above. Among the most relevant innovations, there are the possibility to include, in the configurations, plants up to a total installed power of 1 MW each, and to enlarge the geographical boundaries, thus allowing to include members that belong to the same primary cabin. To diffuse even more the concept of RECs, the 199/2021 Decree allowed communities to have maximum the 30% of installed power belonging to already existing plants, meaning plants active form before the 15th of December 2021, while instead plants built after the 15th of December 2021 can directly become part of the community.

Table 1 summarizes the differences between the transitional regulatory framework announced by the *Milleproroghe* Decree and the definitive regulatory framework started with 199/2021 legislative Decree.

Table 1: Differences between the transitional regulatory framework and the definitive regulatory framework.

	Art. 42-bis Milleproroghe	D. Lgs 199/2021
REC's perimeter	Secondary MV/LV substation	Primary HV/MV substation
Plants power	200 kW_p	1.000 kW_p

	Art. 42-bis Milleproroghe	D. Lgs 199/2021
Eligible plants	RES systems connected after 3/1/2020	RES systems connected after 12/15/2021; among the existing plants only up to 30% in power
Admitted subjects	Families, SMEs, local territorial entities	Families, SMEs, local territorial entities, third sector, large companies
Available services	Production, consumption, storage, sharing, energy sale	In addition: home automation, energy efficiency, EV charging

Between December 2020 and April 2022, the Technical Rules of GSE regulated access to the incentive service for electricity shared in configurations of CSC and RECs. The document was updated in April 2022 in line with the regulatory framework and with GSE public consultation outcomes.

In November 2022 the MASE document public consultation [12] identifies criteria and methods for granting incentives aimed at promoting the construction of systems powered by sources renewables included in RECs. With this document the interested parties could submit observations and proposals to the decree draft implementation.

In December 2022 Integrated Text on Widespread Self-Consumption (TIAD) was approved[13].TIAD regulates the economic regulation and the requirements/procedures to access to the service for collective self-consumption. For collective self-consumption configurations, among which CSC and RECs, the following economic benefits are expected:

- avoided cost of use of the network;
- incentive for self-consumption
- GSE contribution for electricity submitted into the grid and sold.

In February 2023 the MASE draft [14] implementation Decree came out. It regulates the incentive methods to sustain electric energy produced by renewable energy systems inserted into configurations of self-consumption for renewable energy sharing and defines criteria and methods for granting the contributions provided by the National Recovery and Resilience Plan (PNRR).

The MASE Decree draft (resuming from the MISE 2020 Decree) regulates two types of economic benefits for those who intend to start a REC or CSC configuration:

1) **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.
2) **PNRR contribution** provide non-repayable contributions up to 40% of the eligible costs for the development of 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. The first instalment is paid upon completion of 30% of the works. The balance, equal to 10%, is paid with the final reimbursement request certifying the conclusion of the projects. The expenses must be incurred after the start of the works and proven with payments made by bank transfer.

1.3.1 Maps for primary substations

In conjunction with the publication of the MASE draft, some distributors such as *Edistribuzione* have published on their websites the maps with the indication of the primary electrical substations to which the Points of distribution (PODs) of a given area are linked. According to the article 10 of the TIAD, to access the CSC or to create a REC, the PODs must be under the portion of the distribution network underlying the same primary substation. It is a fundamental prerequisite both to benefit from the incentives and to enhance/valorise self-consumed energy based on the network avoided costs.

Various distributors posted some early versions of the primary substation maps and on September 30, 2023, came into operation a centralized portal with distribution of the national territory in terms of primary cabins managed by the GSE [15]. The interactive map of the conventional areas underlying the primary substations present on the Italian national territory is accessible online. The tool made available by GSE, as required by TIAD, allows to geolocalize the conventional areas and to verify that the connection points for which it is intended to access the service for widespread self-consumption are in the conventional area underlying the same primary substation.

The map (as the following figure shows) can be consulted by entering both the individual address and the geographical coordinates and it allows to find all the relevant information:

- the unique code of the conventional area consisting of 11 alphanumeric digits, for example "AC001E00934").;
- the company distributor name;
- municipal boundaries.

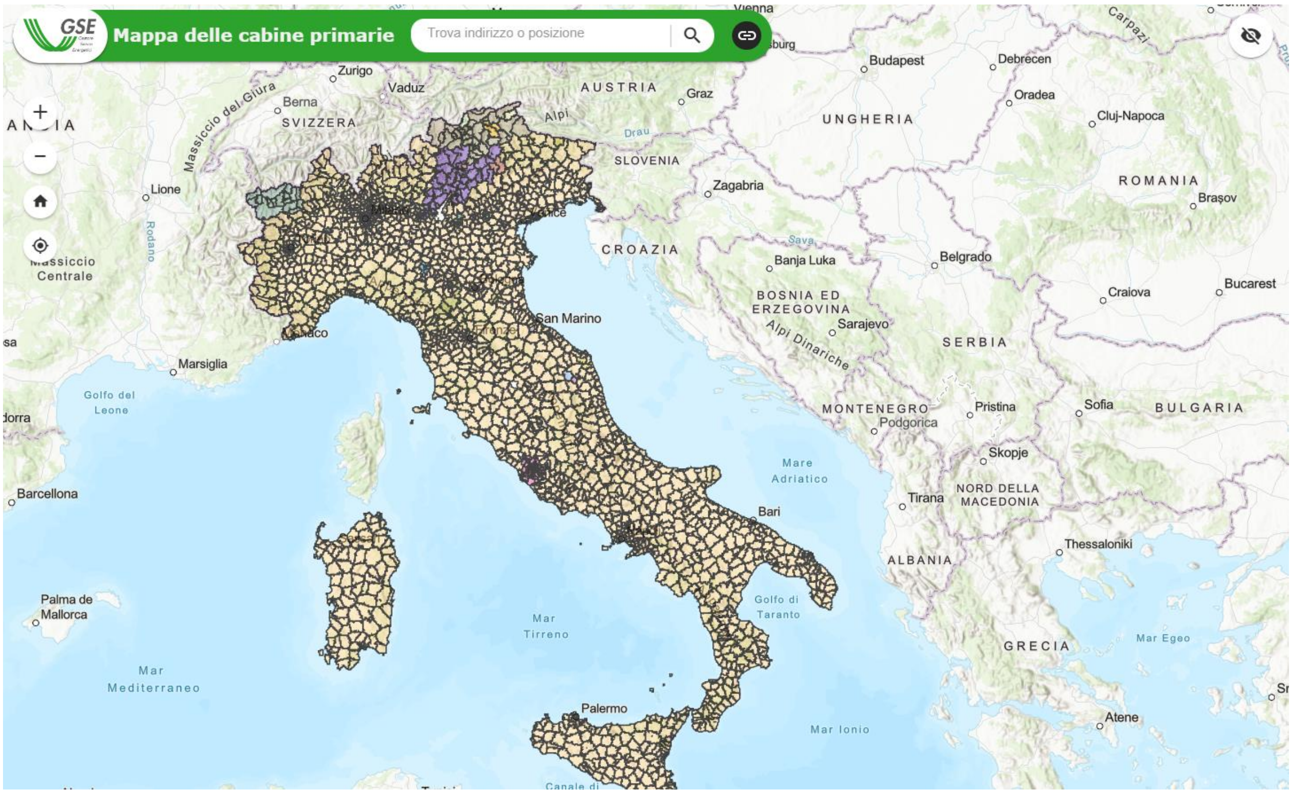


Figure 3: GSE map layout for primary substation.

1.3.2 Advantages and critical issues of the main legal forms of RECs

Under Italian legislation, renewable energy communities are legal entities that can take different forms. Among the main ones emerge (i) the cooperative society, (ii) the third body association (ETS) and (iii) the participatory foundation.

Table 2: Advantages and critical issues of the main RECs' legal forms.

LEGAL FORM	ADVANTAGES	CRITICAL ISSUES
Cooperative	• Suitable for RECs of significant dimensions • Deductible VAT • Only a part of the income is taxable (mutual purpose)	• High management costs • Entry of local authorities subjected to the Consolidated Law on publicly held companies. • Incentives' exemption tax absent
Third body association	• Low management costs • Free entry for local authorities • Simplified procedure for agreements with local authorities	• Absence of patrimonial separation • Non-deductible VAT
Participatory foundation	• Expressly admitted by the Court of Auditors for public-private partnership initiatives. • In case of local authorities' participation,public financing must necessarily be a majority one	• High management costs • In case of participation of public entities, the public contracts code is required. • Citizens have lesser protections from a governance point of view

1.3.3 Missing steps and critical points

There are some critical points related to the regulatory framework and to incentives that could cause a further delay in energy community development in Italy:

1) Long times for the transposition of the legislation and little clarity in the period between the old decree and the entry into force of the new one;
2) Complexity of the administrative/bureaucratic process for the community set-up;
3) Variability of economic benefits based on installed power and consumption profiles with consequent difficulty in evaluating convenience of the investment;
4) PNRR non-repayable contribution addressed to a limited target (municipalities with less than 5 thousand inhabitants).

The robust construction and effective management of RECs require certain aspects to be carefully considered. The ones of a purely social nature, i.e. not referring to the technical-economic conditions considered in the previous paragraphs. These aspects play both as assumptions and as implications of the development of REC and are configured as challenges that must be faced with appropriate tools to avoid risks inefficiency and ineffectiveness of REC projects. The challenge, first of all, and in general terms, is that relating to the first term of the binomial "energy community", that is, the construction (and maintenance) of the community understood as a group of people (legal in this case) which shares objectives, actions and rules for implementing them, but which also has or should have one own identity. Concretely, this challenge consists in the need to build trust around a project (the REC), of motivating subjects to participate or to find the right incentives (economic and otherwise) that they know about generate interest in membership. The latter should not be understood simply as the most predisposed subjects in economic and motivational terms (who can anyway represent a useful trigger for starting the community) but they must be carefully selected to the need to build aggregates that can become true communities.

It is necessary to underline that the challenge of community building can at the same time be configured as an opportunity. In fact, building a REC on pre-existing communities, trust and solidarity in a territory is certainly easier than proceeding with the aggregation of heterogeneous subjects belonging to social contexts and different territories and bearers of different sensitivities. In this sense the territory, and the bodies responsible for its government such as municipalities, are important resources in direct construction or promotion and legitimation of initiatives.

There are some of the 'social risks' to which RECs are exposed:

- low recruitment, low participation, and dropout. The voluntarism of membership is a principal cornerstone of every collective action initiative (which the RECs have in common with the historical cooperatives) and it is the basis of their functioning but what guarantees and limits can be had with respect to the loss consisting of members which can cause membership to fall below a vital physiological (and not legal) threshold;
- dimensional growth and social impact. A certain degree has been detected in experiences like RECs of incompatibility (trade-off) between 'social aspects' (prerequisites and benefits) and dimensional growth. That is, the problem arises in terms of maintaining the community when it expands and differentiates the membership too much and the connection with the territory is lost with consequences in terms of identity, participation, coordination, and local social benefits;
- Reproduction of pre-existing gaps and low social impact, the experience of action initiatives collective like the RECs developed in the last 20-30 years in Europe (see chapter 1) highlight how participation

is mostly the prerogative of social groups medium-high economic, social and educational, with a residual participation share of the larger groups vulnerable and marginal. These dynamic risks reproducing, if not increasing, social gaps pre-existing, which is why a careful analysis of the subjects to be aggregated is more necessary than ever territory in the planning phase of the REC.

1.4 Governance

At the administrative level, a REC must profile itself as a legal entity with open and non-discriminatory participation, whose purpose is to provide environmental, social, and economic benefits rather than financial profits to its members or the territories in which the community operates. Members belonging to a REC continue to benefit from their end-customer status and may also disassociate themselves from the community body at their discretion. Those who wish to create an energy community need to establish a legal entity and define rules to govern the relationships among its members. In addition, it is essential to identify a contact person who will maintain relations with GSE, which is the authority in charge of the monitoring and access to energy valorisation and incentive services. In the case of energy communities, the contact person is the community itself.

Regarding the type of legal entity, various solutions can be opted for (e.g., consortium or cooperative societies). Cooperative or unrecognised social-purpose associations can easily comply with the regulations set in the national framework and provide sufficient flexibility to operate RECs of different sizes involving heterogeneous profiles. The reference rules do not impose a specific legal form but are all consistent in the prescribe objectives and essential characteristics that guide the choice and limit the field.

A REC:

- must be a legal entity, naturally of a collective type since it is a community. It will have toit is therefore a participated entity, with or without legal personality, but with legal subjectivity i.e. with the ability to be the owner of subjective legal situations autonomously from that of members or components, equipped with an organization and its own bodies;
- must not have profit as its main purpose. To be understood, prudentially, both in subjective sense ,as profit for the shareholders, and in an objective sense, as the search for profits, It is important to clarify that it is not a profit-making purpose to give a benefit to the individual participants below form of spending savings, proportional to one's consumption capacity and not in the form of remuneration of the equity investment. This leads to the exclusion of entities that are necessarily with a prevalent profit motive (partnerships and capital companies, except social enterprises ex Legislative Decree 112/2017), and to identify as possible legal forms only those that have or can have a principal purpose other than profit. The profit-making purpose, without prejudice to the non-prevalence, is not excluded: where organizational models are adopted (e.g. consortium company) that allow distribution of profits, clauses must also be included that exclude or limit such distribution.
- The statutes must also comply with the following requirements and contents:
    - main objective consisting in the provision of environmental, economic or social benefits at a global level of community to members or to the local areas in which the community operates;
    - corporate object consistent with what is prescribed by the regulations;
    - right of entry for all those who meet the requirements indicated by the regulations (rule of "open door", without prejudice to the reservation of control to the subjects listed in the art. 31, co. 1 letter b), of the legislative decree 199/2021 located in the relevant perimeter;

- maintenance of end customer rights and right of withdrawal at any time without prejudice to pre-agreed payment of charges for sharing in the investments incurred, however fair and proportionate;
- economic conditions of entry and participation (e.g. membership fees) not excessively burdensome.

The possible governance models are different, and the possible ones are different regulations depending on the relationships between members, to be determined based on their nature (persons, legal entities, public administrations, SMEs). There's the need to diversify the categories of different members with a view to the stability of governance, to the plants' availability, to the costs of investments, and in general to the necessary operation sustainability. Some possible legal forms are briefly described below.

Table 3: Possible legal forms to establish a REC.

POSSIBLE LEGAL FORMS TO ESTABLISH A REC
Recognized and unrecognized associations
Participatory foundations
Consortia and consortium companies
Cooperatives

A typical organizational module compliant and compatible with all the limits described is that of associations (First Book, Title II of the civil code). **Associations** are collective organizations that have a purpose other than profit. Ancillary to institutional activities, they can carry out economic activities, but the distribution of any profits achieved is precluded. They can have legal personality (recognized) or not (unrecognized). The legal personality results in perfect patrimonial autonomy: the assets of the members are separate the latter is always and only responsible for the entity and its obligations. For associations that intend to achieve recognition, however, the possibility of providing categories of members with is not guaranteed different administrative powers: in fact, it appears that in some cases difficulties have been identified by the authorities responsible for the recognition procedure in consideration of the principle of strict democracy (for which everyone the members must essentially have the same administrative powers). Recognized associations are established by public deed and the deed of incorporation and statute must indicate name, purpose, assets adequate to achieve it, headquarters, rules on the organization and on the administration, rights and obligations of members, conditions of admission. The REC could, with the concurrence of all the other requirements established by the legislation, also take the form of a qualified association as ETS Third Sector Body pursuant to Legislative Decree 117/2017 – Title IV (which refer for detailed regulations [16]).

The **participation foundation** is an atypical model of foundation that combines the personal element, typical of associations, and the patrimonial element, characteristic of foundations. It lacks a clear discipline in the legal system except that found in the Third Sector Code (Title IV). In any case, the model presents the advantage of perfect financial autonomy and that of possibility of having members with diversified administrative powers. A public deed is required for incorporation. For Third Sector foundations, a minimum asset of €30,000 is required.

The profit motive is not per se prevalent even in **consortia and consortium companies** (articles 2602 – 2615-ter of the civil code), even if these entities can pursue a profit-making purpose (and therefore in the statute the consortium purpose must be indicated as prevailing and not the profit-making one). Strictly by law, only entrepreneurs could participate in consortia and consortium companies. In fact, the consortium (and the consortium company which is precisely a consortium established in corporate form) to be precise, pursuant to art. 2602 cod. Civ. is the contract with which several entrepreneurs establish a common organization for the regulation or for the carrying out certain phases of the respective enterprises. The possibility is then discussed for non-entrepreneurs to participate in consortia and consortium companies. However, they have long been admitted, with particular reference to consortium companies, even “mixed” structures, i.e. with the participation of members who are “non” entrepreneurs but whose presence is considered instrumental to the realization of the consortium’s objectives (as one might well assume in the case of energy communities).

Cooperatives are companies with variable capital (so the capital can increase or decrease depending on of the entry or exit of members), established to jointly manage a business which aims to provide to members (mutual purpose) the desired goods or services. They are registered in the register of cooperatives. Members can be both natural persons and legal entities and the distribution of profits can also take place to a limited and secondary extent. This is a model certainly suitable for a REC, combining the criterion of per capita voting with the characteristics of the joint-stock company. Cooperative societies allow for bottom-up training and participation is open and democratic as the possibility of assigning control only to some members is excluded (the different categories of members of a cooperative could be used to distinguish the members are located in the Municipalities, but not to give priority to some of them within them categories). The admission and exit of members are very easy as, being a company with variable capital, the variation does not entail modification of the articles of association. The minimum number of members is 9. Public administrations can also participate. For the art. 3 Legislative Decree 175/2016, in fact, “the public administrations can participate exclusively in companies, including consortiums, established in the form of joint-stock companies or limited liability companies, even in a cooperative form". In this case it applies the same rule as for consortia: in the case of a cooperative company established with the presence of public administrations, the methods of incorporation must be observed, and the contents of the established corporate documents must be respected by Legislative Decree 175/2016 for investee and controlled companies. The constitution (art. 2521 of the civil code) must take place by public deed, with subsequent filing to the Business Register.

1.5 Incentives and financing

In Figure 4, as an example, 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) 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.

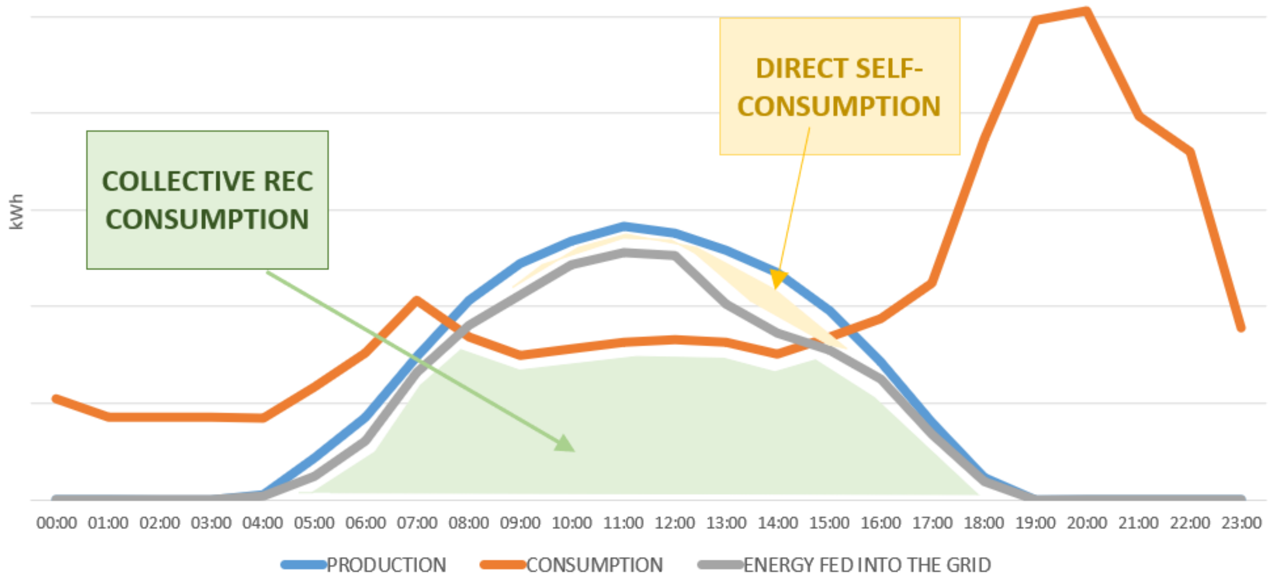


Figure 4: Aggregate REC load profile together with PV plants production.

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.

In order 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 [17].

Energy shared within a REC will favour of an explicit incentive, i.e., an economic compensation expressed in €/MWh. Therefore, the part of energy shared in a year by the REC will be detected and valued at this fee. The discounted charges linked to the technical benefits achieved must be added to the explicit incentive thanks to self-consumption. With the transitional rules, the explicit incentive is set at €110/MWh, to which are added up to approximately €8-9/MWh of returned charges, for a total value of approximately €120/MWh. From the point of view of the definitive legislation, there are changes regarding the incentives linked to energy sharing (Figure 5). For the incentive tariff on shared energy, the publication of the ministerial MASE (Ministry of the Environment and Energy Security, under the previous legislature called MISE) decree is still awaited.

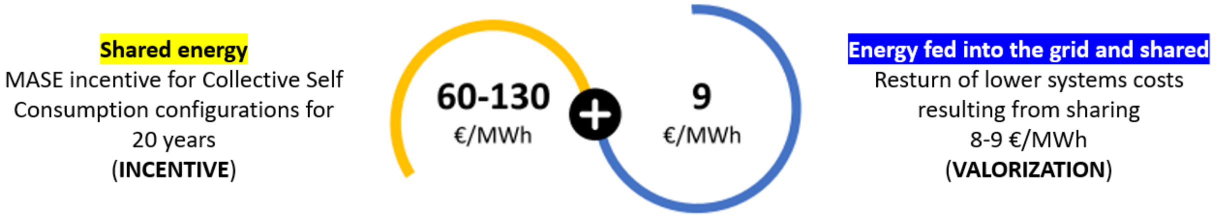


Figure 5: REC's shared energy incentive.

The draft of the new decree provides for an incentive differentiated by the size of the plant. It varies in function of the **hourly zonal price Z_p**: the higher the value of the Z_p, the lower the incentive paid for shared energy and vice versa. The incentive will therefore be characterized by a different minimum and maximum value depending on the plant size (Table 4).

Table 4: Incentive value for shared energy within a REC

PLANT SIZE P	INCENTIVE	MINIMUM INCENTIVE VALUE	MAXIMUM INCENTIVE VALUE
[kW]	*[€/MWh]*	*[€/MWh]*	*[€/MWh]*
P ≤ 200 kW	80 + max (0;180-Z_p)	80	120
200 kW < P < 600 kW	70 + max (0;180-Z_p)	70	110
P > 600 kW	60 + max (0;180-Z_p)	60	100

Furthermore, in the case of photovoltaic plants the incentive is corrected to consider the different levels of insolation related to the different geographical areas.

Table 5:Incentive correction factor for photovoltaic plants

GEOGRAPHICAL AREA	CORRECTION FACTOR
Lazio, Marche, Toscana, Umbria, Abruzzo	+4 €/MWh
Northern Italy (Emilia-Romagna, Friuli-Venezia Giulia, Liguria, Lombardia, Piemonte, Trentino-Alto Adige, Valle d'Aosta, Veneto	+10 €/MWh

In the event that the PA takes advantage of the PNRR capital contributions, a reduction factor F is applied to the incentive previously introduced as follows:

$$Incentive = Incentive \cdot (1 - F)$$

where:

- 'Capital Account Incentive' is the premium rate reduced due to the use of the capital account contribution;
- 'Incentive' is the premium rate without any deduction;
- F is a parameter that linearly varies between 0 (if no capital contributions are envisaged) and a value equal to 0.40 (in the event that the capital account contribution is equal to 40% of the investment). This reduction factor is not applied in the case of energy shared by withdrawal points that are owned

by territorial bodies and local authorities, religious bodies, third sector and environmental protection bodies.

All the energy fed into the grid by the REC production plants can be sold on the market, i.e it is possible to opt for dedicated withdrawal [18]. In 2019 the average valorisation from dedicated withdrawal amounted to around 50 €/MWh. This valuation is defined by the Autorità di Regolazione per Energia Reti e Ambiente (ARERA) and is equal to the hourly zonal price that forms on the Market of the Day Ahead (MGP). It is therefore a market price, characterized by volatility. In 2021, because of an increase in the costs of gas raw materials, an average price of 125 €/MWh was recorded. In 2022, the average price more than doubled, equal to approximately €300/MWh, again caused by the increase in gas raw material costs. In 2023 (current at the time of this writing) the prices of market appear to be tending to decline, however remaining at high values (225 €/MWh).It is important to underline that the incentives provided for RECs (as well as those for collective self-consumers) will replace the on-site exchange mechanism [19], which will be definitively repealed at the end of 2024. The logic is precisely to encourage instant self-consumption instead of deferred consumption over time using the grid as a storage system.

A member of a REC who is a consumer-producer is called prosumer, and the term [20] refers to users that are not just passive consumers but are active actors in the various stages of the production process as producers. They are active players in the management of energy flows, reaching a relative energy autonomy and economic benefits [21]. This implies that prosumers can generate electricity just to meet their own needs (off-grid *prosumption*) and/or generated surpluses for other users feeding energy into the network (on-grid *prosumption*) [22]. Moreover, it is important to clarify the term *prosumption* as the ability to produce a part of what one consumes in a sustainable manner.
A prosumer even before sharing self-produced energy towards the REC, will self-consume a portion or all the energy produced by its own plant in a configuration of Efficient User System (SEU). This share of on-site self-consumption is an additional valorisation (indirect) deriving from the RES plant, connected to the savings achieved in the bill for the quota of energy not taken from the grid. Finally, ARERA provides for a priority for the attribution of shared energy evaluated on an hourly basis of the date of entry into operation of the plant in the context of the REC, i.e., the 'older' plants of the REC configuration will have priority in the allocation of shared energy.

Renewable Energy Communities are part of Mission 2, Component 2 of the National Plan Recovery and Resilience (PNRR) - M2C2: renewable energy, hydrogen, network and sustainable mobility, Investment 1.2 "promotion of renewables for energy communities and self-consumption". It is planned to invest in energy communities and collective self-production structures with a focus on the areas in which a greater socio-territorial impact is hoped for. The investment is aimed at public companies Administrations, families, and micro-enterprises in municipalities with fewer than 5.000 inhabitants, thus supporting the economy of small municipalities, often at risk of depopulation, and strengthening social cohesion. The goal is to provide resources to install approximately 2.000 MW of new electricity generation capacity.

Piedmont region has approved a RES program on October 7th, 2022. With a budget of almost 1.5 billion euros, over 500 million more than in the 2014-20 period, the Program will allow the support of the Piedmont system in facing the great challenges for development, combining relaunching of competitiveness together with and sustainable and inclusive growth.

The Program is divided into five Priorities [24]:

- Priority I - CSR, competitiveness and digital transition (Strategic Objective 1);
- Priority II - Ecological transition and resilience (Strategic Objective 2);
- Priority III - Sustainable urban mobility (Strategic Objective 2);
- Priority IV - Infrastructure for skills development (Strategic Objective 4);
- Priority V - Cohesion and territorial development (Strategic Objective 5).

According to the logic aimed at promoting territorial strategies, REC members (businesses and public bodies) will be able to access the resources following the calls publication for implementation of the various Actions.

CHAPTER 2 Case study: “REC *Dora5laghi*”

The case study analysed in this thesis work is that of the Renewable Energy Community *Dora5laghi*. The driver of this REC project is represented by the Public Administrations of Borgofranco d'Ivrea, Chiaverano, Lessolo, Montalto Dora, Quincinetto and Quassolo. The 6 territories are so called Dora5 Laghi for this project. Municipalities with less than 5.000 inhabitants are included in the PNRR, by mission 2C2.1, investment 1.2 [23]. In Italy, Piedmont and Lombardy are the regions where most of these smaller realities are clustered.

The idea of building a REC came directly from the major of Borgofranco d’Ivrea, Fausto Francisca, who is keen of making his municipality and the surrounding ones more sustainable and efficient. He was also willingness of developing other projects such as SECAP (Sustainale and Energy Climate Action Plan), that includes both actions for the mitigation of CO_2 emissions and for adaptation to climate change impacts, in order to achieve the objectives set by the Covenant of Mayors for Climate and Energy.

Borgofranco d'Ivrea is a small municipality located in the Piedmont region of northern Italy. Situated in the province of Turin, the area is nestled within the picturesque landscape of the Ivrea Morainic Amphitheatre, which is characterized by rolling hills and charming countryside scenery. It is situated approximately 50 kilometres northeast of Turin, the regional capital of Piedmont and it is strategically positioned at the foothills of the Alps, offering stunning views of the surrounding mountain ranges. The area's proximity to both the Alps and the Po River Valley contributes to its unique natural beauty and diverse ecological features.

The call promoted by *Fondazione Compagnia di San Paolo*, has allowed the territory to carry forward the commitments made and start the energy transition process by facilitating the construction of a technical, economic, and social model to create RECs on the territory, that will be built in 2024 through a partnership with Environment Park, the company commissioned to realize the feasibility study of the REC.

2.1 Objective

The initiative/project involves carrying out a series of technical, administrative, legal, and territorial animation activities aimed at establishing a Renewable Energy Community called *Dora5Laghi* within a cluster of six neighbouring or adjacent municipalities coordinated by Borgofranco d' Ivrea. The Municipalities involved are Borgofranco d'Ivrea, Chiaverano, Lessolo, Montalto Dora, Quincinetto, Quassolo.

The REC *Dora5Laghi* will be promoted by the 6 Municipalities, but the plan is to involve citizens, SMEs and third sector bodies, religious bodies, and associations. All these subjects will be able to obtain benefits and advantages in different ways. Those in conditions of **energy poverty** will be beneficiaries of specific services such as: energy efficiency interventions and installation of photovoltaic systems in their homes, purchase of IT media and strengthening of social welfare services through collaboration with municipal social services. **Citizens and SMEs** will benefit from agreements and concessions with commercial activities and municipal services offered by local sponsors and PAs. All services provided by the REC will be managed through an IoT platform, developed ad hoc, usable by all members and thanks to which it will be possible to benefit from the services, agreements and concessions provided by the partners and sponsors of the project.

The initiative involves a multidisciplinary group of professional experts who can support the Municipal Administrations in a series of analyses and insights necessary for the establishment of the RECs and their subsequent operation and management. In fact, the objective of the approved project is to promote the development of more RECs in the reference area. Feasibility studies are the basis for equipping the territory of tools for the realization of each one.

This study makes possible to pursue specific objectives of environmental policies and territorial measures to fight against climate change, valorising the territorial peculiarities, diversifying by source of procurement, as well as promoting interventions or services in favour of sustainable and shared mobility like the development of infrastructure and services for recharging electric vehicles. One of the goals is to involve a specific number of users in situations of economic hardship. The fight against the phenomena of energy poverty also takes place through energy redevelopment interventions in the social sphere.

2.2 Expected results

The expected results consist mainly in the realization of a roadmap with the strategies to be implemented for the creation of RECs in the area. From a quantitative point of view, the first result consists in the census of energy consumption, analysing the electricity bills and then calculation of the potential RES production in public areas through the software PVgis/QGIS for all the municipalities of the Cluster. The strategies developed allow the further step to implement concrete actions for the creation of a REC, involving citizens and the economic fabric. From an economic point of view, one of the main results consists in the generation of economic flows and jobs at the local level, brought by the creation of RECs and the need to install new RES plants, thus creating investments. The main expected result is to increase the local generation capacity of renewable energy in the area to enhance energy security and resilience. It requires collaboration among community members, local government, energy providers.

2.3 Roadmap

The activities implemented for this cluster can be divided into four macro groups: technical, administrative-legal, social and involvement of subjects eligible for RECs (families, SMEs, local authorities, third sector, religious and research bodies).

The **first technical engineering activity** has the aim of identifying the potential for production and consumption of renewable energy, in RECs configuration in the territories involved in the initiative, through a series of analyses:

- definition and quantification of the users present in the territories of the six Municipalities;
- identification of electricity consumption aggregated by sector and type of user;
- identification of existing RES plants and in particular those connected from 1/3/2020 and 15/12/2021 eligible under the regulations currently in force (art. 42 bis *Milleproroghe* and Legislative Decree 199/2021) for the REC configuration;
- identification of the installable potential of RES systems, in particular PV, on the roofs of public, municipal, and private buildings (residential or owned by entities eligible for REC);
- identification of the first configurations of (existing) renewable energy producers, both public and private, and consumers in order to start the RECs in the shortest possible time;
- identification of the sites where to install the new PV systems that can be financed by the future PNRR announcements;

- feasibility study of these plants joined by economic and financial analyses to demonstrate their profitability and economic sustainability.

The **second activity of an administrative-legal nature** has the objective of formally establishing the REC and will be developed in parallel with the technical activities to reduce times and prepare the territory for participation in the PNRR announcement. This activity is considered particularly delicate as the choice of the legal and administrative form of the REC will determine the responsibilities and obligations of future administrators as well as any administrative management costs. In fact, as explained in chapter 1.4, there are numerous possible legal forms that currently comply with the requirements defined by the national regulations on RECs. By way of example it is possible to cite: recognized and non-recognised associations, third sector bodies, consortia or consortium companies, cooperatives, participatory foundations. Each of these may have pros and cons and aspects to consider (who is responsible for the obligations? with what assets? Is it necessary to provide an initial capital? who pays it? Etc.). The few examples of RECs existing on the national territory and recognized by GSE cannot fully represent replicable models as the conditions in the individual territories are different, in relation to the level of involvement of the PA or the different number and type of members. It requires a tailor-made work which from time to time may identify different legal forms. Therefore, the activities that are intended to be carried out by involving legal experts are:

- identification of the legal form of the REC *Dora5Laghi;*
- definition of the REC statute;
- definition of membership and exit rules for members;
- definition of the roles of public bodies and private entities participating in the REC;
- establishment of the legal entity REC *Dora5Laghi.*

The **third activity** then has the objective of defining the **operating mechanisms and services offered by the future REC *Dora5Laghi*** to manage future revenues to implement policies of a social nature and to combat the phenomenon of energy poverty and the growing "high bills". It provides:

- economical support to the population in difficulty to contain the increase in energy costs due to the current international crises which are having strong repercussions on the energy market resulting in the phenomenon of high bills;
- establishment of a fund for future investments in renewable energy production plants with the aim of increasing energy production and the proceeds from the REC *Dora5Laghi*;
- definition of the type of services to support members (e.g., energy efficiency interventions and installation of new photovoltaic systems, purchase of IT media and strengthening of social-welfare services through collaboration with municipal social services, agreements and concessions with commercial activities and municipal services offered by local sponsors and PA);
- definition of the rules for the distribution of GSE contributions and development of an IOT platform to manage the energy-social services that the REC will be able to provide to its members.

The **fourth activity** finally has the objective of **involving the greatest number of subjects eligible for the energy communities**, from the municipal territories involved in the new REC *Dora5Laghi*. This activity aims to involve citizens, families, SMEs and third sector and religious bodies in the entire process of designing and developing the REC. Meetings may be organized in all the municipalities involved to communicate the progress of the activities, collect indications and suggestions in a participatory process involving the communities themselves. This macro activity allows the municipal administrations involved to develop a shared action that respects the needs of the population.

Figure 6: Financed activities' roadmap.

2.4 Economic and social impact

Thanks to the funding disbursed, it is possible to manage effectively and efficiently the funding opportunities made available from the PNRR. The National Recovery and Resilience Plan (PNRR) is a term primarily associated with the European Union's response to the economic and social challenges posed by the COVID-19 pandemic. It's a framework that member states use to outline their strategies for recovery, resilience, and transformation in the aftermath of the pandemic. Key aspects of PNRRs include:

- **Funding:** PNRRs involve significant funding from the EU's Recovery and Resilience Facility, which provides financial support to member states to help them address the economic and social impacts of the pandemic;
- **Reforms and Investments**: each member state develops its own PNRR, which outlines a combination of reforms and investments aimed at boosting economic growth, enhancing resilience, and promoting sustainable development;
- **Focus Areas:** PNRRs typically cover a range of areas, including but not limited to digitalization, healthcare, education, infrastructure, green transition, and social policies;
- **Green Transition:** many PNRRs have a strong focus on promoting the green transition, which involves investments in sustainable and renewable technologies, energy efficiency, and climate mitigation and adaptation measures.

On the analysed territory, the targets of the Announcement are to:

- promote actions with a return for the public bodies, as well as for the communities that they serve;
- stimulate the partnerships between little local public bodies aimed at expanding the scale of design and implementation of the interventions;
- strengthen the skills and the experience of the staff working for the territorial public bodies' institutions, creating an asset in terms of know-how that could be further exploited.

As explained in chapter 1.5, the National Recovery and Resilience Plan includes Renewable Energy Communities under Mission 2: Green Revolution and Ecological Transition aims to increase the share of renewable energy. To achieve this goal, multiple investments are planned, including 2,20 billion euros for the development of renewable energy communities and self-consumption in Municipalities with less than 5.000 inhabitants.

The implementation proposal developed by MASE provides for an allocation of 2,200 million euros of resources for the provision of capital contributions up to 40% of the eligible costs for renewable energy plants (including upgrades) inserted within energy communities and collective self-consumption configurations. Systems up to a maximum of 1,000 kW may be incentivized, with a maximum financing cost equal to €1,500/kW for systems up to 20 kW, €1,200/kW for systems with power exceeding 20 kW and up to 200 kW, 1,050 €/kW for systems with power exceeding 200 kW and up to 600kW, and 1,050 €/kW for systems with power exceeding 600 kW and up to 1,000 kW; the benefit will be paid by the GSE in several tranches, regarding the progress of the works.

To access this contribution, it is necessary that the start of work occurs after the date of submission of the application for contribution (eligible expenses must be incurred after the start of the works), as well as being in possession of the qualification for the construction and operation of the plant and the estimate connection to the electricity grid definitively accepted. The plants that benefit from the contribution must enter into operation within eighteen months from the date of submission of the request, and in any case no later than June 30th, 2026. The aforementioned provisions are those currently contained in the MASE draft decree e will have to be verified when the notices relating to the PNNR incentives are released.

2.5 Users' identification and their characteristics

The study of municipal RECs starts from a basic configuration in which only renewable source plants and electricity utilities owned by the municipalities are considered. Later, it is assumed the penetration of a growing number of domestic users and of small companies in the community. The information collected to identify the surfaces on which to hypothesize the installation of electricity production plants from solar sources, concern:

- the POD of any building on which to place the photovoltaic system, whose the energy produced can go partly into physical self-consumption and the remaining part introduced into the grid to be valorised as shared and incentivized energy;
- the address of the building or land involved in the construction of the system;
- a brief description of the building, for example if it is the town hall, a school, a sports hall, and so on;
- the surface of the ground or the roof of the building, providing for the latter also a brief description of its type (for example if it is a flat or pitched roof);
- the exposure of the roof pitch(es) or the ground, reported;
- the geographical coordinates of the installation site of the system, to facilitate correct identification of the indicated surface.

The first step is to identify the users present within the area, associating their annual consumption with each of them. For each Municipal building in the territory the following information have been analysed:

- POD location addresses;
- annual and monthly consumption of electricity divided in the three bands F1, F2, F3;
- type of subject (registered to the municipalities or to other entities);
- type of user (non-domestic, schools, libraries, town hall).

In Figure 7 the steps followed in this study are shown.

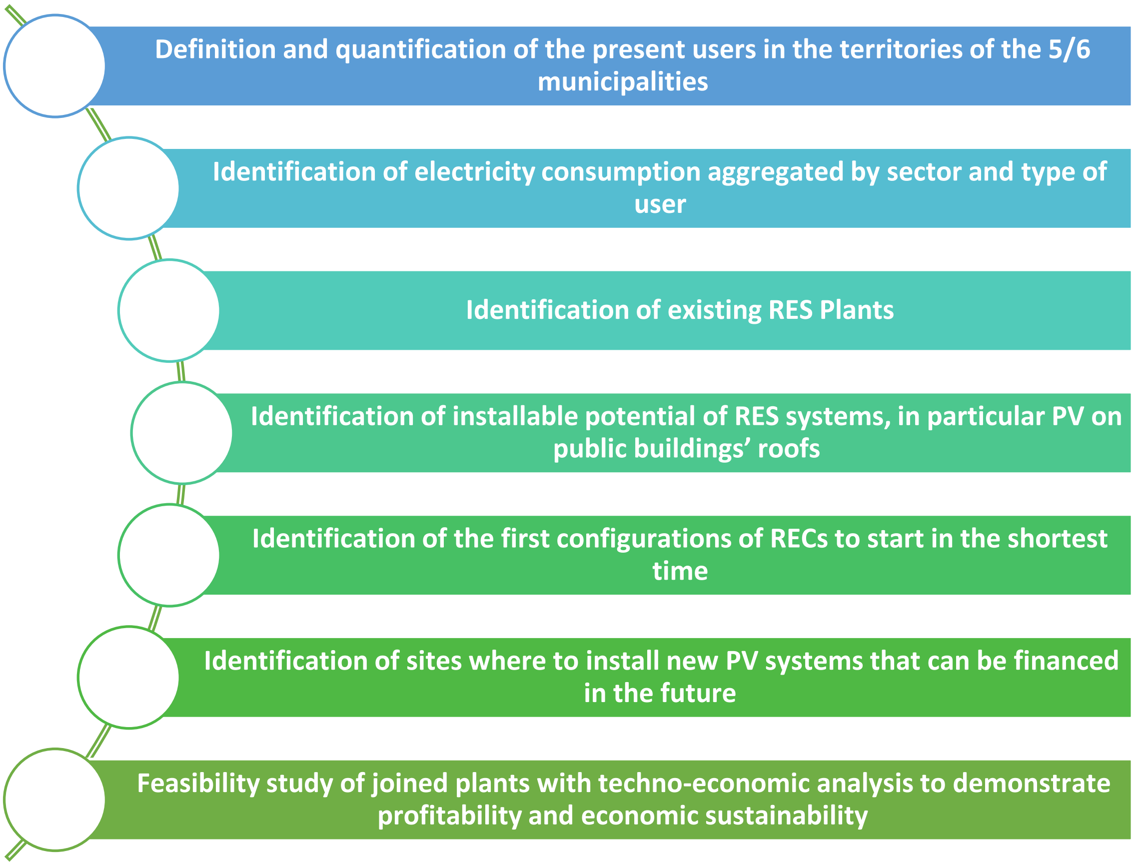


Figure 7: Summarized approach in this study (personal elaboration)

CHAPTER 3 Methodological approach

The analysis requires the annual hourly load profiles of all the electrical users included in the configuration and the annual hourly production profiles of the REC's renewable source plants, to be combined to calculate the REC’s energy flows. Therefore, to carry out the study, a preparatory activity of collection and pre-processing of the essential data is required.

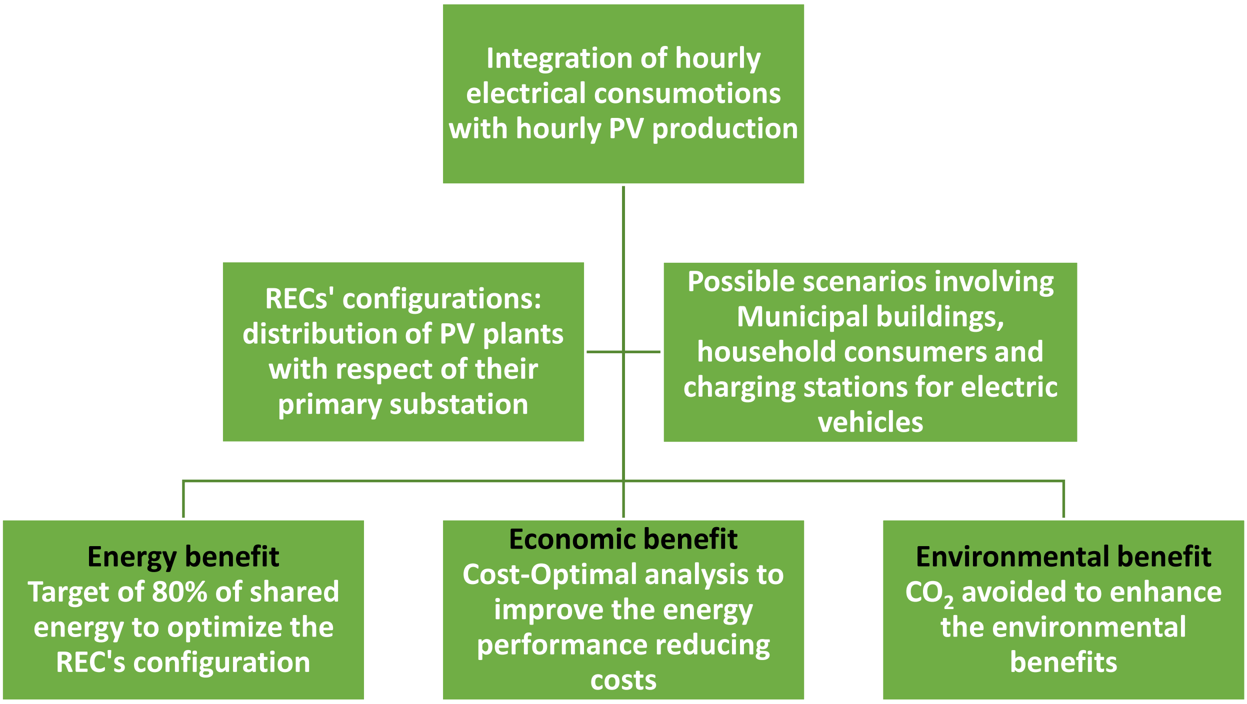


Figure 8: scheme of adopted methodology (personal elaboration).

3.1 Buildings and their electricity consumption

The feasibility study for the establishment of RECs in the territory has begun with the census of the building stock of each Municipality. It has been asked to municipal administrations to share the list of PODs of municipal utilities, with related characteristics such as the type of user. In Table 6 below there is the list of buildings with their locations provided by the municipal technical office.

Table 6: List of Municipal buildings to start the feasibility study.

CODE	MUNICIPALITY	USER	ADDRESS	POD	ROLE
1BO	Borgofranco d'Ivrea	Sede Protezione Civile	Piazza Pertini 3	IT001E03946765	Prosumer
2BO	Borgofranco d'Ivrea	Casa Campiglie	Via caporale Ardissone	IT001E03945705	Prosumer
3BO	Borgofranco d'Ivrea	Campo sportivo	Orla Riccio	IT001E01337959	Prosumer
4BO	Borgofranco d'Ivrea	Materna Gioncaretto	Via Guido Rossa 12	IT001E01337586	Prosumer
5BO	Borgofranco d'Ivrea	Comune di Borgofranco	Via Mombarone 3	IT001E01337334	Prosumer
6BO	Borgofranco d'Ivrea	Biblioteca	Via Marini 38	IT001E01337180	Prosumer
7BO	Borgofranco d'Ivrea	Salone Choc	Via Marini 74	IT001E01337161	Prosumer
8BO	Borgofranco d'Ivrea	Materna San Germano	Via Palma 8	IT001E01336890	Prosumer
9BO	Borgofranco d'Ivrea	Elementari	Via Roma 25	IT001E01336862	Prosumer
10BO	Borgofranco d'Ivrea	Magazzino	Via Baio 47	IT001E01336460	Prosumer
11BO	Borgofranco d'Ivrea	Ex scuola Elementare	via Andrate 82	IT001E01336259	Prosumer

CODE	MUNICIPALITY	USER	ADDRESS	POD	ROLE
12BO	Borgofranco d'Ivrea	Cimitero Baio Dora	Via Ivrea	IT001E01336063	Consumer
13BO	Borgofranco d'Ivrea	Materna Baio	Via Nicoletta 2	IT001E01335997	Prosumer
14BO	Borgofranco d'Ivrea	Ex materna Baio	Via Presbitero 11	IT001E01335817	Prosumer
15BO	Borgofranco d'Ivrea	Archivio storico	Via dei Ribelli 18	IT001E00507866	Prosumer
1QUA	Quassolo	Comune di Quassolo	Piazza Violetta 5	IT001E01296013	Prosumer
2QUA	Quassolo	Fontana della piazza	Piazza Combattenti	IT001E01296118	Consumer
3QUA	Quassolo	Punto acqua	Via San Gregorio 18	IT001E02983612	Consumer
4QUA	Quassolo	AIB Pro Loco	Piazza Violetta 12	IT001E01296001	Prosumer
5QUA	Quassolo	Cimitero	Via San Gregorio 5	IT001E03959967	Prosumer
6QUA	Quassolo	Salone deposito cucina	Via Solferino 2	IT001E01295972	Prosumer
7QUA	Quassolo	Ex scuola	Via del Ponte 2	IT001E01296149	Prosumer
8QUA	Quassolo	Sala musica	Via Solferino 2	IT001E01295971	Prosumer
9QUA	Quassolo	Municipio	Piazza Municipio 1	IT001E00347595	Prosumer
10QUA	Quassolo	Torre Campanaria	Piazza Municipio	IT001E01295995	Prosumer
11QUA	Quassolo	Ambulatorio medico	Piazza Violetta 5	IT001E03945625	Consumer
12QUA	Quassolo	Cantina comunale	Via Garibaldi 8	IT001E03945626	Consumer
1QUI	Quincinetto	Campo sportivo	Loc. Ghiaro via Bredda	IT001E00257992	Prosumer
2QUI	Quincinetto	Auditorium	Via XXV Aprile 2	IT001E10213011	Prosumer
3QUI	Quincinetto	Punto informazione turistica	Via Molino	IT001E01295549	Prosumer
4QUI	Quincinetto	Municipio	Via Val 5	IT001E01295809	Prosumer
5QUI	Quincinetto	Sedi associative	Via Stazione 32	IT001E01295228	Prosumer
6QUI	Quincinetto	Scuola materna	Via Comm. Buat 13	IT001E02137250	Prosumer
7QUI	Quincinetto	Scuola elementare	Via Comm. Buat 11	IT001E01295320	Prosumer
8QUI	Quincinetto	Biblioteca	Via XXV Aprile 20	IT001E00317857	Prosumer
9QUI	Quincinetto	Ambulatorio	Via Piemonte 6	IT001E01295323	Prosumer
10QUI	Quincinetto	Centro anziani	Via Piemonte 6	IT001E03940574	Prosumer
11QUI	Quincinetto	Salone ballo	Via XXV Aprile 2	IT001E03961064	Prosumer
12QUI	Quincinetto	Palestra	Via val Palestra	IT001E01295808	Consumer
1MO	Montalto Dora	Impianti sportivi	Via Vecchiolino 31	IT001E04552025	Consumer
2MO	Montalto Dora	Sede scuola di musica	Via Aldo Balla 15	IT001E01302273	Prosumer
3MO	Montalto Dora	Alloggi	Via Casana 6	IT001E04552021	Prosumer
4MO	Montalto Dora	Pompe antincendio	Via Aosta 81	IT001E01870069	Prosumer
5MO	Montalto Dora	Biblioteca civica	Piazza IV Novembre 0	IT001E03939458	Prosumer
6MO	Montalto Dora	Spazio espositivo del parco archeologico	Piazza IV Novembre 3	IT001E03939726	Consumer
7MO	Montalto Dora	Palazzo comunale	Piazza IV Novembre 3	IT001E03939464	Prosumer
8MO	Montalto Dora	Casa passaggio livello (ex casermetta)	Via Martinis 19	IT001E03944926	Prosumer
9MO	Montalto Dora	Sede associazione	Piazza IV Nov. 6 bis	IT001E03939727	Prosumer
10MO	Montalto Dora	Impianti sportivi	Via Vecchiolino 31	IT001E04552024	Consumer
11MO	Montalto Dora	Depuratore acqua	Via Braidella	IT001E04552022	Prosumer
12MO	Montalto Dora	Municipio	Piazza IV Novembre 2	IT001E04552020	Prosumer
13MO	Montalto Dora	Saletta riunioni	Piazza PRAT 2	IT001E04552027	Consumer
14MO	Montalto Dora	Anfiteatro	Via Vecchiolino 1	IT001E04552023	Prosumer
15MO	Montalto Dora	Centro incontri	Via Roma 1	IT001E04552028	Prosumer
16MO	Montalto Dora	Impianti sportivi	Via Vecchiolino 31	IT001E04552026	Consumer
17MO	Montalto Dora	Centro del lavoro	Via Mazzini 54	IT001E04552030	Prosumer
18MO	Montalto Dora	Asilo nido	Via Ivrea	IT001E04552031	Prosumer
19MO	Montalto Dora	Diga lago Pistono	Strada delle Vigne	IT001E00300534	Consumer
20MO	Montalto Dora	Associazione sportiva dilentantistica	Regione Ghiare 2	IT001E04552038	Consumer
21MO	Montalto Dora	Ambulatorio medico comunale	Via Mazzini 52	IT001E04552029	Consumer
22MO	Montalto Dora	Cimitero	Reg.Trinità Via Martinis	IT001E04552037	Consumer
23MO	Montalto Dora	Scuola elementare	Via Matteotti 1	IT001E04552040	Prosumer
24MO	Montalto Dora	Scuola media	Via E. De Filippo 14	IT001E04552039	Prosumer
25MO	Montalto Dora	Protezione civile	Via Casana 8	IT001E04620338	Prosumer
26MO	Montalto Dora	Edifico diga/pompe acquedotto	Reg. Montaragna 19	IT001E02860710	Prosumer
1CHI	Chiaverano	Ufficio turismo	Corso Zuffo 4	IT001E01325222	Prosumer
2CHI	Chiaverano	Museo del fabbro	Via Ivrea 3	IT001E01324879	Prosumer
3CHI	Chiaverano	Cooperativa acqua potabile	Corso Zuffo 12	IT001E01325218	Prosumer
4CHI	Chiaverano	Ecomuseo anfiteatro morenico di Ivrea	Corso Centrale 53	IT001E01324895	Prosumer
5CHI	Chiaverano	Sede per associazioni	Via IV Alpini 10	IT001E01325066	Prosumer

CODE	MUNICIPALITY	USER	ADDRESS	POD	ROLE
6CHI	Chiaverano	Case Perona	Via Montalto Dora ?	IT001E01324926	Prosumer
7CHI	Chiaverano	Biblioteca/foresteria	Piazza Marconi	IT001E01324948	Prosumer
8CHI	Chiaverano	Palazzetto multiuso	Piazza Ombre	IT001E02249838	Prosumer
9CHI	Chiaverano	La rotonda	Via Casassa	IT001E01324843	Consumer
10CHI	Chiaverano	Palazzo comunale	Piazza Ombre	IT001E01325177	Prosumer
11CHI	Chiaverano	Scuola elementare Pertini	Via Andrate 4	IT001E01324468	Prosumer
12CHI	Chiaverano	Centro di incontro	Via Andrate 2	IT001E01324469	Prosumer
13CHI	Chiaverano	Teatro Bertagnolio	Via del Teatro 19	IT001E01324790	Prosumer
14CHI	Chiaverano	Scuola dell'infanzia	Piazza Ombre	IT001E02249839	Prosumer
15CHI	Chiaverano	Cooperativa acqua potabile	Via Peronetto 42	IT001E01324241	Prosumer
16CHI	Chiaverano	Scuola dell'infanzia	Casale Terrico Sotto 1	IT001E10194135	Prosumer
1LE	Lessolo	Ex scuola	Via Mario Franza 71	IT001E04387200	Prosumer
2LE	Lessolo	Scuola elementare	Via Battisti 4	IT001E04387197	Prosumer
3LE	Lessolo	Cimitero	Via Roveto	IT001E02486872	Consumer
4LE	Lessolo	Scuola materna	Via Vittorio Veneto 29	IT001E02028047	Prosumer
5LE	Lessolo	Municipio	Via Cesare Battisti 3	IT001E04387195	Consumer
				IT001E04387196	Consumer
6LE	Lessolo	Mercato	Via IV Novembre	IT001E04387194	Consumer
7LE	Lessolo	Punto acqua	Via IV Novembre	IT001E02113867	Consumer
8LE	Lessolo	Scuola media	Via Caffaro Allera	IT001E04387202	Consumer
9LE	Lessolo	Palestra	Via Caffaro Allera	IT001E01304819	Prosumer
10LE	Lessolo	Biblioteca	Via Battisti 9	IT001E04398162	Consumer

The 91 buildings shown in Table 6 have different uses:

- 16 are intended for schools;
- 27 buildings host associations, meeting centres and clinics;
- 4 buildings house museums;
- 5 libraries;
- 10 house the municipal offices;
- 3 host ERP accommodation;
- 3 warehouses.
- 10 water points;
- 4 cemeteries;
- 9 are sports buildings.

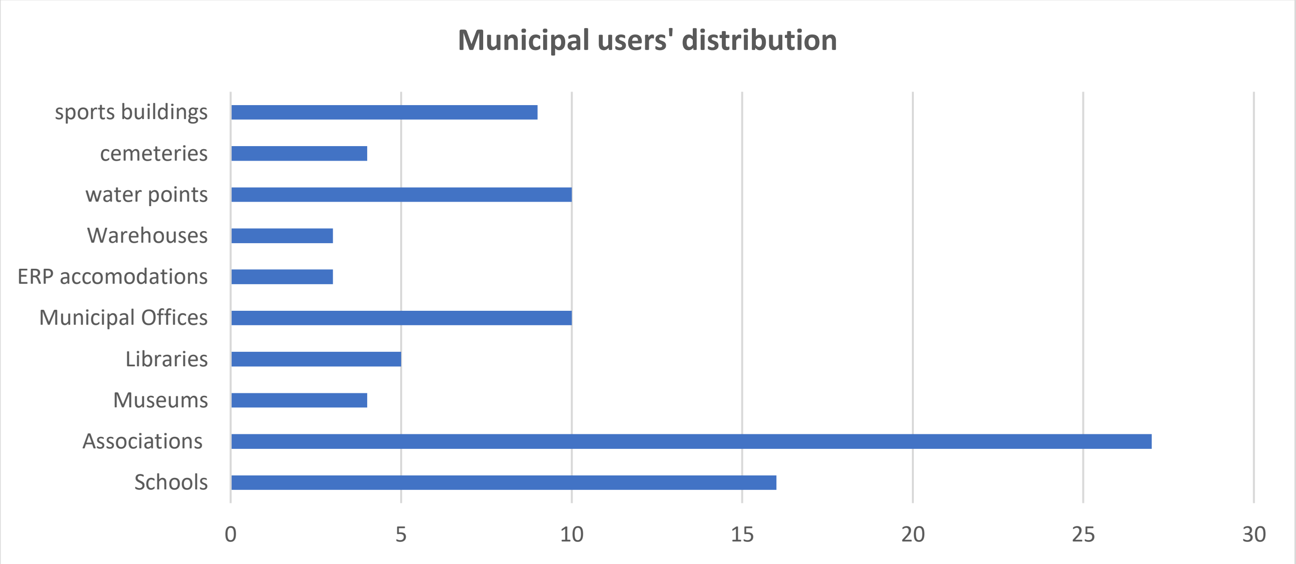


Figure 9: Municipal users' distribution in categories

The electricity utilities of all buildings are registered directly to the Municipalities. There are no buildings with energy utilities registered to third parties. The consumption invoiced in the bill, in this case for the year 2019, are reported with reference to the time slots to which they refer. The meters installed for measuring electricity consumption, in fact, can detect the customer's consumption by distinguishing the time slot in which these occur. The time slots, defined by ARERA, are periods of time to which different energy prices correspond, and they are divided as follows:

- band F1 from Monday to Friday, from 08:00 to 19:00, excluding national holidays;
- band F2: from Monday to Friday from 07:00 to 08:00 and from 7pm to 11pm; on Saturdays from 07:00 to 23:00, excluding national holidays;
- band F3: from Monday to Saturday from 00:00 to 07:00 and from 23:00 to 00:00; on Sundays and holidays it includes all hours of the day.

Single rate contracts are also stipulated for users whose consumption energy are distributed evenly throughout the day. The single-rate tariff provides a constant price of the energy component per the whole day regardless of the time of use and the day of the week. In practice, it is used to distinguish energy consumption with the F0 band electricity of these users, which are typically public lighting. The structure of the data collected on the monthly electricity consumption of municipal users, divided into time slots, and expressed in kilowatt hours [kWh], is shown as an example in Table 7.

Table 7: F1, F2, F3 hourly bands.

	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

Afterwards, municipal administrations shared the monthly electricity consumption, divided into hourly bands, reported in Table 8 as in their electricity bills.

Table 8: Municipal buildings with their electricity consumption in year 2019

Municipality	Number of Municipal buildings	F1	F2	F3	F1	F2	F3	Yearly 2019 consumption
	N°	*[kWh]*	*[kWh]*	*[kWh]*	*[%]*	*[%]*	*[%]*	***[kWh]***
Borgofranco d'ivrea	15	28.872	17.032	22.413	42,26%	24,93%	32,81%	68.317
Quassolo	12	9.854	7.718	13.146	32,08%	25,13%	42,80%	30.718
Quincinetto	12	24003	16317	17310	41,65%	28,31%	30,04%	57.630
Chiaverano	16	30340	18652	27379	39,73%	24,42%	35,85%	76.371
Lessolo	10	26725	12508	15816	48,55%	22,72%	28,73%	55.049
Montalto Dora	26	42958	28440	26079	44,07%	29,18%	26,75%	97.477
TOTAL	**91**	**162.752**	**100.667**	**122.143**	**100%**	**100%**	**100%**	**385.562**

Overall, the annual consumption of these 91 buildings in 2019 amounted to **385.562 kWh/year.**

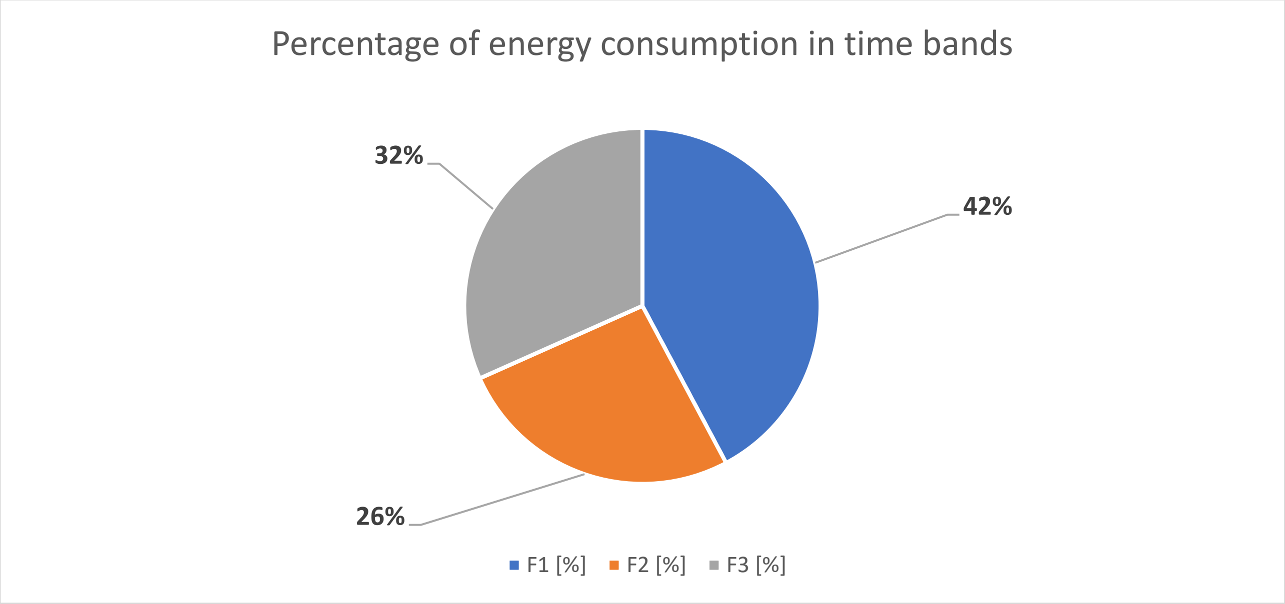
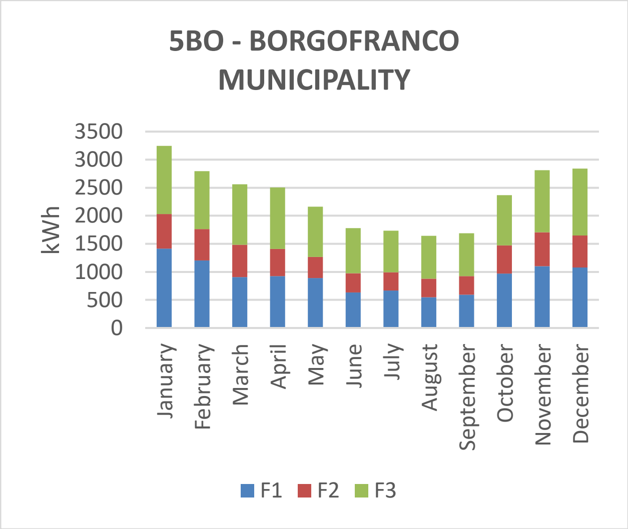
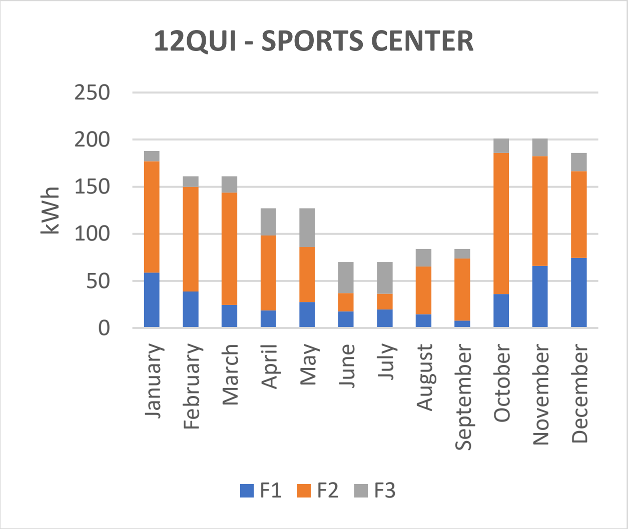


Figure 10: Percentage of energy consumption divided in time bands F1, F2, F3.

Based on the data collected, it is possible to define histogram graphs for some category of user with the breakdown of consumption by months and by bands.





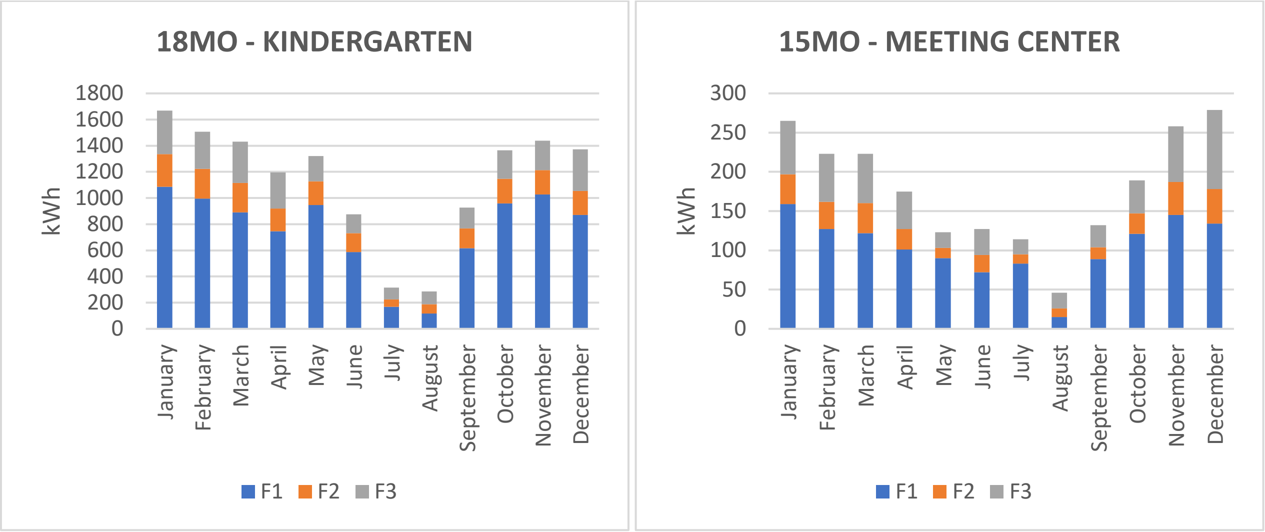


Figure 11:Consumption by months and by bands for some categories of users

From the analysis of the graphs, the distribution of consumption over the months depends on the combination of the intended use and the hours of light which can vary from month to month.

- Some buildings (schools, libraries, and warehouses) present a significant variation in electricity consumption based on the hours of light during the year. In fact, the months with the highest consumption are the winter ones while those where consumption is lower are the spring/summer ones. In these cases, consumption mainly depends on internal lighting. Schools also have a further reduction in the summer period at the end of the school year.
- Some schools instead have a constant distribution of consumption over the various months of the year and a reduction in consumption in the months of July and August when the school is closed.
- Other buildings present an inverse annual trend with higher consumption in the summer period such as some sports fields.
- Municipal buildings, on the other hand, have a constant consumption trend throughout the year.

3.2 Production of renewable energy from PV plants

The tools used to estimate the PV plants' producibility are QGIS and PVGIS. The first phase of the study is the solar analysis of the territory. Global solar radiation [kWh/m^2] is calculated based on the geomorphological characteristics, such as slope, exposure, and aspect of the surface. Consequently, the flux of solar incident radiation on the territory is computed. The figure below shows the value of the annual radiation that affects the analysed territory, given by the sum of the radiation calculated for each month. It emerges that the value varies from a minimum of 500 to a maximum of 2.000 kWh/m^2.

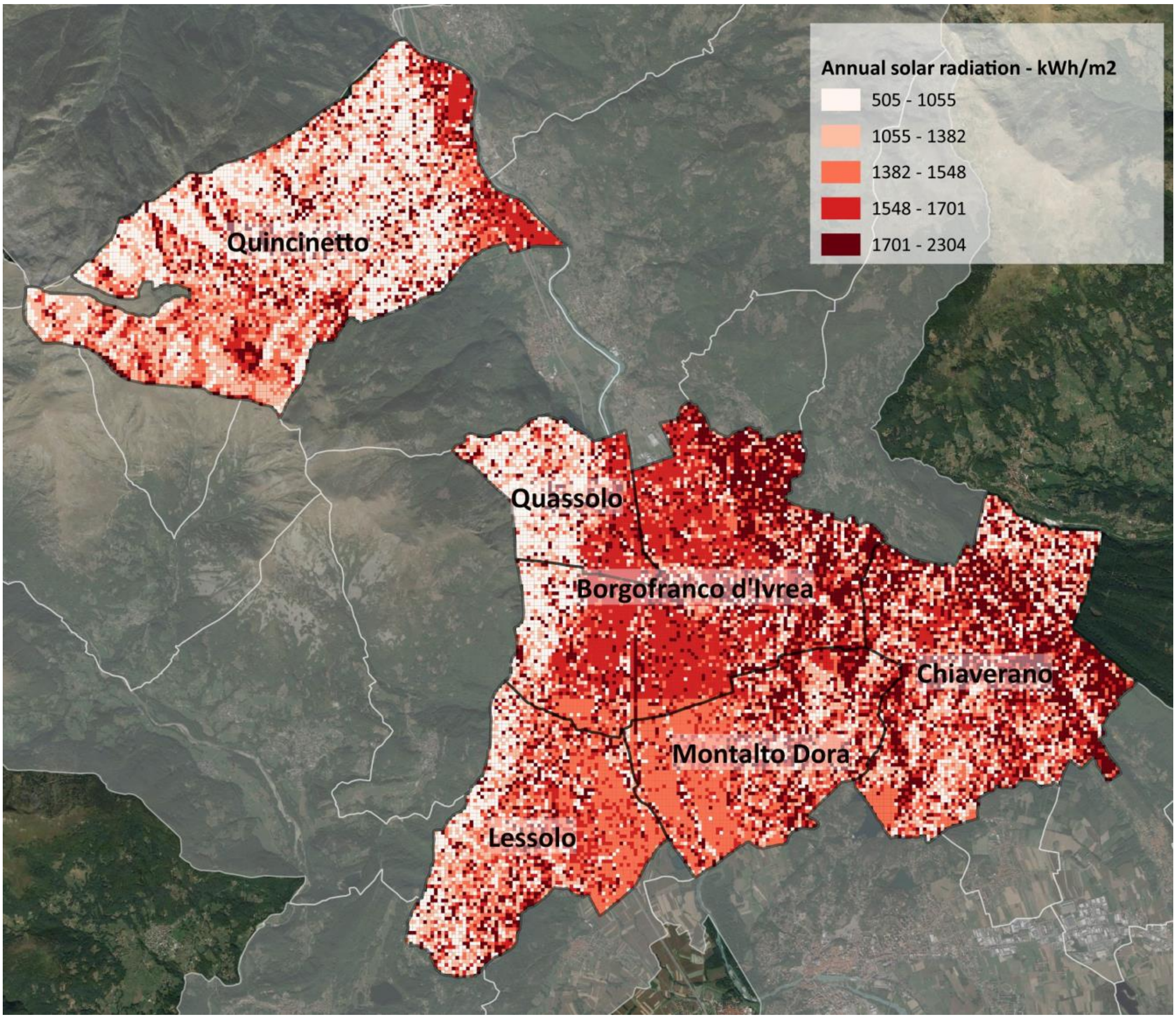


Figure 12 Map of annual solar radiation in the Dora 5 Laghi area (personal elaboration).

The solar analysis leads to a specific solar radiation value on the different areas of the territory. It is possible to define an average value of annual solar radiation valid for the entire *Dora 5 Laghi* territory, which is equal to 1.400 kWh/m^2. It is higher in the municipalities of Borgofranco d'Ivrea and Chiaverano, as reported in the table below.

Table 9: Average annual radiation in the municipal area.

Municipality	Average annual radiation in the municipal area *[kWh/m^2]*
Borgofranco d'Ivrea	1.534
Chiaverano	1.507
Lessolo	1.384
Montalto Dora	1.484
Quassolo	1.285
Quincinetto	1.263
Dora 5 Laghi	**1.412**

As regards the monthly radiation, the following average values valid for the *Dora 5 Laghi* area are obtained.

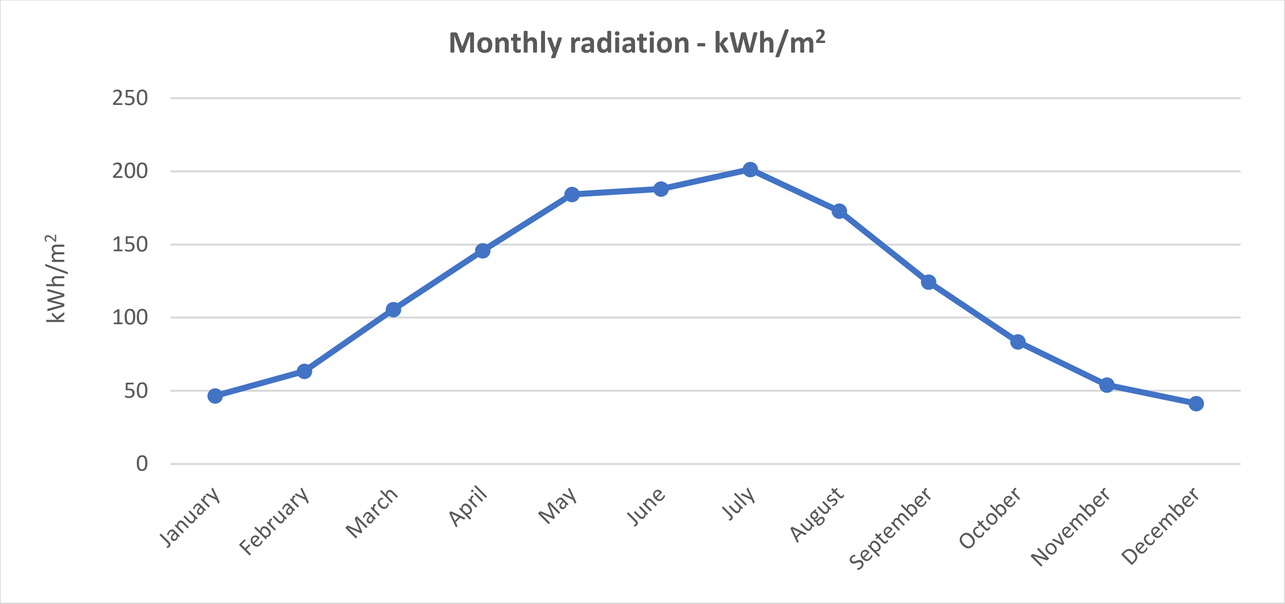


Figure 13: Monthly radiation for the Dora5laghi area

3.2.1 QGIS

The tool used to evaluate the PV potential is "r.sun", from QGIS (Geographic Information System) software. The expected outcome is the evaluation of the energy potential that can be produced through photovoltaic technologies, considering the geomorphological properties of the area. For this analysis the Digital Surface Model (DSM 5x5m) was used, a raster file in which each cell corresponds to the altitude value above sea level and has a detail of 5 meters x 5 meters. From the DSM the layer of aspect and the layer of slopes are produced. The slope (expressed in degrees) algorithm calculates the angle of inclination of the terrain from an input raster layer. The final aspect raster layer contains values from 0 to 360 that express the slope direction: starting from North (0°) and continuing clockwise. Incoming solar radiation (insolation) originates from the sun, it is modified as it travels through the atmosphere, it is further modified by topography and surface features, and it is finally intercepted at the earth's surface as the global solar radiation made up of direct, diffuse and reflected components. The *r.sun.insoltime* [24] in QGIS computes direct (beam), diffuse, and reflected solar irradiation raster maps for given day, latitude, surface, and atmospheric conditions. The global radiation is calculated in an average day for each month. To have a monthly data, it is necessary to multiply the values obtained by the number of days proper to the month under consideration. Once calculated the yearly amount of irradiation, it is necessary to assign the corresponding amount of irradiation to individual buildings by converting the raster data, previously calculated, to vector data. In order to calculate the photovoltaic potential, it is necessary to hypothesize various technological solutions, each one of which is characterized by a particular efficiency and panel size. Usually, the most used modules are made of crystalline silicon.

The results of incident solar radiation were calculated to obtain the value of photovoltaic energy production, using the Suri correlation [25]:

$$E = PR \cdot H_s \cdot S \cdot \eta$$

Where:

- E is the electrical energy produced by year [kWh/y];
- PR is the performance index of the system (≈ 0,75);

- Hs is the cumulative annual solar radiation [kWh/m^2 /y];
- ɳ is the conversion efficiency (0,14);
- S is the working surface of the panel [m^2] (about 30-40% of the roof area).

For the local building heritage, the reference database for the analysis was the BDTRE, updated to 2023, of the Geoportal of the Piedmont Region [26]. The last step is to associate the previously calculated solar irradiance values on the points with the building through the Join Attribute. The result is the PV production on each roof belonging to the six Municipalities. For each building indicated by the BDTRE, a potentially available surface equal to 40% of the total coverage is considered. Overall, in the *Dora 5 Laghi* area there is an available surface area of approximately 488.000 m^2 and the photovoltaic potential is approximately 75.000 MWh/year. Considering the subdivision of the buildings by primary substation, the territory of the Municipalities of Chiaverano and Lessolo is divided between the two cabins present. The highest PV producibility corresponds overall to the AC001E01319 substation, although the difference between the two is minimal. The potentially available surface area, which is greater than the AC001E01317, has an impact on that. Below is a summary of the results obtained.

Table 10:Total PV Municipalities' potential.

Municipality and primary substation	Number of buildings	Potentially available surface (40%) *[m^2]*	PV potential *[MWh/year]*
AC001E01317	**5.399**	**242.940**	**36.859**
Chiaverano	2.021	74.557	11.671
Lessolo	1.391	75.581	11.107
Montalto Dora	1.987	92.803	14.080
AC001E01319	**5.038**	**245.624**	**38.452**
Borgofranco d'Ivrea	2712	159.256	25.677
Chiaverano	159	2.618	400
Lessolo	233	10.994	1.542
Quassolo	534	26.177	4.089
Quincinetto	1400	46.579	6.743
Dora 5 Laghi	**10.437**	**488.564**	**75.311**

Figure 14 below represent the potentially producible energy data in a graduated colour scale, where the red colours correspond to higher values of the potentially annually producible PV energy. The data represented for the entire territory and the insights for each municipality are reported.

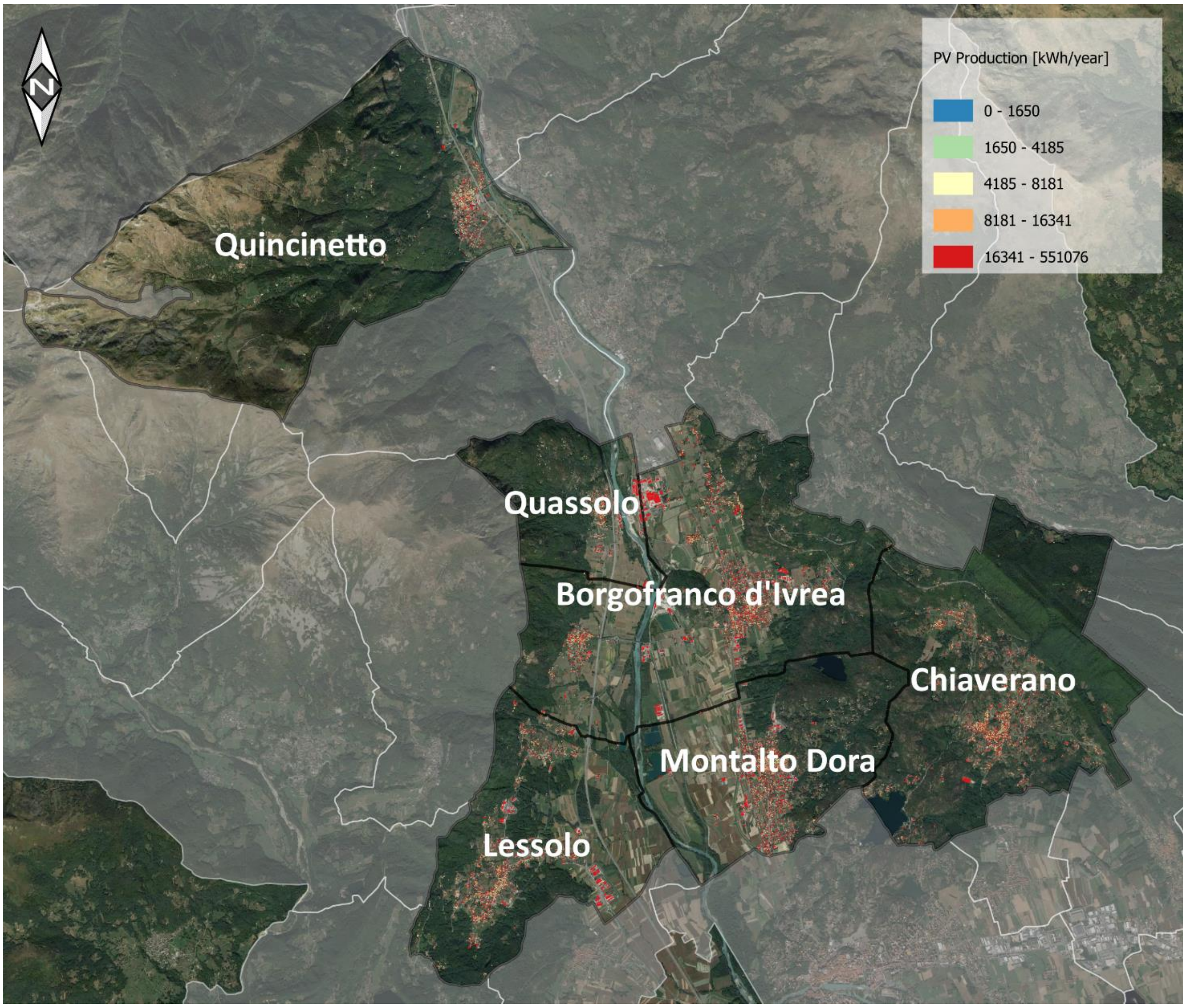


Figure 14: PV production in each Municipality (personal elaboration).

The following graph shows the distribution of photovoltaic potential among the municipalities in the *Dora 5 Laghi* area.

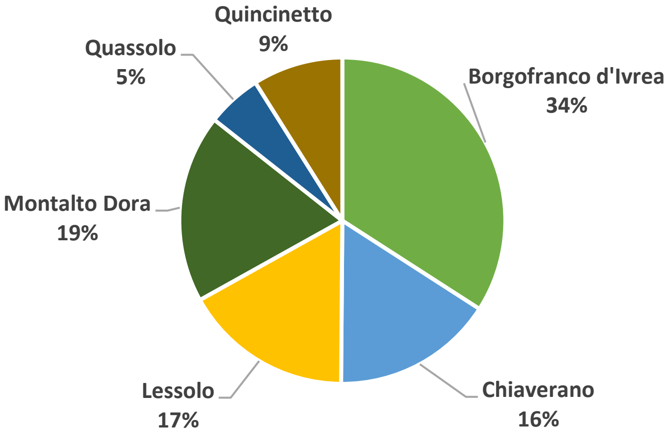


Figure 15: Distribution of PV potential among Municipalities.

A focus on each Municipality annual solar radiation and PV production follows. First there is a total view and then only on Municipal buildings considered for this study.

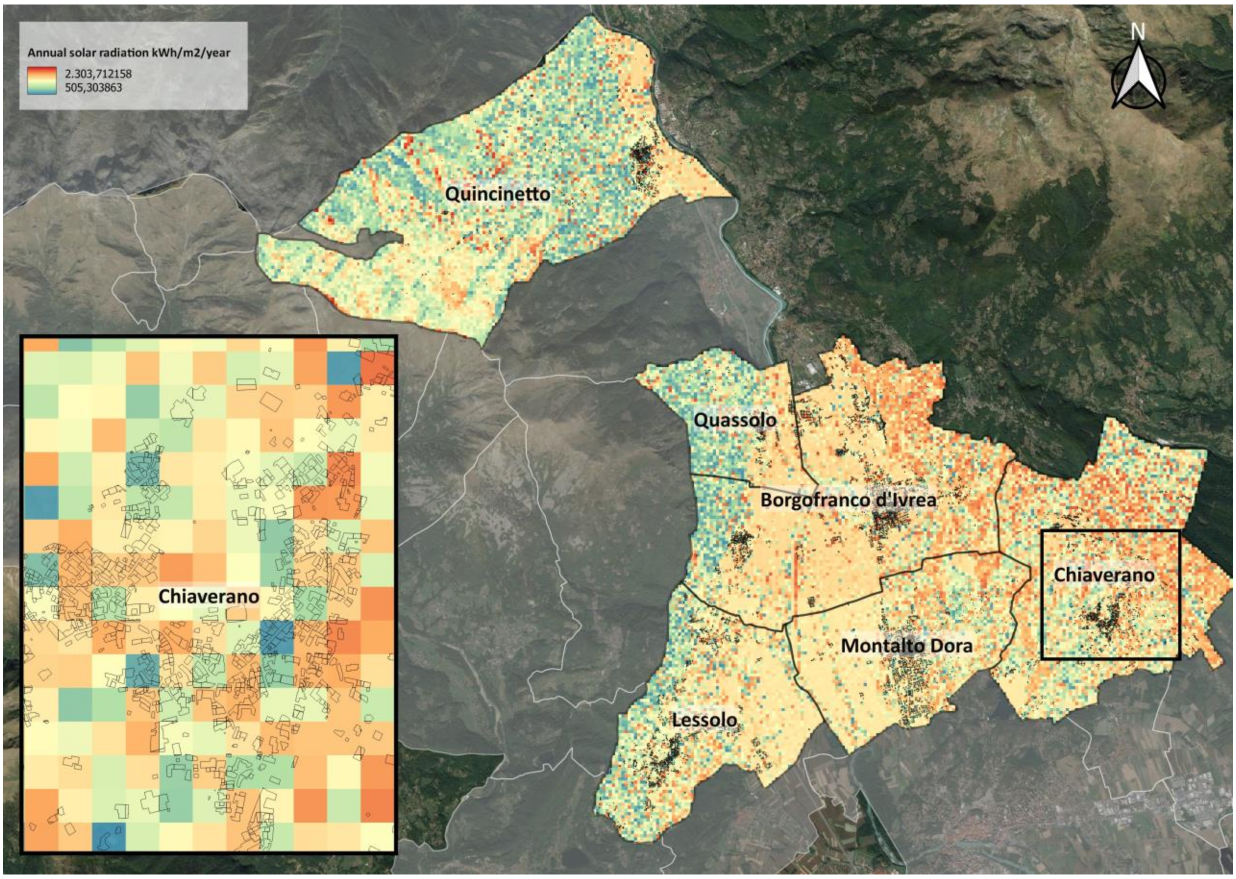


Figure 16: Chiaverano Annual solar radiation [kWh/m2/y].

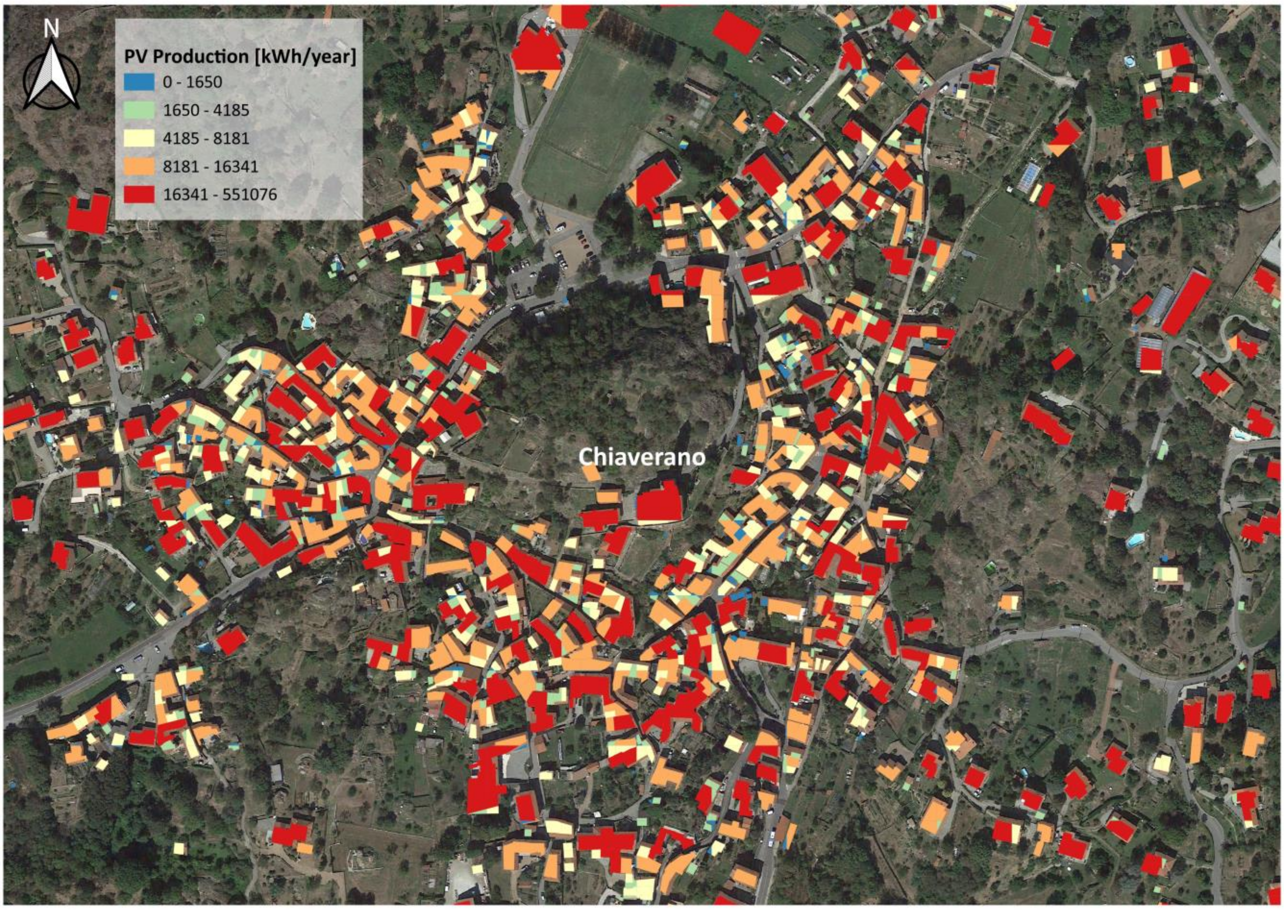


Figure 17: Chiaverano global and Municipal buildings' PV production (personal elaboration)

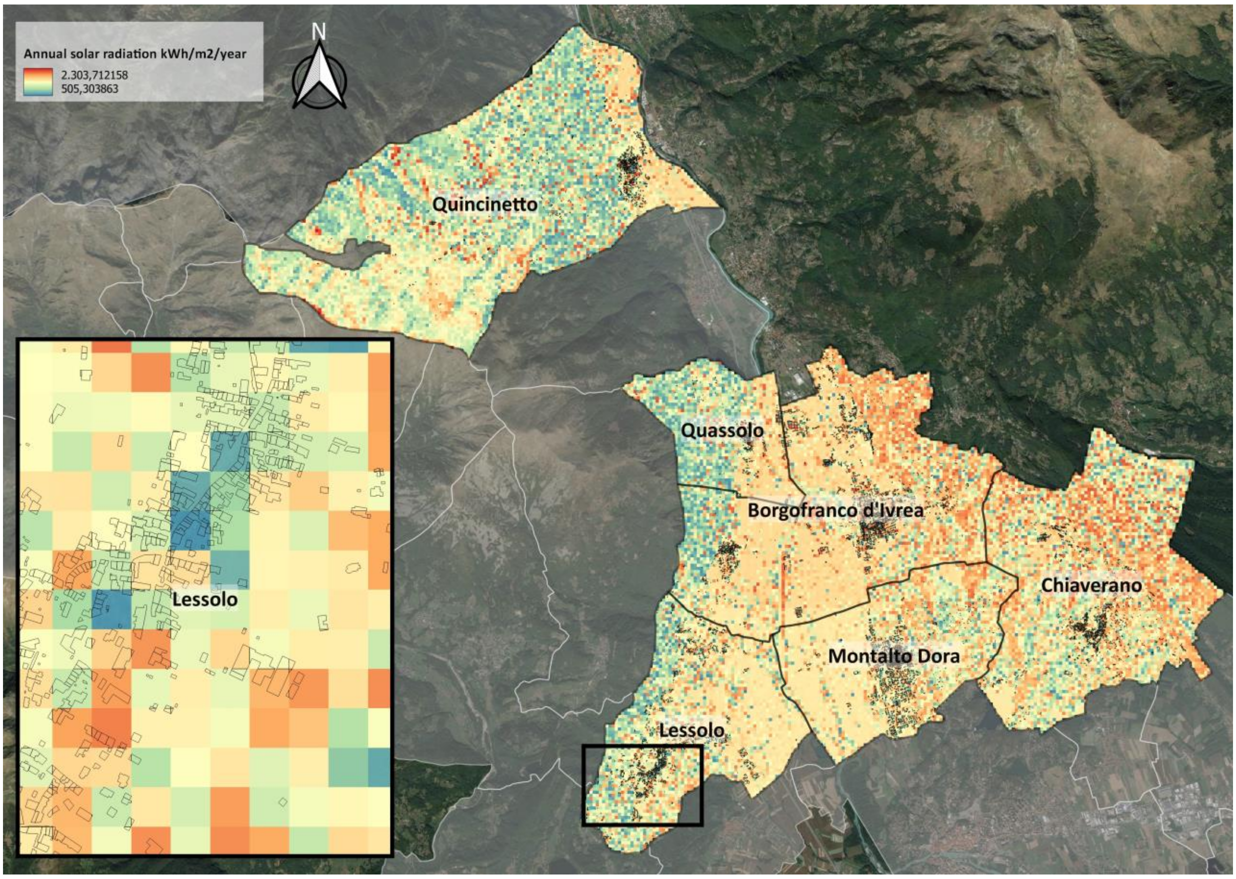


Figure 18: Lessolo Annual solar radiation [kWh/m2/y].

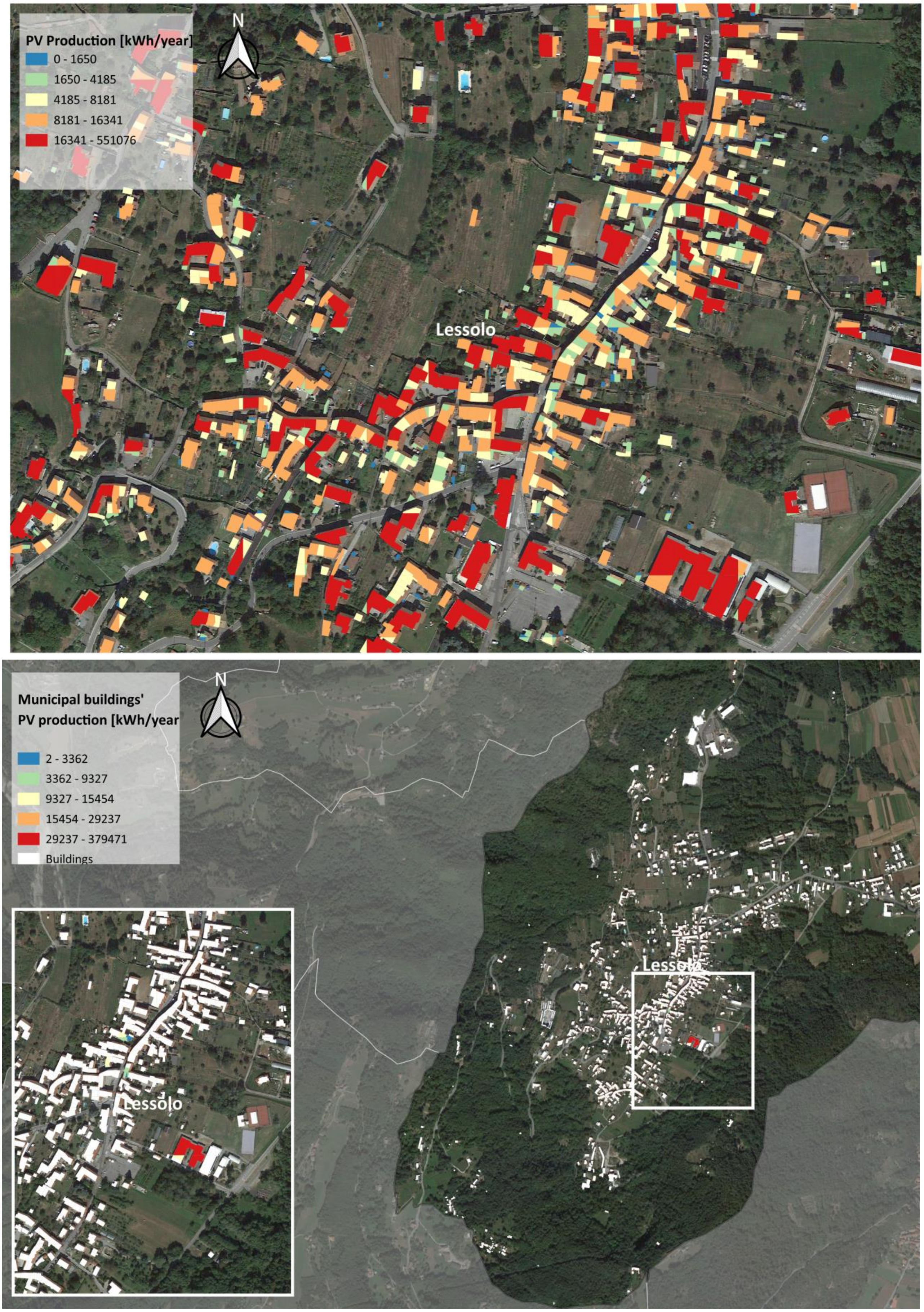


Figure 19: Lessolo global and Municipal buildings' PV production (personal elaboration)

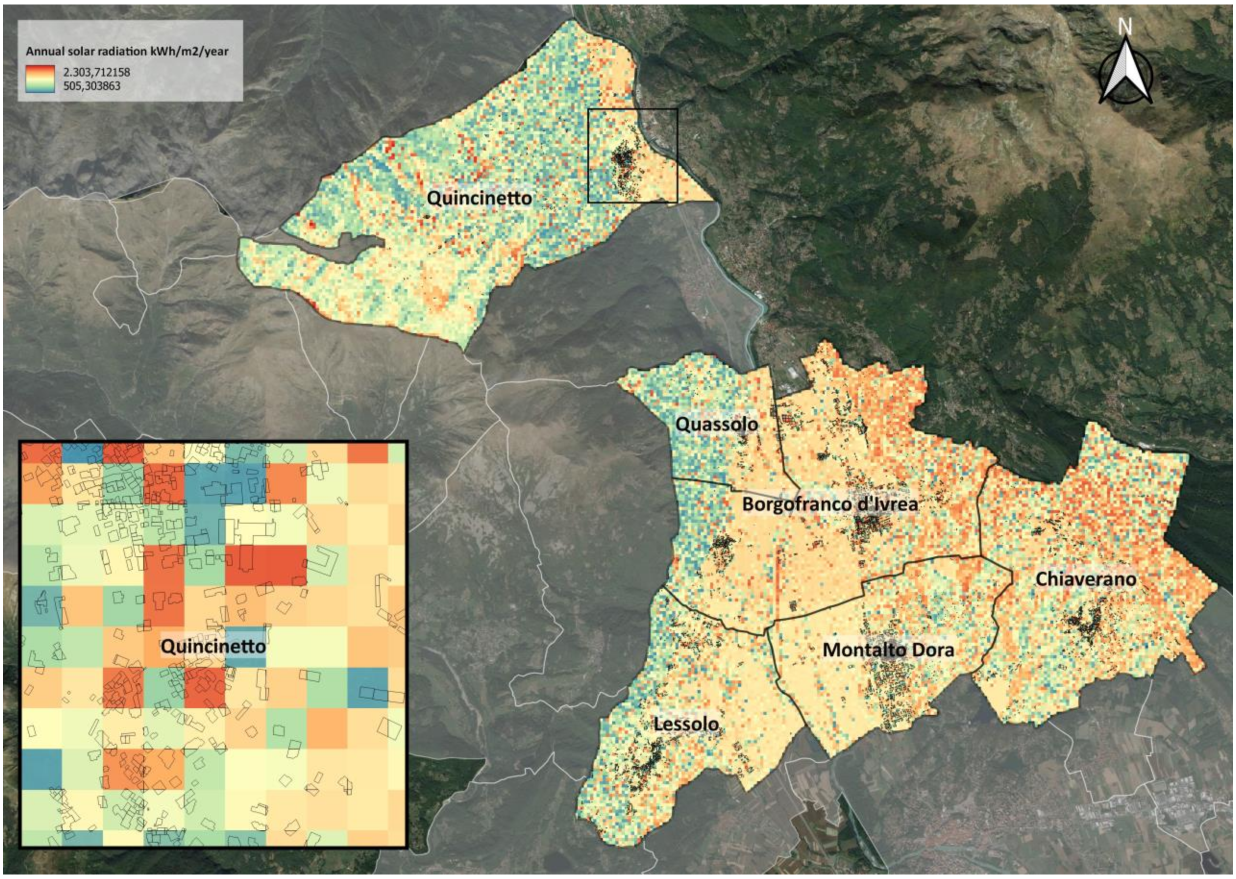
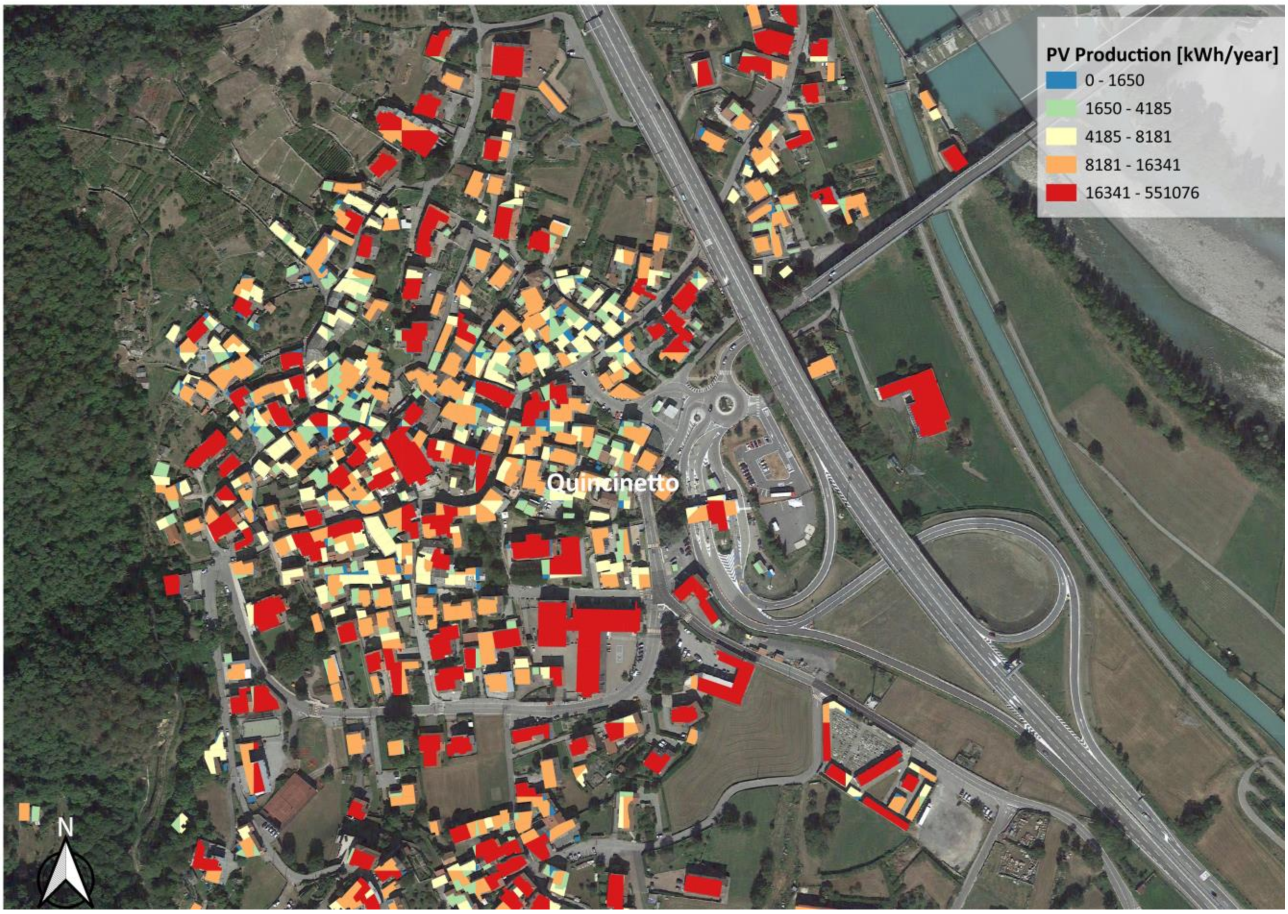


Figure 20: Quincinetto Annual solar radiation [kWh/m2/y].



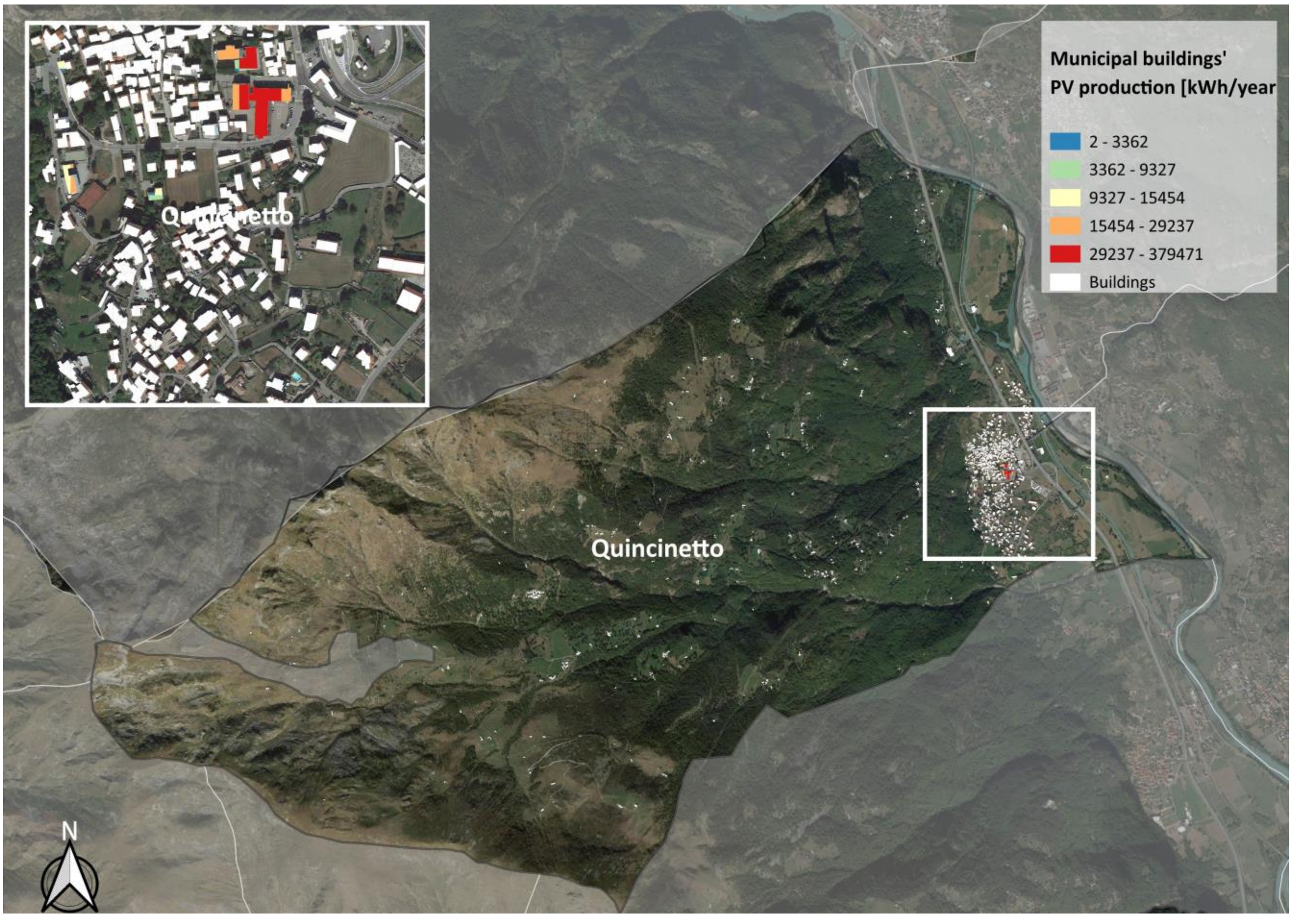


Figure 21: Quincinetto global and Municipal buildings' PV production (personal elaboration)

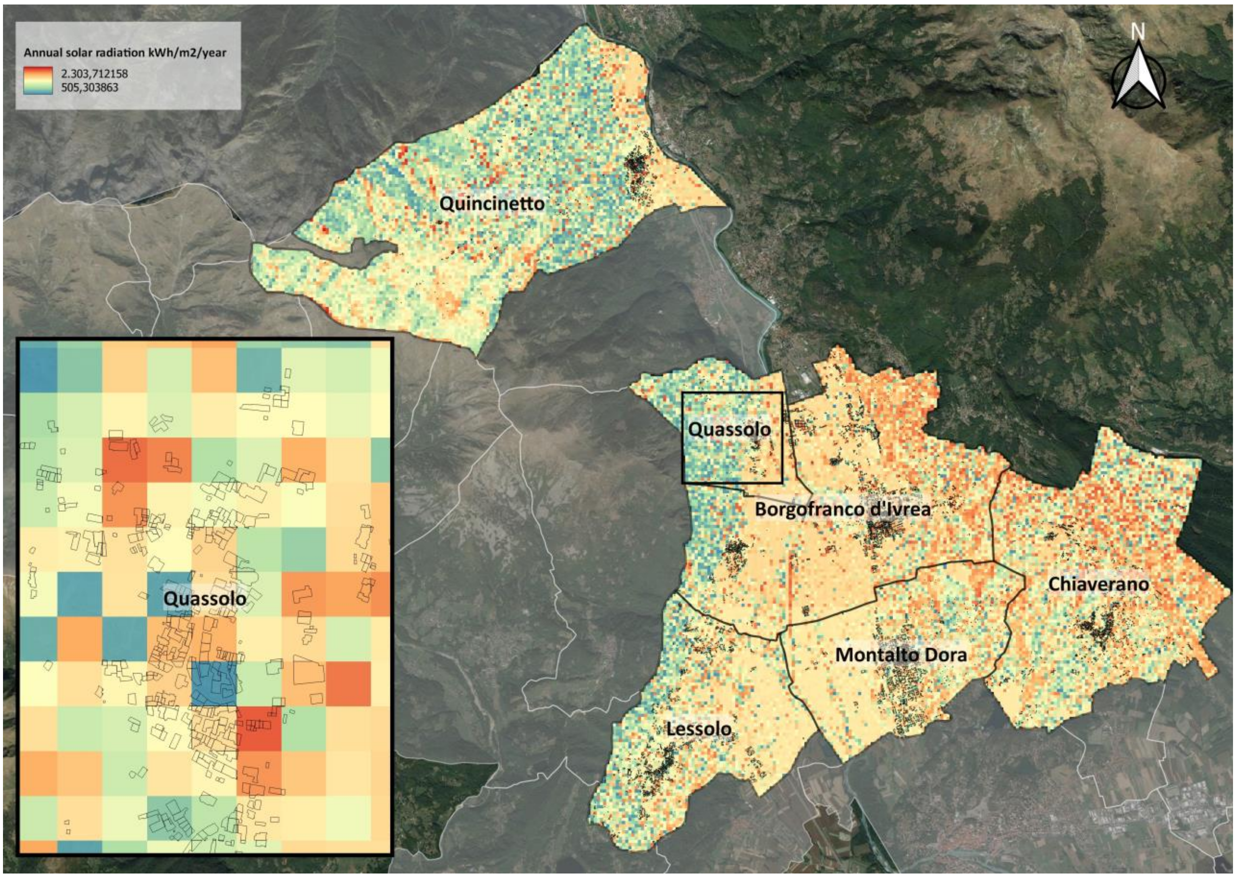


Figure 22: Quassolo Annual solar radiation [kWh/m2/y].

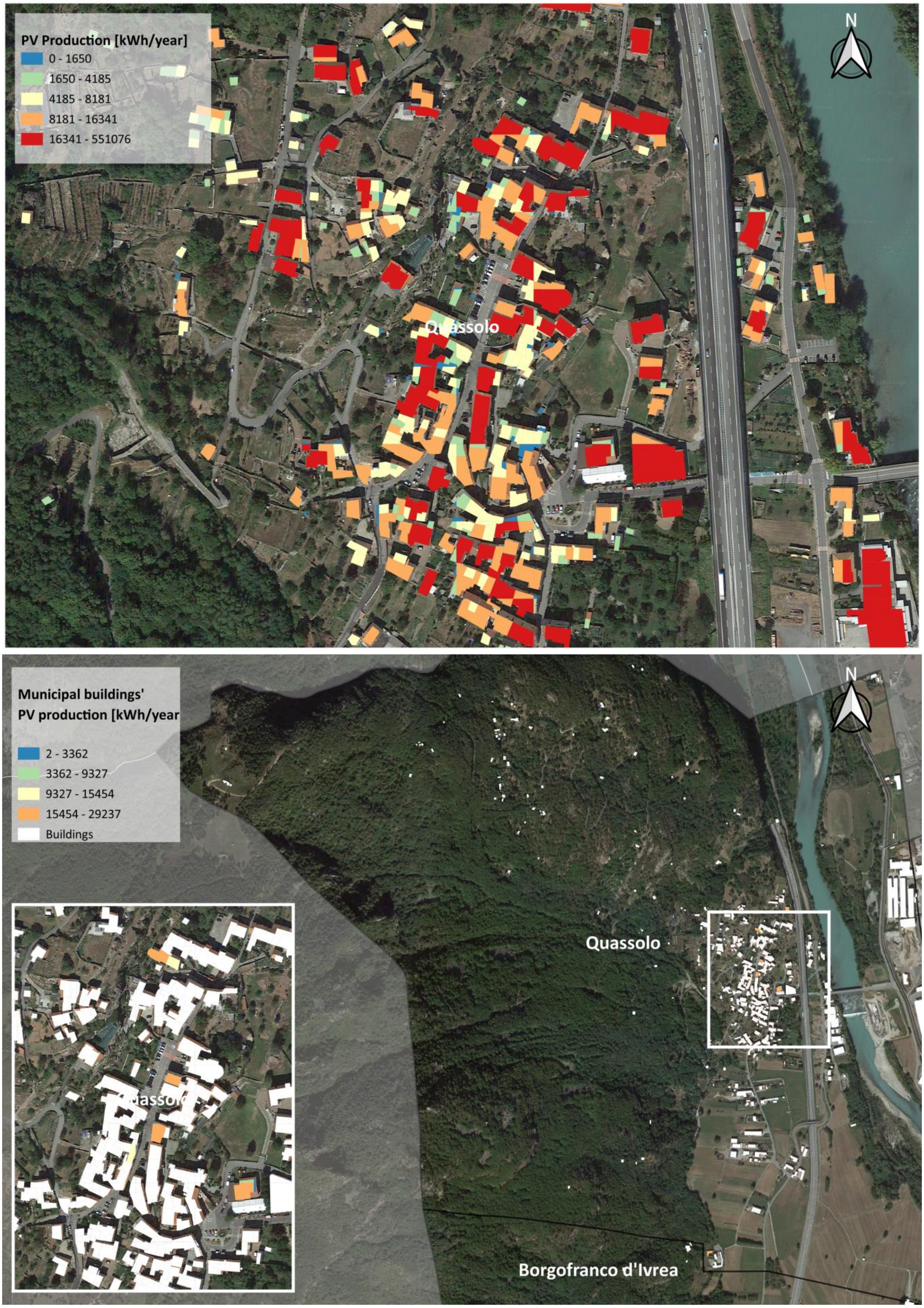


Figure 23: Quassolo global and Municipal buildings' PV production (personal elaboration)

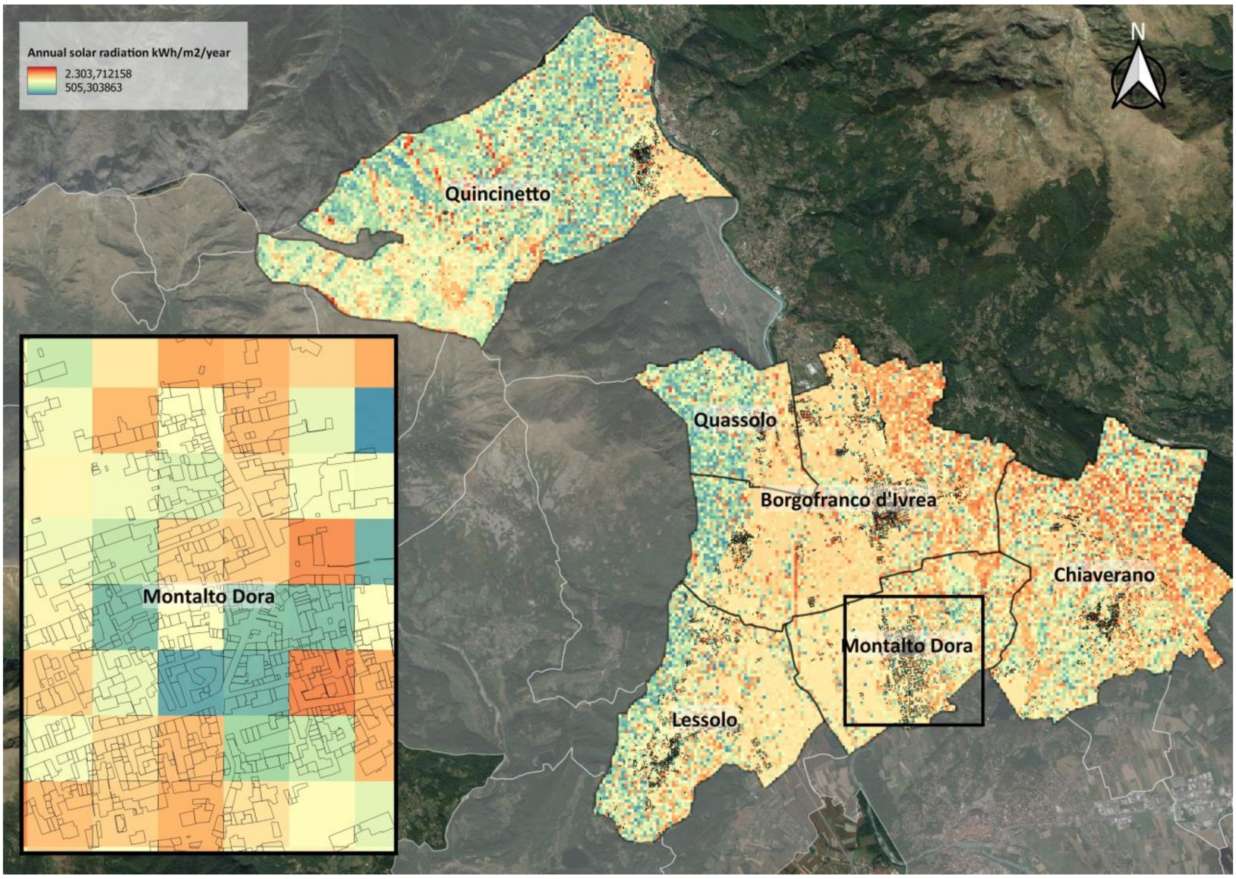


Figure 24: Montalto Dora annual solar radiation [kWh/m^2/y].

Figure 25: Montalto Dora global and Municipal buildings' PV production (personal elaboration)

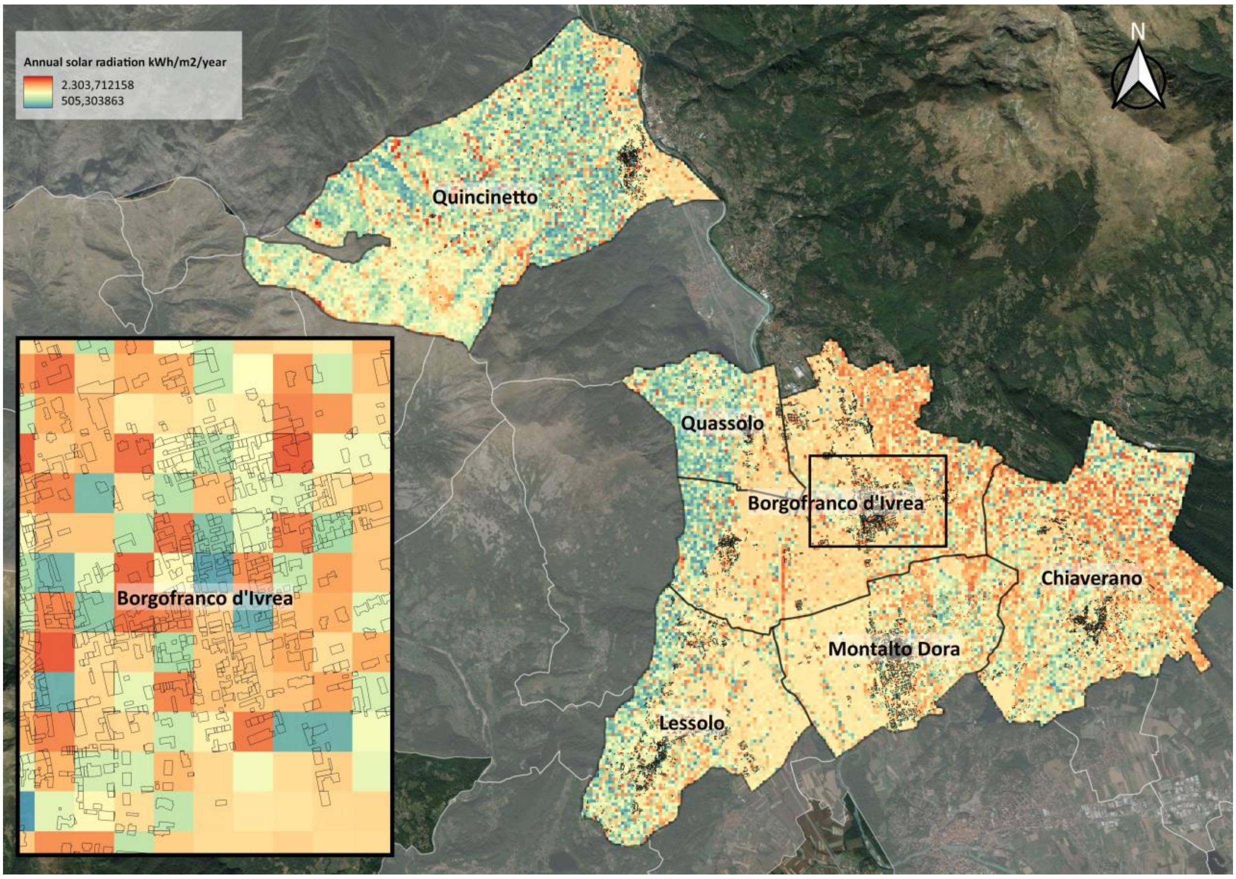


Figure 26: Borgofranco d'Ivrea annual solar radiation [kWh/m^2/y].

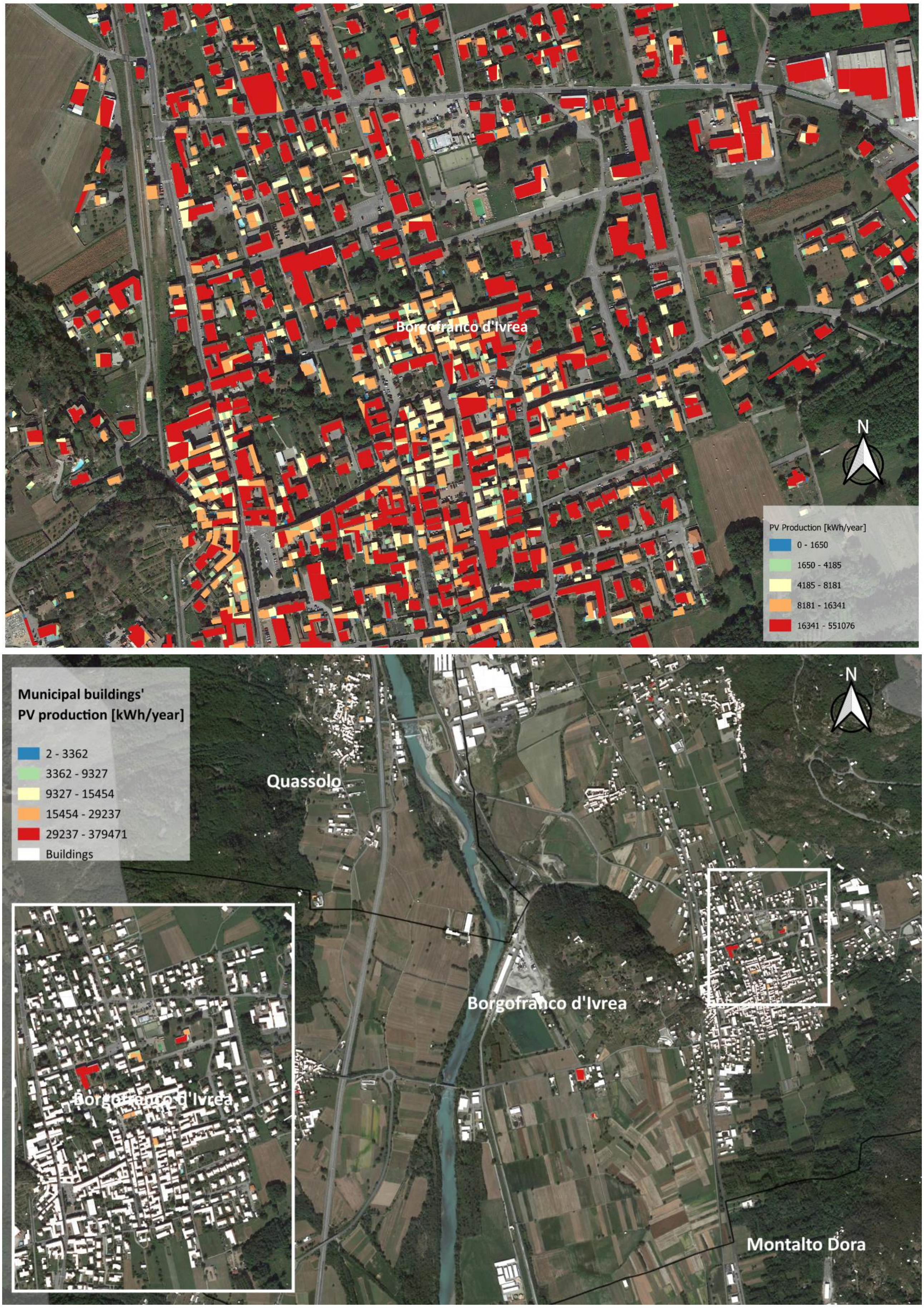


Figure 27: Borgofranco d'Ivrea global and Municipal buildings' PV production (personal elaboration)

The mapping from the BDTRE provides information on the type of use of the buildings, therefore the details of the electricity that can be produced from photovoltaics and the surface area available by type of use of the buildings are reported below. Disposing the values of producible energy in decreasing order, it emerges that the residential ones correspond to a greater potential, as they are also predominant in terms of available surface area.

Table 11:PV Municipalities' potential based on buildings' use.

Type of building use	Potentially available surface (40%) *[m²]*	PV potential *[MWh/year]*
Residential	348.309	53.506
Industrial	68.601	11.035
Mixed use	22.179	3.396
Other	16.706	2.438
Commercial	11.589	1.779
Agricultural	7.370	1.127
Instruction	5.752	830
Place of worship	2.851	411
Accommodation	1.838	287
Public service	1.779	260
Recreational	909	133
Healthcare	682	110
Total	**488.564**	**75.311**

It should be noted that the photovoltaic producibility data reported so far do not consider the PV systems already installed. Therefore, from ATLAIMPIANTI [29] the data on the number of systems and on the installed power in 2023 is obtained for each Municipality, estimating their photovoltaic producibility through the PVGIS software. These values were subtracted from those of the producibility estimated at a territorial level, as summarized below. A still installable photovoltaic potential of **73.800 MWh emerges**.

Table 12:PV data separated from existing PV plants.

Municipality	PV plants installed until 2023	Installed power *[kW]*	Electrical energy producibility *[MWh/year]*	Territorial PV potential *[MWh/year]*	Installable PV potential *[MWh/year]*
Borgofranco d'Ivrea	83	419	531	25.677	25.146
Chiaverano	59	237	295	12.072	11.777
Lessolo	51	551	680	12.650	11.970
Montalto Dora	52	223	277	14.080	13.803
Quassolo	5	38	45	4.089	4.044
Quincinetto	17	137	153	6.743	6.590
Total	**267**	**1.605**	**1.450**	**75.311**	**73.861**

In the end, making a comparison between the electricity consumption of the Municipalities and the photovoltaic potential that can still be installed on the roofs of buildings, it emerges that the energy needs would be totally covered. The electricity consumption reported for 2019 was obtained from the energy inventory drawn up in the Action Plan for Sustainable Energy and Climate (SECAP).

Table 13: Installable PV potential with respect to Electrical Energy Municipalities' PV consumption

Municipality	Installable PV potential *[MWh/year]*	Electrical energy consumption in 2019 (SECAP) MWh
Borgofranco d'Ivrea	25.146	5.877
Chiaverano	11.777	2.774
Lessolo	11.970	5.491
Montalto Dora	13.803	5.204
Quassolo	4.044	662
Quincinetto	6.590	1.777
Total	**73.861**	**21.785**

Considering the primary substations perimeter and the other municipalities near the area of Dora 5 Laghi, it emerges that the REC could become larger thanks to their joining, as the following figure shows.

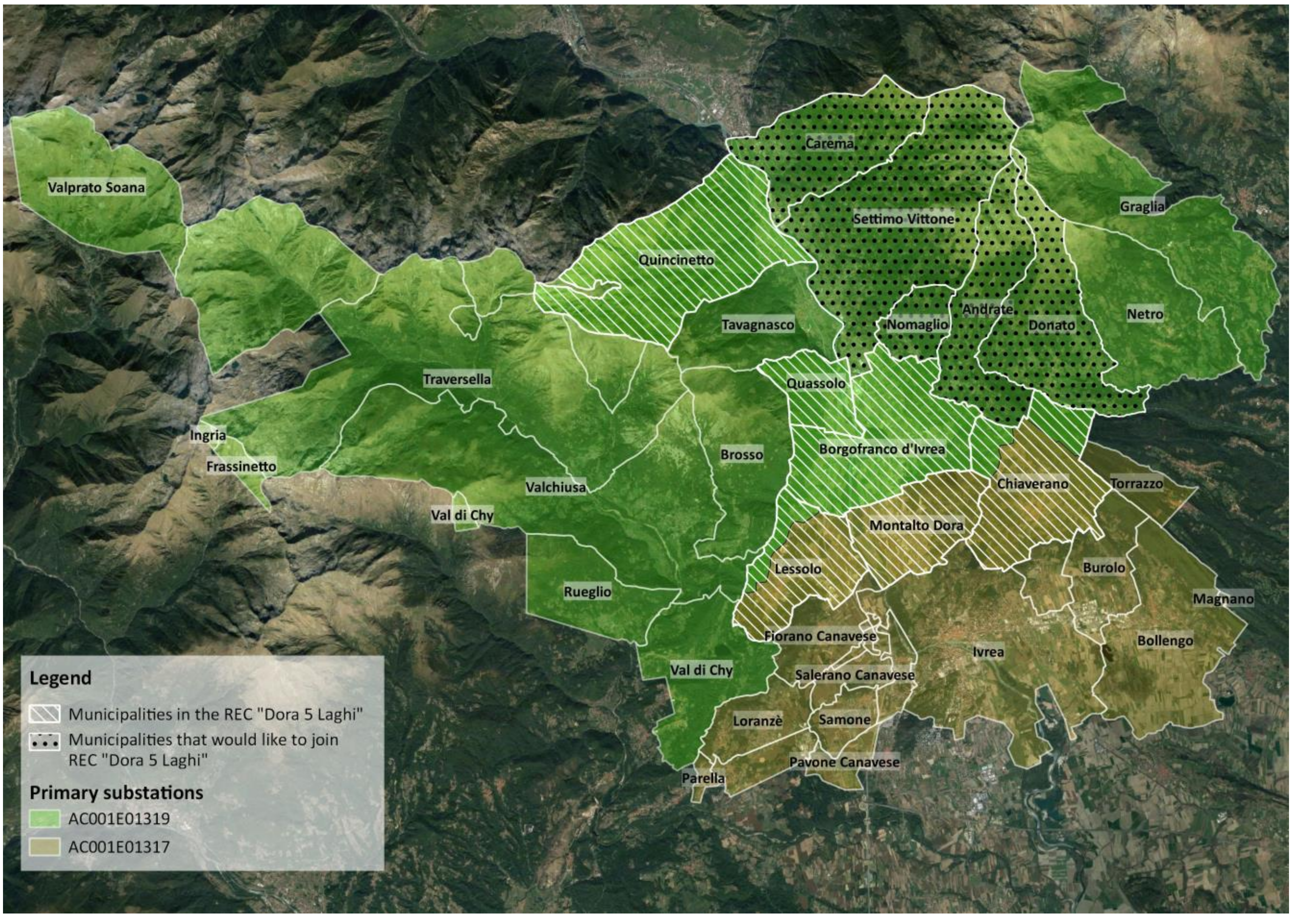


Figure 28: Municipalities in the primary substations analyzed in this study that could aggregate in the REC in the future.

3.2.2 PVGIS

The PV producibility for each hour H of the year is obtained using the PVGis Tool (Photovoltaic Geographical Information System) which provides information about the radiation and producibility for each location in Europe and Africa. The photovoltaic PVGIS is an accessible online platform developed by the European Commission Joint Research Centre [27]. Established as an independent scientific research centre in support of European policies, it makes use of the contribution of European scientists and researchers. By entering the geographical coordinates of the area of interest, this tool allows you to calculate the incident solar radiation on the terrestrial surface and extract information about other variables such as diffuse and direct radiation, albedo etc. Besides, it predicts theoretical energy production of a photovoltaic system, knowing its location [28].

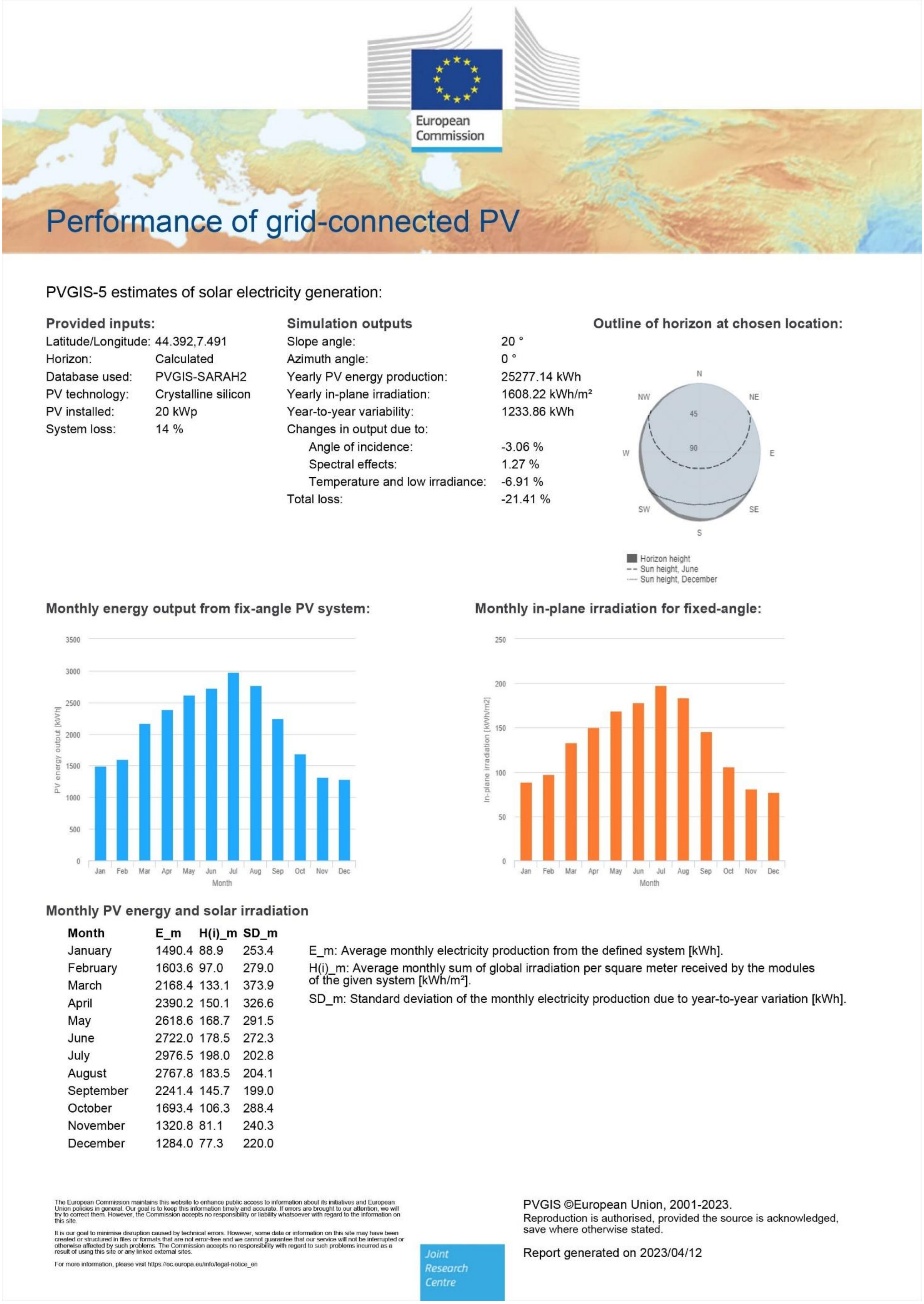
The input data required by the PV GIS Tool are:

- Latitude and Longitude of the plant: they are calculated directly by PV GIS after locating the building on the map made available by the Tool itself;
- Solar radiation: calculated directly by PV GIS based on geographical coordinates;
- Photovoltaic Technology: monocrystalline silicon photovoltaic modules were mainly considered apart from any curved roofs where the thin-film technology most easily integrated in roofs of this type was selected;
- System power: for each building the system power is computed based on the available coverage area using the following formula:

  $$\mathbf{P_{peak}=A_{FV}*p_{peak}}$$

  Where P_{peak} is the system peak power and A_{FV} is the area available for FV installation measured in m^2 (computed by using Google Earth) and p_{peak} is the system peak power per unit area = 0.2 (kW/m^2);
- System losses that reduce the energy produced by the plant (due for example to losses in cables, inverters, dirt accumulated on the modules, etc.) = 14%;
- Assembly system: for buildings with pitched roofs, the modules are integrated into the roof covering of the building while for buildings with a flat roof, the option chosen is that of a support structure;
- Inclination: in case of buildings with pitched roofs, the inclination is set to 20°; in case of flat roofs, the horizontal solution is adopted;
- Azimuth: the angle of the PV modules with respect to the south direction is defined based on the orientation of the roof slopes where they’re inclined. In case of flat roofs, the orientation indicated is South (0°).

Regarding the PV production on rooftops, the solar energy potential depends on the suitable roof area available, on the roof slope, and on the roof orientation (south-faced tilted roofs have a higher productivity). The solar energy that can be produced on each roof was assessed considering standard PV systems with an efficiency of 14% and an inclination of 20°.



Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

Provided inputs:

Latitude/Longitude:	44.392,7.491
Horizon:	Calculated
Database used:	PVGIS-SARAH2
PV technology:	Crystalline silicon
PV installed:	20 kWp
System loss:	14 %

Simulation outputs

Slope angle:	20 °
Azimuth angle:	0 °
Yearly PV energy production:	25277.14 kWh
Yearly in-plane irradiation:	1608.22 kWh/m²
Year-to-year variability:	1233.86 kWh
Changes in output due to:	
Angle of incidence:	-3.06 %
Spectral effects:	1.27 %
Temperature and low irradiance:	-6.91 %
Total loss:	-21.41 %

Outline of horizon at chosen location:

Monthly energy output from fix-angle PV system:

Monthly in-plane irradiation for fixed-angle:

Monthly PV energy and solar irradiation

Month	E_m	H(i)_m	SD_m
January	1490.4	88.9	253.4
February	1603.6	97.0	279.0
March	2168.4	133.1	373.9
April	2390.2	150.1	326.6
May	2618.6	168.7	291.5
June	2722.0	178.5	272.3
July	2976.5	198.0	202.8
August	2767.8	183.5	204.1
September	2241.4	145.7	199.0
October	1693.4	106.3	288.4
November	1320.8	81.1	240.3
December	1284.0	77.3	220.0

E_m: Average monthly electricity production from the defined system [kWh].

H(i)_m: Average monthly sum of global irradiation per square meter received by the modules of the given system [kWh/m²].

SD_m: Standard deviation of the monthly electricity production due to year-to-year variation [kWh].

Report generated on 2023/04/12

Figure 29: PVGIS tool input screen

The inputs necessary for the analysis are briefly illustrated in the table, with indications on the choices made for the analysis.

Table 14: input to calculate the annual producibility of photovoltaic systems.

INPUT	DESCRIPTION	VALUE
Lat/Lon	Latitude and Longitude of the PV system	Depend on the plant location
Solar radiation database	Database used for the analysis, based on satellite surveys	Database PVGIS-SARAH2
PV technology	Photovoltaic modules' technology	Crystalline silicon
Installed peak PV power [kWp]	Peak power of the PV system	Depends on the plant
System loss [%]	System losses that reduce the energy produced by the plant due to losses in cables, inverters, dirt accumulated on the modules	14%
Mounting position	How the modules are mounted (on a support structure or integrated directly into the roof of the building)	Roof integrated. (If horizontal roof, support structure)
Slope [°]	Photovoltaic modules' inclination angle with respect to the horizontal plane	20° (0° if horizontal roof)
Azimuth [°]	Photovoltaic modules' angle with respect to the south	Depends on the roof orientation

Table 15Table 15: Municipal buildings' PV production potential shows the results obtained from this analysis of the production potential of buildings. It was not performed for buildings 12BO, 2QUA, 3QUA, 10QUA, 11QUA, 12QUI, 1MO, 4MO, 6MO, 10MO, 13MO, 16MO, 19MO, 20MO, 21MO, 22MO, 9CHI, 3LE, 5LE, 6LE, 7LE, 8LE, 10LE because they are modest in size or because PV panels are already installed on their roofs.

Table 15: Municipal buildings' PV production potential

CODE	ROOF SURFACE *[m²]*	ORIENTATION	POWER *[kW$_p$]*	ANNUAL PRODUCTION *[kWh]*
1BO	50	SSE	10	12.757
2BO	102	varie	20,4	21.532
3BO	135	varie	27	37.465
4BO	110	SSE	22	30.263
5BO	106	varie	21,2	24.609
6BO	128	varie	25,6	27.819
7BO	217	varie	43,4	49.663
8BO	100	varie	20	24.055
9BO	350	varie	70	74.995
10BO	1400	varie	280	307.408
11BO	18	SW	3,6	4.401
13BO	50	S	10	12.872
14BO	75	SSE	15	10.390
15BO	44	S	8,8	11.210
1QUA	95	SSW	19	22.532
4QUA	70	ESE	14	16.475
5QUA	82	SSE	16,4	20.261
6QUA	45	SSW	9	10.409
7QUA	130	S	26	29.633
8QUA	55	SSW	11	12.722
9QUA	45	SSW	9	10.581
12QUA	200	varie	40	40.264
1QUI	290	S	58	21.072
2QUI	115	S	23	27.602
3QUI	18	SW	3,6	3.490

CODE	ROOF SURFACE *$[m^2]$*	ORIENTATION	POWER *$[kW_p]$*	ANNUAL PRODUCTION *[kWh]*
4QUI	220	varie	44	43.347
5QUI	33	varie	6,6	6.513
6QUI	240	varie	48	53.202
7QUI	95	S	19	22.086
8QUI	30	S	6	7.023
9QUI	40	SE	8	9.371
10QUI	30	SE	6	7.028
11QUI	210	E	42	44.506
2MO	42	SW	8,4	10.500
3MO	140	varie	28	32.812
5MO	44	SSE	8,8	11.643
7MO	105	varie	21	21.943
8MO	30	WSW	6	7.050
9MO	36	varie	7,2	7.873
11MO	220	S	44	49.683
12MO	136	varie	27,2	29.366
14MO	56	varie	112	120.984
15MO	48	varie	9,2	10.484
17MO	70	SSE	14	18.529
18MO	50	E	10	11.071
23MO	540	varie	108	126.442
24MO	900	SSE	180	237.879
25MO	198	varie	39,6	47.186
26MO	14	SE	2,8	3.524
1CHI	85	WSW	17	19.946
2CHI	58	varie	11,6	12.968
3CHI	55	SE	11	13.777
4CHI	65	SE	13	16.404
5CHI	120	varie	24	26.971
6CHI	50	SE	10	12.737
7CHI	50	S	10	13.330
8CHI	500	varie	100	102.728
10CHI	97	varie	19,4	24.911
11CHI	280	SSE	56	70.368
12CHI	60	SSE	12	15.079
13CHI	260	varie	52	61.159
14CHI	380	varie	76	82.682
15CHI	23	S	4,6	6.067
16CHI	60	SE	12	14.790
1LE	48	E	9,6	10.607
2LE	85	SSW	17	21.780
4LE	50	SSW	10	12.828
9LE	500	SE (H)	100	10.495
TOTAL			**2.177**	**2.354.152**

The potential that can be installed on the roofs of municipal buildings is approximately **2.177 kW_p** for an annual production of approximately **2.354.152 kWh.**

3.2.3 Comparison of QGIS and PVGIS PV production with roof-integrated PV technology

The annual relative errors ε are calculated considering E_{1kWp} related to the calculated results of QGIS and by PVGIS:

$$\varepsilon = \frac{E_{PVGIS} - E_{QGIS}}{E_{PVGIS}}$$

Table 16: Annual relative errors considering E_{1kWp}.

Borgofranco d'Ivrea ε	Chiaverano ε	Lessolo ε	Quassolo ε	Quincinetto ε	Montalto Dora ε
4,05%	4,38%	3,02%	3,30%	1,34%	2,93%
1,92%	5,44%	3,06%	2,39%	3,72%	0,49%
1,98%	2,87%	0,68%	2,97%	2,77%	3,02%
1,46%	4,90%	0,69%	0,67%	2,19%	2,71%
1,03%	6,57%	1,75%	2,23%	0,86%	0,71%
4,70%	4,14%		1,93%	2,41%	4,74%
4,64%	4,64%		3,27%	4,95%	1,78%
3,53%	5,08%		4,43%	0,65%	6,01%
3,49%	3,66%			3,36%	2,14%
1,25%	6,21%			3,60%	2,42%
5,01%	4,50%			4,52%	2,83%
2,11%	3,20%				6,51%
2,54%	2,34%				1,18%
3,66%	1,93%				3,65%
	4,67%				2,51%
					6,01%

Table 16 shows that the relative error ε is always positive and between 0% and 10% meaning that the PV producibility value for one kW_p calculated with PVGIS is always higher than the one computed with QGIS. This result was expected because in PVGIS the roof slope is given in input while QGIS DSM considers a flat surface. PVGIS returns punctual data while QGIS returns territorial data. Besides, on PVGIS the PV hourly production can be downloaded for the precise year while the value computed on QGIS takes an average irradiance value between the years.

A further comparison on annual irradiance values is made taking as an example one building in Quassolo, 12QUA, with latitude equal to 45.52° and longitude equal to 7.83°. The tools, measuring the total irradiance, compared for this building are QGIS, PVGIS and the Global Solar Atlas [29].

Table 17: QGIS, PVGIS, GSA annual monthly irradiance comparison [kWh/m²/month].

	QGIS *[kWh/m²/month]*	PVGIS *[kWh/m²/month]*	GSA *[kWh/m²/month]*
January	39,174	56,860	91,700
February	59,261	82,960	96,200
March	105,198	130,840	124,900
April	150,164	124,500	108,400
May	193,025	158,610	113,500

	QGIS *[kWh/m^2/month]*	PVGIS *[kWh/m^2/month]*	GSA *[kWh/m^2/month]*
June	197,755	196,200	129,200
July	211,379	200,380	148,900
August	179,713	150,310	129,500
September	125,354	116,830	95,900
October	80,452	72,260	81,600
November	47,297	37,820	73,600
December	33.537	39.490	78.100
TOTAL	**1.422,309**	**1.271,500**	**1.367,060**

The annual radiation values in Table 17 are compared. QGIS and PVGIS measurements are closer during summer months and more different during winter while Global Solar Atlas values are more homogeneous during the year. The total annual values are in any way comparable.

3.3 Data elaboration

3.3.1 Hourly energy consumption profiles

The hourly consumption estimation of the municipal utilities included in the configuration is a complex task, in lack of measured values on the hourly withdrawals of electricity from the net. Despite the presence in the scientific literature of various methodologies to address the problem of generating load profiles synthetic, for different categories of users, starting from consumption electricity monthly, it was decided to adopt the approach outlined by Energy Services Manager (GSE). GSE, in fact, has prepared a methodology for profiling energy withdrawals on an hourly basis, to be applied in cases where the real hourly data measurements are missing.

The procedure consists in considering hourly load profiles standards that depend on the type of user and have been rendered available for a reference year from the GSE. There are four different withdrawal curves that have been reported in relation to the type of user in Low Voltage (LV):

1. hourly profile of withdrawals relating to domestic users;
2. hourly profile of withdrawals relating to lighting public users;
3. hourly profile of withdrawals relating to power utilities of public charging infrastructure for electric vehicles;
4. hourly profile of withdrawals relating to non-domestic users.

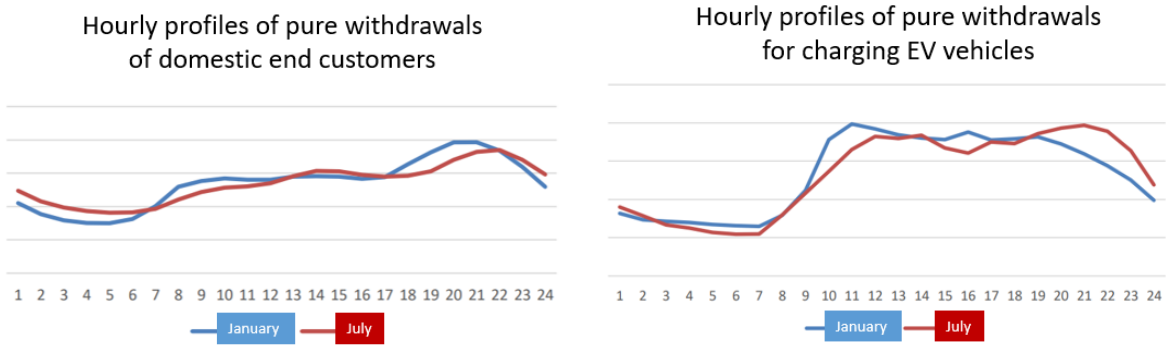


Figure 30:Example curves for domestic end customers and public charging infrastructure for electric vehicles with seasonality effect (pure withdrawals)

In Figure 30 the reference hourly curves are shown respectively for the utility's households and power utilities of public charging infrastructure for electric vehicles, differently for a day in the month of January e of July, to show the effect of seasonality on consumption.

In Figure 31 there is a typical profile of a non-domestic end customer daily consumption for a weekday with the seasonality effect [30]. The profile is expressed in percentage coefficients defined on the basis of the weight that each hour has within the day. So, for each municipal user selected, it is first assigned a standard load profile based on the type. This profile is finally scaled so that the total monthly consumption in the various time slots (if the rate is not single-hour) coincides with the value reported on the bill.

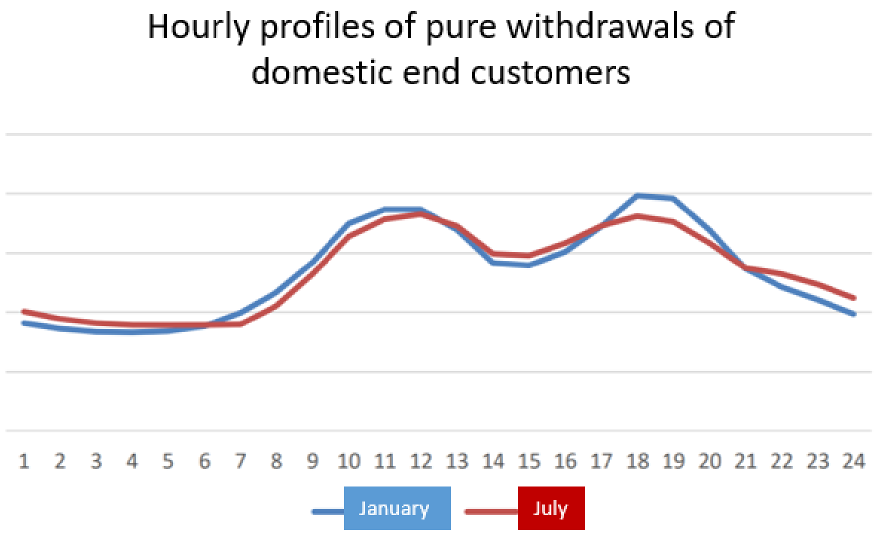


Figure 31: Example curves for non-domestic end customers with seasonality effect (pure withdrawals)

Once the monthly consumption recorded in the bill was defined and divided into time bands F1, F2 and F3, an hourly consumption profile for each building analysed has been reconstructed based on typical trends for each intended use. Initially, typical daily consumption trends were identified for each intended use of the buildings. Below there is the manual reconstruction of a typical profile of a third sector (schools, libraries, municipalities) end user daily consumption for a weekday.

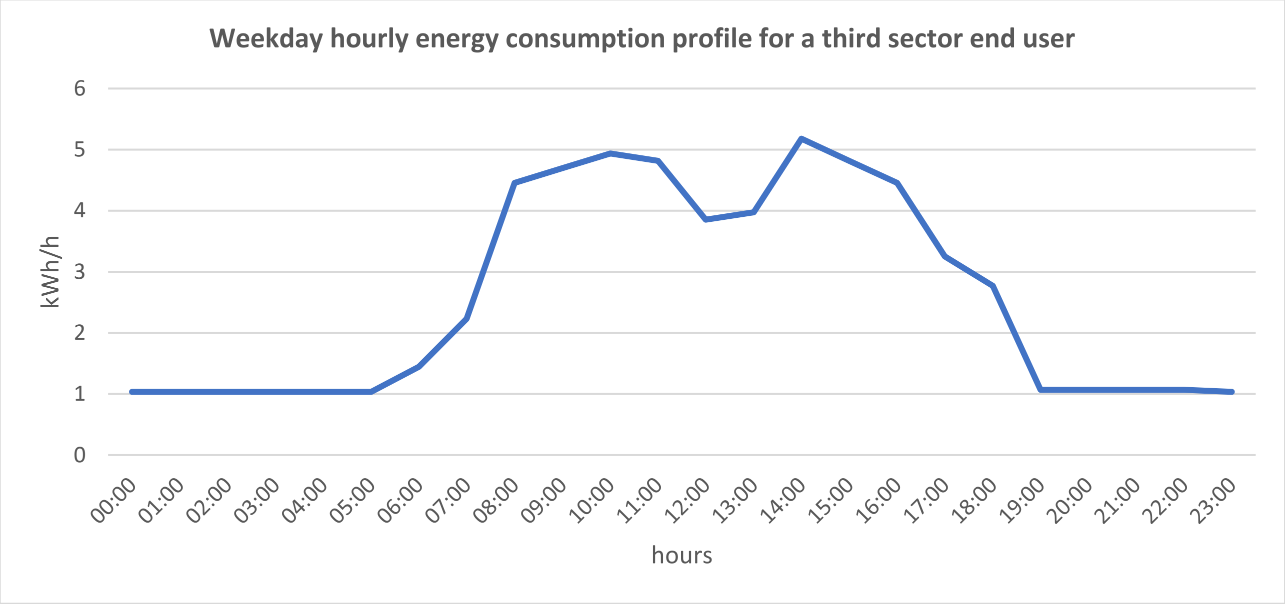


Figure 32: Weekday hourly energy consumption profile for a third sector end user

The graph represents the normalized trend of consumption. As it can be seen, the peaks are concentrated in the working hours, with a small depression in the lunch break and values close to zero in all other hours. Complementary to the Figure 33 profile, those for pre-holidays and holidays were also built. The day before a holiday was defined with consumption mainly concentrated in the morning working hours which is then reduced to a very low baseload value in the afternoon hours. The public holiday, however, is modelled with a constant baseload value throughout the day, typical of unoccupied tertiary buildings in which the IT and air conditioning systems are in operation.

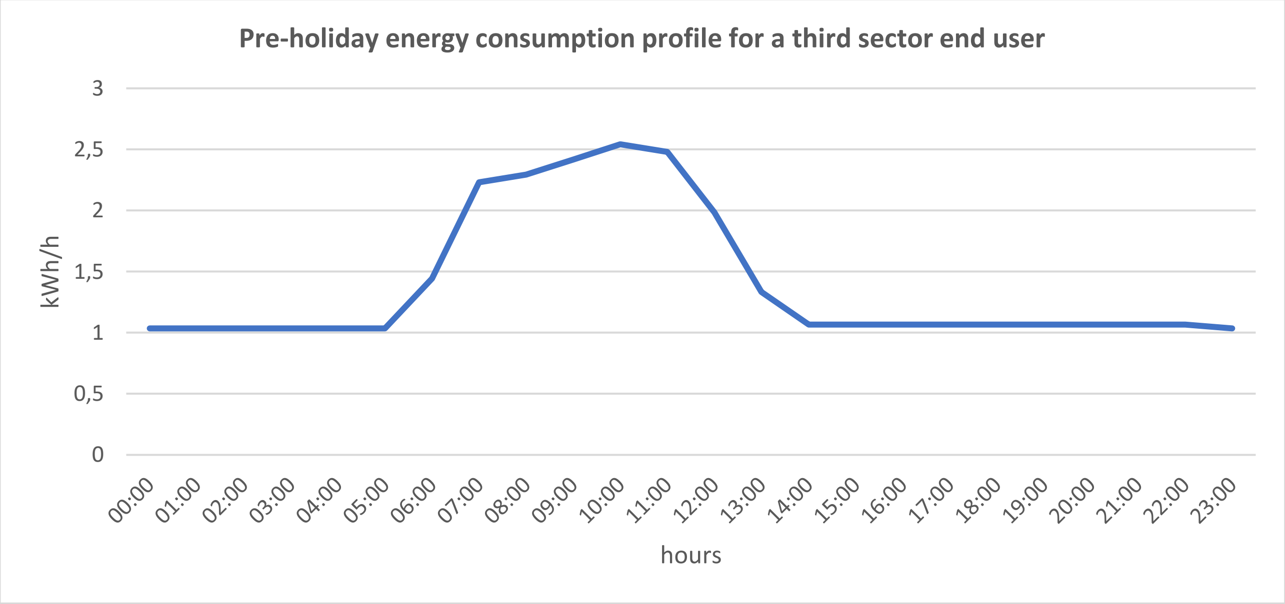


Figure 33: Pre-holiday hourly energy consumption profile for a third sector end user

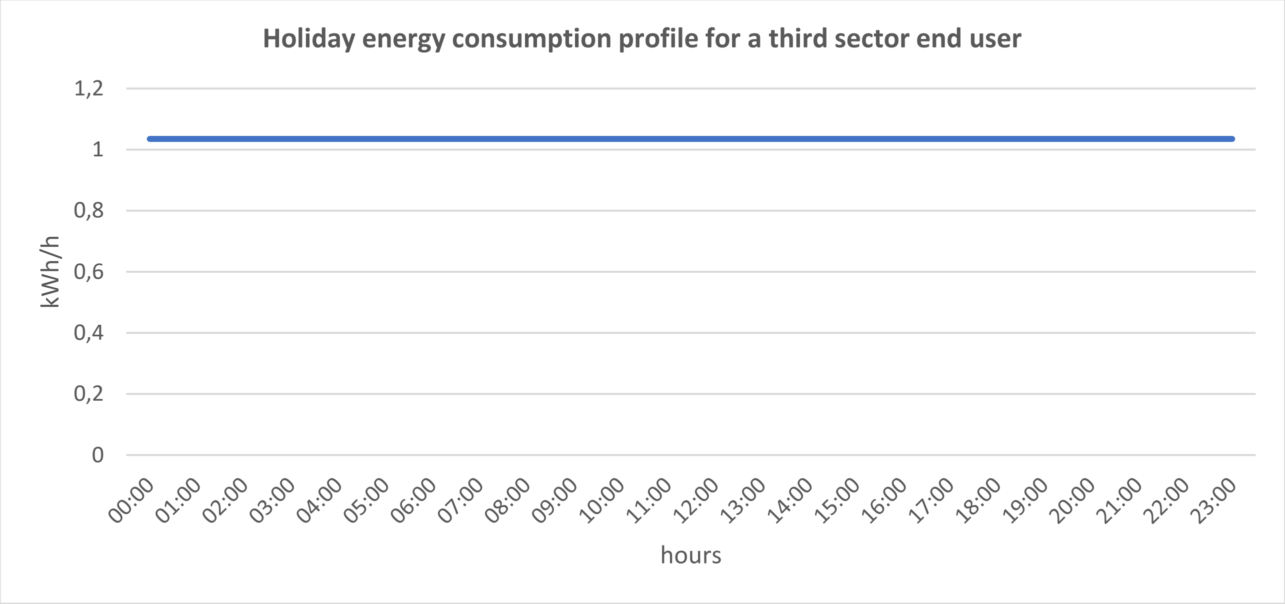


Figure 34: Holiday energy consumption profile for a third sector end user

Starting from these three typological trends, relative variants have been developed for different uses such as schools, sports centres, and socio-health centres. For example, sports centres normally have consumption concentrated in the afternoon and evening hours and between the various days of the week they also have consumption on the pre-holiday's days and holiday's days.

It is therefore known, from the electricity bills, the analysed buildings' monthly energy consumption divided into bands while the daily consumption profiles have been hypothesized. These two categories of information represent a constraint that must be respected in the reconstruction of hourly consumption for the typological year.

A normalized annual consumption trend was therefore constructed with an hourly resolution that respected the previously defined daily profiles. At that point the normalized values belonging to a given band F were multiplied by a factor for which the sum of all consumption occurring in that band and in each month was equal to the known value.

Table 18: Example of a school annual consumption divided in bands.

Month	F1	F2	F3
January	1086	249	334
February	996	227	285
March	891	225	316
April	746	173	278
May	946	182	193
June	587	143	146
July	168	57	90
August	118	70	97
September	615	153	159
October	959	189	217
November	1027	187	225
December	871	182	319

It was therefore verified that by satisfying the equality of monthly consumption by bands, the profiles maintained an appropriate trend for the specific users' class. This procedure inevitably has a component of manual calibration based on the knowledge of the various types of buildings since only specific monthly consumption values divided by bands are known.

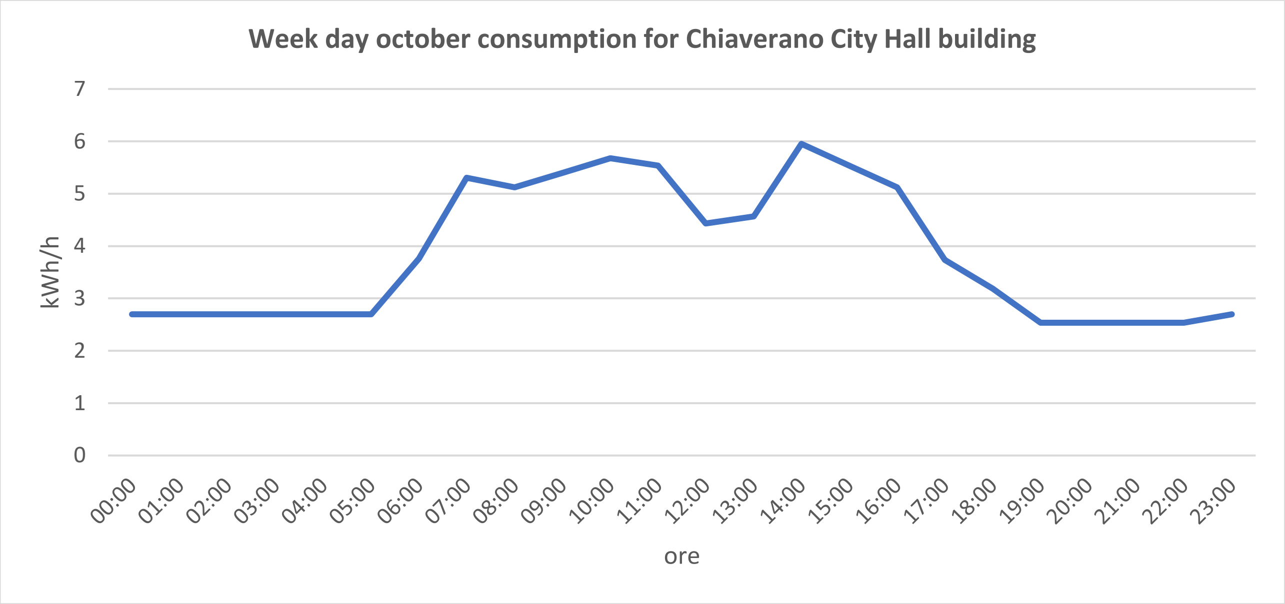


Figure 35: Weekday October consumption for Chiaverano city hall building

As an example, the daily profile of a weekday of a Chiaverano municipal building has been reported in Figure 35. The factor that satisfies the sum of monthly consumption by band has already been applied to the normalized trend; the shape of the curve has retained a shape comparable to the normalized typological one from which this study started and for this reason the hourly values can be considered validated and truthful. The same methodology was applied for the various daily profiles of each building by performing a manual calibration.

3.3.2 Hourly energy production profiles

In this study, it is assumed that the production plants of energy from renewable sources of the RECs are photovoltaic systems, as they turn out to be simpler to implement, compared to other sources such as wind, hydroelectric, biogas or biomass, considering also the constraints existing on the size and on the connection area of the plants belonging to the community: the maximum power of the single plant cannot overcome 1 MW and the connection points have to belong to a portion of the distribution network underlying the same primary electrical substation.

A primary electrical substation is a critical component of the power transmission and distribution infrastructure that plays a pivotal role in the efficient and reliable supply of electricity to consumers. It serves as an intermediate link between the high-voltage transmission system and the low-voltage distribution network, facilitating the transformation, control, and distribution of electrical power. The primary function of a primary electrical substation is to step down the high voltage electricity received from power generation plants or high-voltage transmission lines to lower, more manageable voltage levels suitable for distribution to residential, commercial, and industrial consumers. Substations achieve this using transformer, which convert electricity between different voltage levels.

Therefore, to have a picture of the production capacity of RECs municipal authorities, respecting the constraints imposed on the configurations by the regulations, a potential study was carried out on the roofs of municipal buildings available for the construction of new photovoltaic systems, choosing the best oriented pitches.

The hourly radiation data have been elaborated for 2019 year using the PVGIS portal.
By the means of PVGIS portal, is has been possible to estimate the power that can be installed on the roofs of buildings together with the annual energy production of the systems, on an hourly scale. As an example, the annual hourly production profile is shown in Figure 36, obtained through PVGIS.

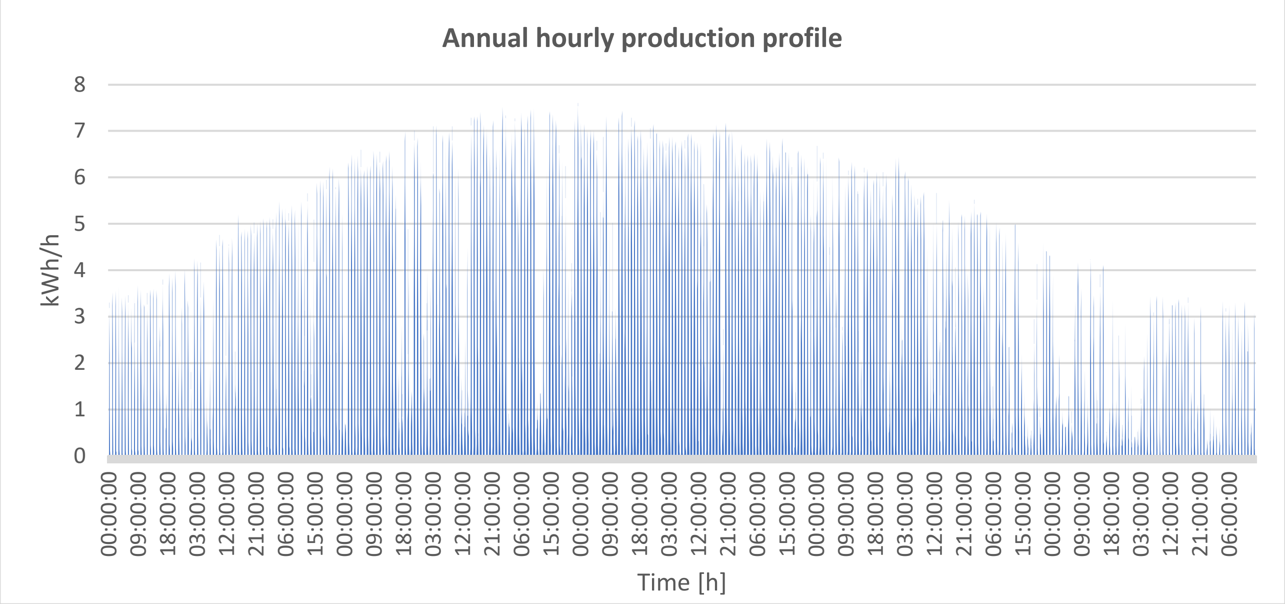


Figure 36: Hourly production, on yearly basis

3.3.3 Energy performance indexes

To evaluate the performance of the configuration, annual characterizing energy quantities are calculated, and appropriate performance indices have been defined.

Hourly data of each day are processed and used to simulate the curves of the production plants over year 2019 of operation, together with the behaviour of the consumers, to identify the percentage of energy related to the real self-consumption, to the virtual self-consumption, and consequently the percentage of energy injected into and taken from the grid. These are the indicators to control in order to evaluate whether the configuration chosen is optimized or not: if low percentages of self-consumption are obtained, this means that it is not optimized, because it would mean that the installed power is overestimated compared to the self-consumption. This necessarily affects the return of the investment because it takes more time to repay the initial investment by simply selling the electricity to the grid through the dedicated withdrawal, rather than accessing to the incentives or savings related to the direct self-consumption. Instead, when the withdrawal from the grid is too high, it means that the configuration it is not optimized, because the sizing of the plant is not in line with the consumption levels for both prosumers and consumers under analysis, being a REC priority reducing the dependability on the grid and increasing the self-sufficiency.

The data related to the hourly input of photovoltaic systems and the reconstruction of hourly user withdrawals, considered as virtual consumers of the energy produced, allows to estimate:

- the total energy produced by the REC PV plants, in the hour h, which can be calculated as:

$$E_{prod,h} = \sum_{i=1}^{m} E_{prod,h}^{(i)}$$

Where m is the number of photovoltaic systems that constitute the REC, $E_{prod,h}^{(i)}$ is the energy produced in the hour h, by the *i-th* plant.

- the energy consumed by all the electrical users inserted in the configuration, in the hour h, computed as:

$$E_{cons,h} = \sum_{j=1}^{n} E_{cons,h}^{(j)}$$

where n is the number of users, $E_{cons,h}^{(j)}$ is the energy withdrawn by the *j-th* user in the hour h.

The total annual production (E_{prod}) and the total annual REC consumption (E_{cons}), can be easily obtained from summations:

$$E_{prod} = \sum_{h=1}^{H} E_{prod,h}$$

$$E_{cons} = \sum_{h=1}^{H} E_{cons,h}$$

where H are the 8760 hourly intervals included in year 2019. Loads could be connected to photovoltaic systems with physical self-consumption, i.e., consuming energy synchronously with respect to production, under the same POD to which the plant is connected. Furthermore, it is possible to combine photovoltaic systems with storage systems. In the evaluation of the basic configuration, these hypotheses are not considered. Therefore, the energy fed into the grid PV plants, in the hour h, ($E_{\text{fed},h}$) coincides with the energy produced:

$$E_{fed,h} = E_{prod,h}$$

The energy withdrawn from the electricity distribution network, in the hour h, ($E_{\text{withdrawn},h}$) coincides with the energy consumed by the users:

$$E_{withdrawn,h} = E_{cons,h}$$

The REC configurations' energy performance is evaluated in terms of:

- Shared Energy (E_{share});
- Self-Consumption Index (SCI);
- Self-Sufficiency Index, (SSI).

In accordance with the law on energy communities (GSE), the shared energy has been calculated, as the minimum, in each hourly period, of electricity produced and fed into the grid by PV plants and the electrical energy withdrawn from all electrical users into the configuration. Shared energy in hour h ($E_{\text{share},h}$) is calculated as:

$$E_{share,h} = \min\,(E_{fed}; E_{withdrawn,h})$$

The percentage of annually shared energy is defined as follows:

$$E_{share} = \sum_{h=1}^{H} E_{share,h}$$

The self-consumption index evaluates how much energy is produced by the PV plants in the possession of the community with respect to the total REC's consumption, it is shared and consumed locally. The calculation of the indicator can also be done on different time bases, but the results will be shown below annual basis. In percentage terms, the index SCI can be calculated as:

$$SCI_{\%} = \frac{E_{share}}{E_{prod}} \cdot 100$$

where the annual energy quantities considered are energy shared E_{share} and the overall energy produced by the PV plants included in the REC, E_{prod}.

The self-sufficiency index allows you to evaluate with respect to the total REC production how much energy is consumed within its perimeter, to satisfy the load request of electrical utilities. In percentage terms, the index SSI can be calculated as:

$$SSI_{\%} = \frac{E_{share}}{E_{cons}} \cdot 100$$

where the annual energy quantities considered are energy shared E_{share} and the overall energy consumed by all the REC electrical loads, E_{cons}.

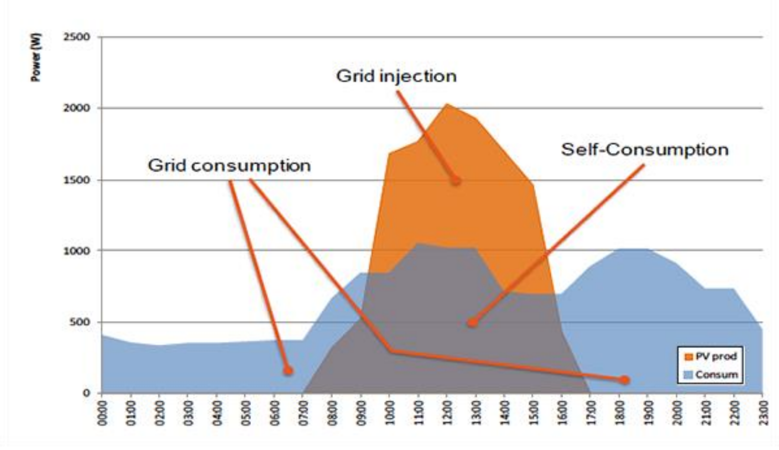


Figure 37: Self-consumption and self-sufficiency [31]

Self-consumption should not be confused with self-sufficiency. The ratio of self-consumption describes the local (or remote under some schemes) use of PV electricity while the self-sufficiency ratio describes how PV production can cover the needs of the place where it is installed. These concepts are completely different, but both play important roles in the debate on the development of prosumers [35].

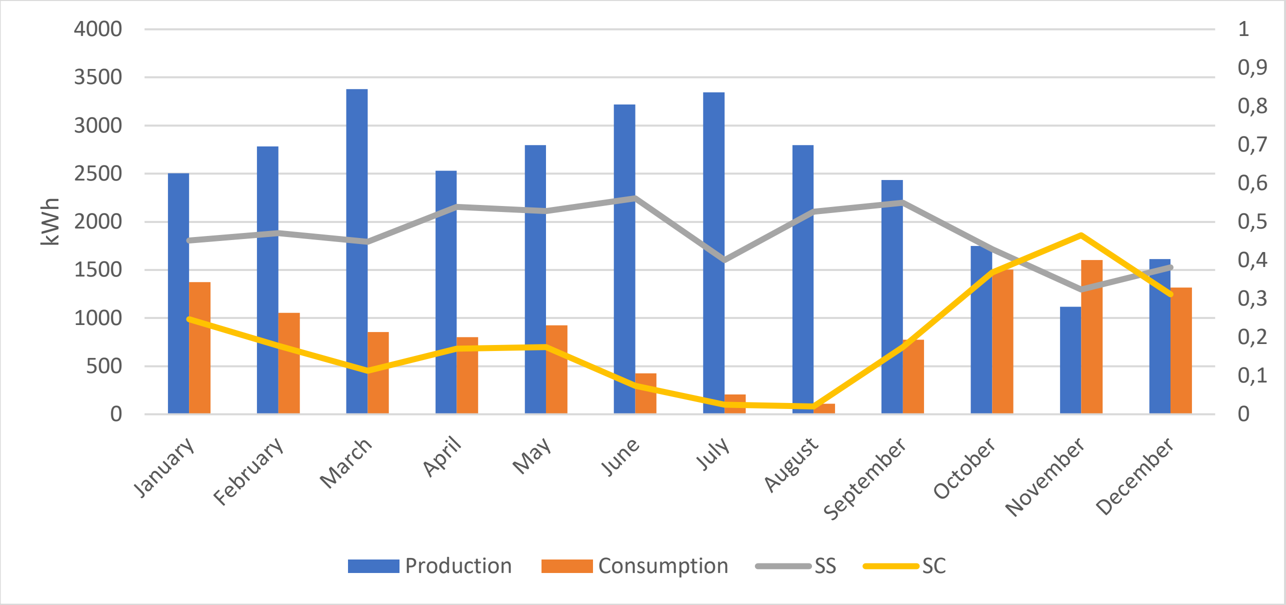


Figure 38:Energy production (blue) and consumption (orange), SCI, SSI, of a school in Borgofranco, monthly.

In Figure 38 a school in Borgofranco d'Ivrea is taken as an example to display the monthly consumption (orange) and the monthly production (blue). Its Self-Sufficiency index varies between 40% and 50% and it's quite constant during the year while its Self-Consumption index varies. It's almost null during summer when the school is closed, and the PV production is at its maximum and increases when production and consumption almost overlap.

CHAPTER 4 REC’s sizing and constitution

Renewable Energy Communities are groups of electrical users connected to the portion of the electrical distribution network underlying the same primary substation (HV-MT transformation substation), which can inject and/or withdraw energy electric. In fact, each user, whose connection point to the network is identified by the code POD, can be characterized by:

- passive elements, i.e. electrical loads that absorb energy from the network;
- active elements represented by:
  - -production plants from renewable sources, which input energy in the network;
  - -any storage systems, which draw energy from the grid during the charging phase and transmit energy to the network in the discharging phase.

The electricity demand of all users belonging to the REC is satisfied from the national electricity grid and from all the source production plants renewable combined with the potential energy accumulations held by the community. In fact, the energy produced by REC's photovoltaic systems:

- can partly go to physical/real self-consumption, towards the user directly connected to the PV generator;
- is partly fed into the national electricity grid, so that the electrical loads of the REC can withdraw it to satisfy their consumption and, in this case, it is detected as shared energy;
- in part can simply be placed on the network and without being shared.

Therefore, the users included in the configuration can share the overproduction of the electricity supplied by the renewable generators, through the network public distribution, in the so-called virtual self-consumption mode. The users associated in the community can be distinguished between the users in:

1. **simple consumers**, interested in energy flows with the grid only incoming;
2. **simple producers**, for which we have outgoing energy flows with the grid;
3. Producers and consumers, or **prosumers,** characterized by energy flows with the network both incoming and outgoing.

This study of municipal RECs starts from a basic configuration, in which only photovoltaic systems and electricity utilities owned by the Municipalities are assumed to be present. Then an aggregation of different consumers is considered.

4.1 Distribution of plants with respect to their primary electrical substation

Based on what is indicated in Legislative Decree 199/2021, the REC it is an autonomous legal entity and the exercise of control powers falls exclusively to natural persons, SMEs, territorial bodies and local authorities, including municipal administrations, research and training bodies , religious, third sector and environmental protection bodies as well as local administrations included in the ISTAT list, which are located in the territory of the same municipalities in which the sharing facilities are located. The main objective of the REC is to provide environmental, economic, or social benefits at the community level or to the local areas in which it operates and not to make financial profits. For businesses, participation in the REC cannot constitute the main commercial and industrial activity, furthermore participation in the REC is open to all consumers,

including those belonging to low-income or vulnerable families. The individual production plants from renewable energy sources admitted to the REC configurations can reach a megawatt of power and must be newly built; however, the possibility of adding existing plants for a maximum power not exceeding 30% of the total power of the plants is given. The perimeter of the REC configurations is defined by the consumption users and the RES plants that are under the same primary substation (MV/HV).
GSE portal gives the possibility of identifying which primary substation a specific user refers to.

In the case of the municipalities involved in this case study, its territory is distributed over two primary cabins: the **AC001E01319** to which the buildings of the municipality of Borgofranco d'Ivrea, Quassolo and Quincinetto refer and the **AC001E01317** to which the municipal buildings of Montalto Dora, Lessolo and Chiaverano as shown in Table 19 and Figure 39.

Table 19: Municipalities' subdivision into clusters based on different primary substation

CLUSTER	PRIMARY SUBSTATION CODE	NUMBER OF BUILDINGS
Borgofranco d'Ivrea, Quassolo and Quincinetto	AC001E01319	39
Montalto Dora, Lessolo and Chiaverano	AC001E01317	52

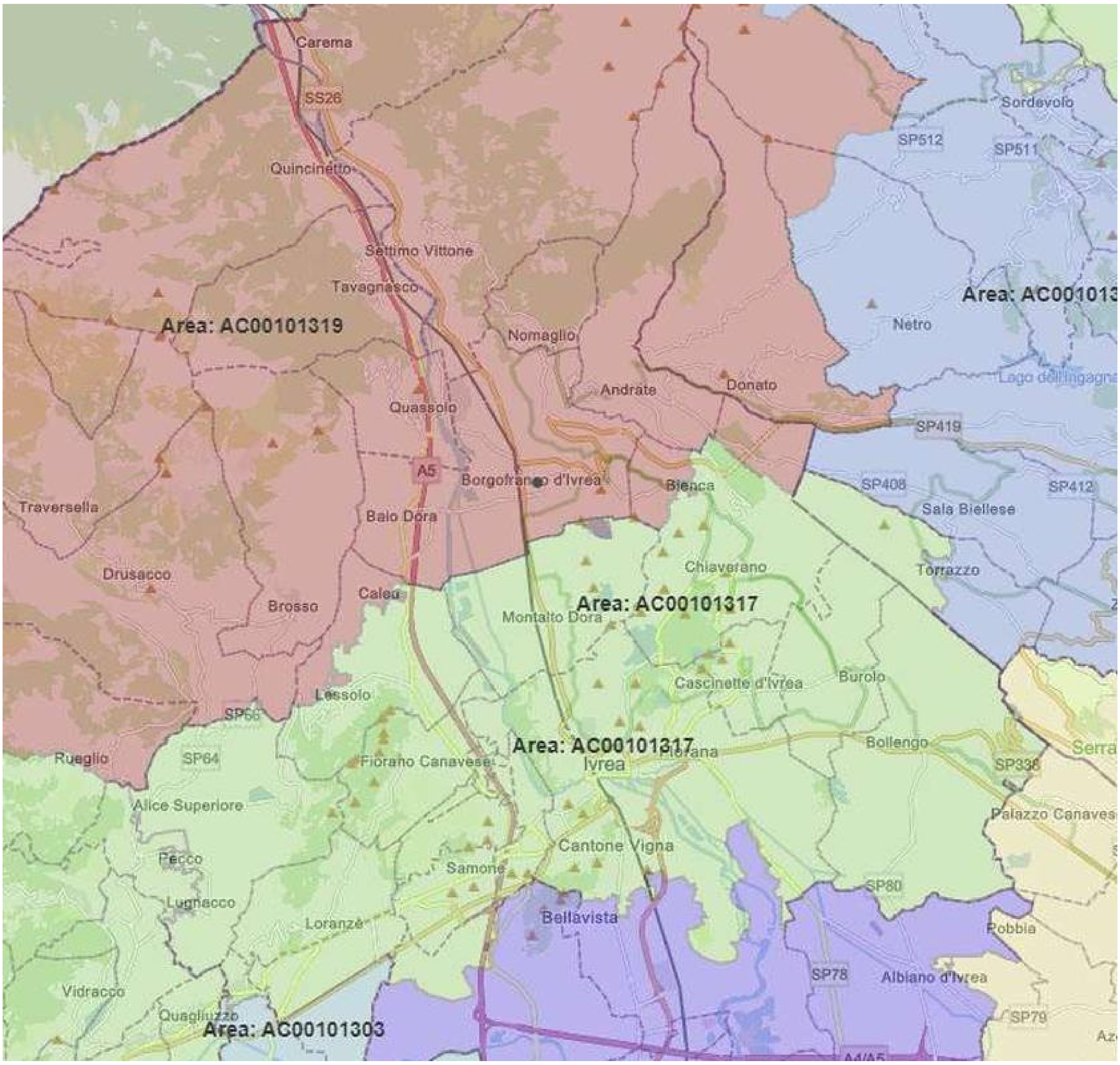


Figure 39: AC001E01319 and AC001E01317 primary substations' areas [32]

The distribution of the buildings on the Municipalities territory is shown in the image below; the areas that refer to the primary cabins have been superimposed on the satellite image shown in Figure 40.

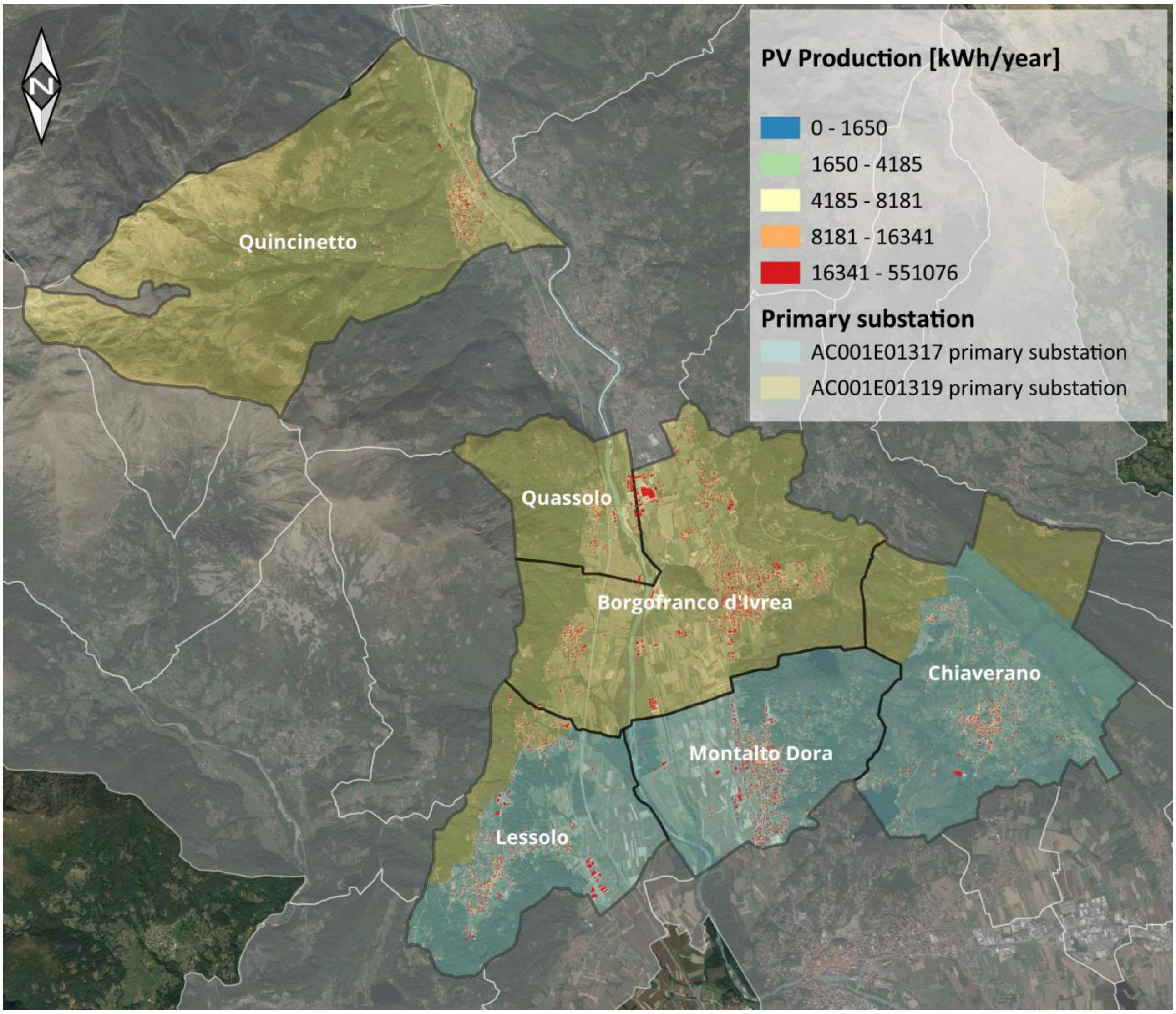


Figure 40: Distribution of the buildings belonging to the two primary substations' areas on the Municipalities' territory.

From this analysis it therefore appears that the buildings and the related consumption and possible RES production can refer to two RECs' configurations underlying the AC001E01319 primary substation and the AC001E01317 substation.

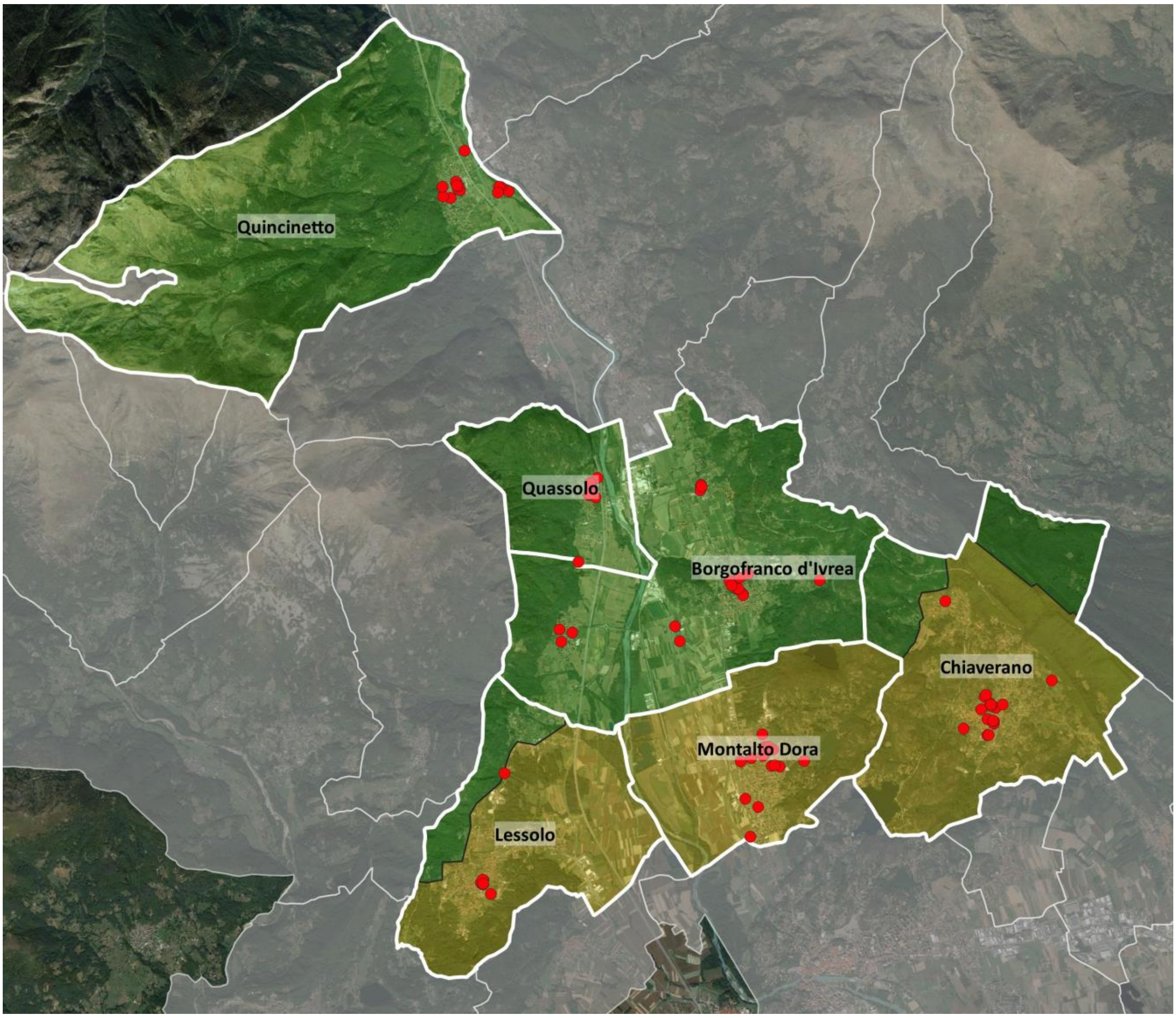


Figure 41: Distribution of Municipal buildings belonging to the two primary substations' areas.

4.2 Energy flows in REC configuration: direct self-consumption and renewable energy fed into the grid.

The hourly consumption analysis results together with those of the PV plants' producibility on the roofs of the municipal buildings made it possible to estimate the value of the energy produced and directly consumed within the single buildings before being fed into the grid and shared among the community for the collective self-consumption.

Considering a generic RES plant and a respective user, the self-consumption is the **share of energy produced** by the plant which is immediately consumed by the user. Without storage batteries, this amount is only taken from the plant; otherwise, it can be taken from the storage system to which is connected. In both cases, this share of energy does not have an impact on the bill, and it is paid by incentives. The objective of the analysis is to maximize this share to optimize economic returns.

The **extra-production** is the share of energy produced by the system that is not immediately consumed by the user. In absence of storage batteries, this quota is transferred to the national grid; otherwise, it charges the storage system to which it is connected.

The **uncovered demand** is the share of energy consumed by the user that is not covered by the energy produced from the plant. In lack of storage batteries, this amount is taken from the national grid and added to the bill; otherwise, it is taken from the accumulation system to which it is connected.

In order to then quantify the revenues, it is necessary to define the parameters associated with them. It was necessary to calculate the total share of self-consumed energy and by each user in the time hour interval, the share of energy fed into the grid in the time interval and the share of energy withdrawn (and purchased) from the network. First, the difference between the energy produced by the PV system in one hour *h* and the building's consumption was evaluated. After, depending on the value obtained, according to the logic reported below, it was possible to obtain the total self-consumed energy in the time interval together with the portion of energy injected into the grid and of uncovered demand.

$$E_h = E_{FV,h} - E_{cons,h}$$

$$E_{fed} = E_{PV} - E_{self-cons}$$

$$E_{uncovered} = E_{tot,cons} - E_{self-cons}$$

$$\text{If } E_{FV,h} > E_{cons,h} \text{ then } E_h = E_{injected\ into\ the\ grid}$$

$$\text{If } E_{FV,h} < E_{cons,h} \text{ then } E_h = E_{withdrawn}$$

In Table 20 the computed annual values are shown.

Table 20: Direct self-consumption and energy fed into the grid for municipal buildings belonging to AC001E01319 primary substation.

AC001E01319					
BUILDING CODE	**ANNUAL CONSUMPTION FOR MUNICIPAL USERS *[kWh]***	**ANNUAL PRODUCTION *[kWh]***	**DIRECT SELF-CONSUMPTION *[kWh]***	**ENERGY FED INTO THE GRID *[kWh]***	**UNCOVERED DEMAND *[kWh]***
1BO	3.150	12.757	1.239	11.518	1.911
2BO	36	21.533	20	21.513	16
3BO	6.529	37.465	2.887	34.578	3.642
4BO	10.951	30.263	4.885	25.377	6.066
5BO	28.250	24.610	11.079	13.531	17.171
6BO	901	27.819	449	27.370	452
7BO	9.964	49.663	4.534	45.130	5.430
8BO	3.412	24.055	2.086	21.969	1.326
9BO	12	74.995	11	74.984	1
10BO	276	307.408	126	307.282	150
11BO	36	4.422	20	4.402	16
12BO	387	0	0	0	387
13BO	2.140	12.872	1.312	11.560	828
14BO	1.677	19.390	830	18.560	847
15BO	594	11.211	292	10.918	302
1QUA	700	11.794	439	11.356	261
2QUA	8.728	0	0	0	8.728
3QUA	5.299	0	0	0	5.299
4QUA	433	16.475	138	16.337	295
5QUA	288	20.262	147	20.115	141
6QUA	1.797	10.409	878	9.531	919
7QUA	3.184	29.633	1.466	28.167	1.718
8QUA	1.615	12.722	778	11.944	837
9QUA	7.812	10.581	2.789	7.792	5.023

AC001E01319					
BUILDING CODE	**ANNUAL CONSUMPTION FOR MUNICIPAL USERS *[kWh]***	**ANNUAL PRODUCTION *[kWh]***	**DIRECT SELF-CONSUMPTION *[kWh]***	**ENERGY FED INTO THE GRID *[kWh]***	**UNCOVERED DEMAND *[kWh]***
10QUA	790	0	0	0	790
11QUA	36	0	0	0	36
12QUA	36	40.264	20	40.244	16
1QUI	12.350	71.072	5.381	65.691	6.969
2QUI	2.644	27.602	1.605	25.997	1.039
3QUI	2.187	3.490	1.055	2.435	1.132
4QUI	9.778	43.346	4.942	38.405	4.836
5QUI	74	6.513	52	6.461	22
6QUI	4.815	53.202	3.008	50.195	1.807
7QUI	13.518	22.086	6.431	15.655	7.087
8QUI	706	7.023	373	6.650	333
9QUI	2.008	9.371	1.017	8.354	991
10QUI	747	7.028	353	6.675	394
11QUI	7.139	44.506	2.689	41.817	4.450
12QUI	1.665	0	0	0	1.665
TOTAL	**156.664**	**1.105.842**	**63.331**	**1.042.513**	**93.333**

The energy self-consumed directly by the users, for the AC001E01319 primary substation, is therefore equal to 40% of the total consumption.

Table 21: Direct self-consumption and energy fed into the grid for municipal buildings belonging to AC001E01317 primary substation.

AC001E01317					
BUILDING CODE	**ANNUAL CONSUMPTION FOR MUNICIPAL USERS *[kWh]***	**ANNUAL PRODUCTION *[kWh]***	**DIRECT SELF-CONSUMPTION *[kWh]***	**ENERGY FED INTO THE GRID *[kWh]***	**UNCOVERED DEMAND *[kWh]***
1MO	4.429	0	0	0	4.429
2MO	431	10.500	205	10.295	226
3MO	1.560	32.812	777	32.035	783
4MO	462	0	0	0	462
5MO	1.439	11.643	691	10.952	748
6MO	106	0	0	0	106
7MO	607	21.943	304	21.640	303
8MO	58	7.050	25	7.025	33
9MO	2.128	7.873	1.011	6.862	1.117
10MO	165	0	0	0	165
11MO	5.005	49.683	1.683	48.000	3.322
12MO	13.248	29.366	7.482	21.883	5.766
13MO	49	0	0	0	49
14MO	10.127	120.984	4.609	116.375	5.518
15MO	2.164	10.484	1.281	9.202	883
16MO	996	0	0	0	996
17MO	425	18.529	232	18.297	193
18MO	13.731	11.071	5.517	5.554	8.214
19MO	1.182	0	0	0	1.182
20MO	9.232	0	0	0	9.232
21MO	882	0	0	0	882
22MO	125	0	0	0	125
23MO	15.532	126.442	8.200	118.242	7.332
24MO	9.351	237.879	5.679	232.200	3.672
25MO	3.589	47.186	1.364	45.821	2.225
26MO	453	3.524	235	3.289	218

AC001E01317					
BUILDING CODE	ANNUAL CONSUMPTION FOR MUNICIPAL USERS *[kWh]*	ANNUAL PRODUCTION *[kWh]*	DIRECT SELF-CONSUMPTION *[kWh]*	ENERGY FED INTO THE GRID *[kWh]*	UNCOVERED DEMAND *[kWh]*
1CHI	3.696	19.946	2.288	17.658	1.408
2CHI	159	12.968	59	12.909	100
3CHI	861	13.776	486	13.290	375
4CHI	2.396	16.404	1.135	15.270	1.261
5CHI	1.060	26.971	558	26.413	502
6CHI	1.613	12.737	811	11.926	802
7CHI	2.318	13.330	1.156	12.173	1.162
8CHI	3.692	104.297	1.568	102.729	2.124
9CHI	60	0	0	0	60
10CHI	27.393	24.911	10.961	13.949	16.432
11CHI	6.318	70.368	4.204	66.164	2.114
12CHI	5.871	15.079	3.272	11.807	2.599
13CHI	15.108	61.158	6.760	54.398	8.348
14CHI	3.037	82.682	1.402	81.280	1.635
15CHI	1.815	6.067	529	5.538	1.286
16CHI	975	14.791	372	14.419	603
1LE	203	10.607	121	10.485	82
2LE	8.308	21.780	4.307	17.473	4.001
3LE	338	0	0	0	338
4LE	38	12.828	20	12.809	16
5LE	20.736	0	0	0	20.738
6LE	283	0	0	0	283
7LE	3.647	0	0	0	3.647
8LE	16.816	111.283	11.328	99.955	5.488
9LE	3.827	0	0	0	3.827
10LE	854	10.492	444	10.048	410
TOTALE	**228.898**	**1.409.444**	**91.076**	**1.318.365**	**137.822**

The energy self-consumed directly by the users, for the AC001E01317 primary substation, is therefore equal to 40% of the total consumption.

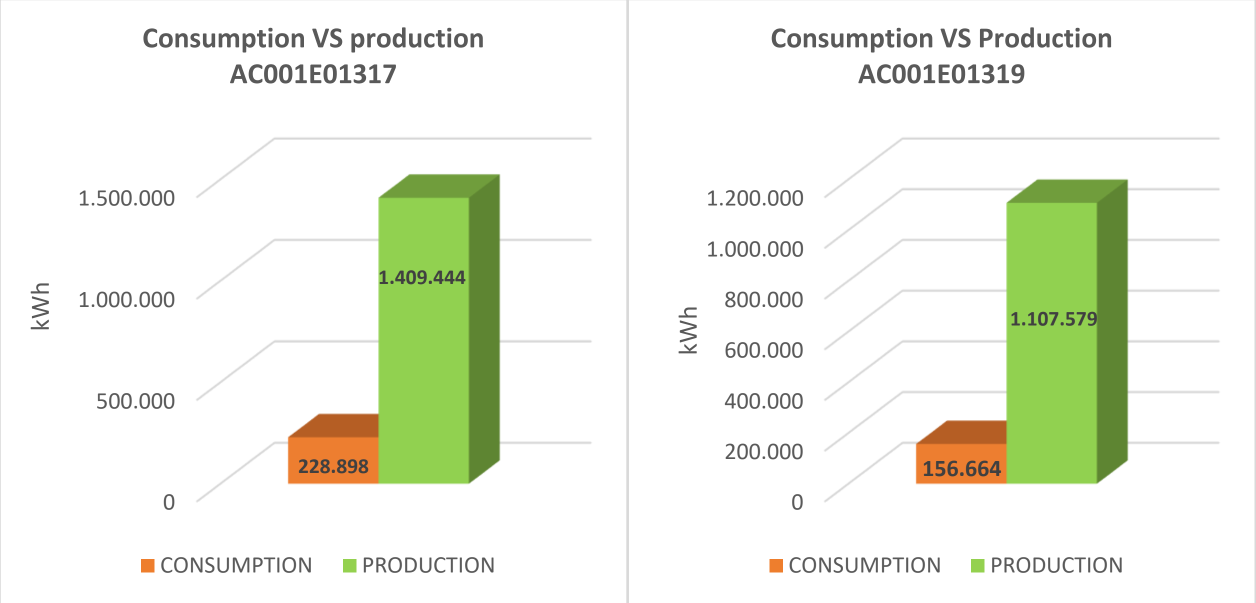


Figure 42: Consumption VS Production for the two RECs.

Below, as an example, the analysis of energy flows is proposed in one summer day and in one winter day. To represent the best situations in terms of production of the photovoltaic system, two sunny days are represented, i.e., the days when the independence from the electricity grid is high.

In particular, the profiles represented in the figures below show the produced, consumed, self-consumed, injected into the network and withdrawn from the network (uncovered demand), referring to January 6th (Figure 43) and June 30th (Figure 44).

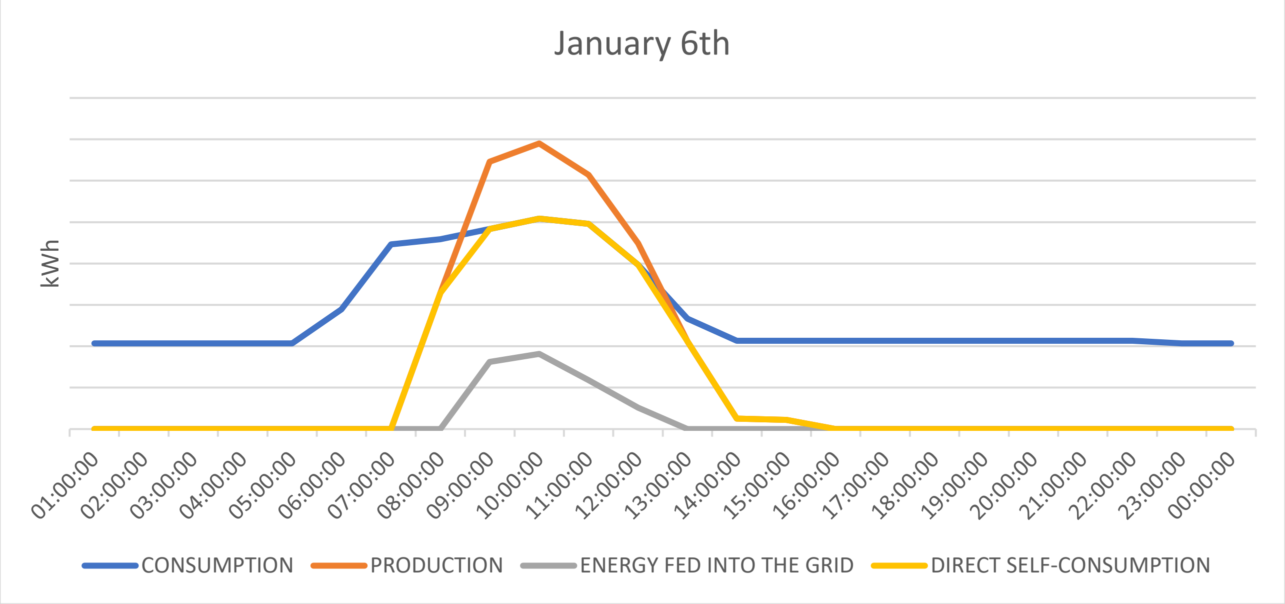


Figure 43: Power profiles on January 6th

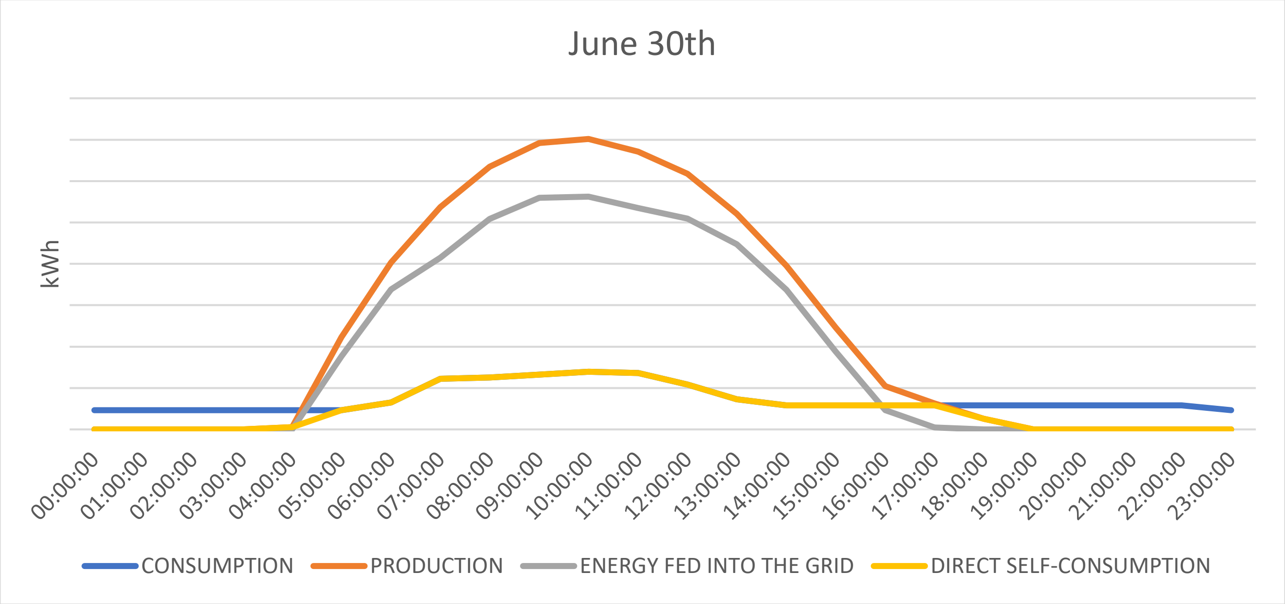


Figure 44: Power profiles on June 30th.

In Figure 45 the single building behaviour is displayed to show the daily trend of energy flows during a sunny day.

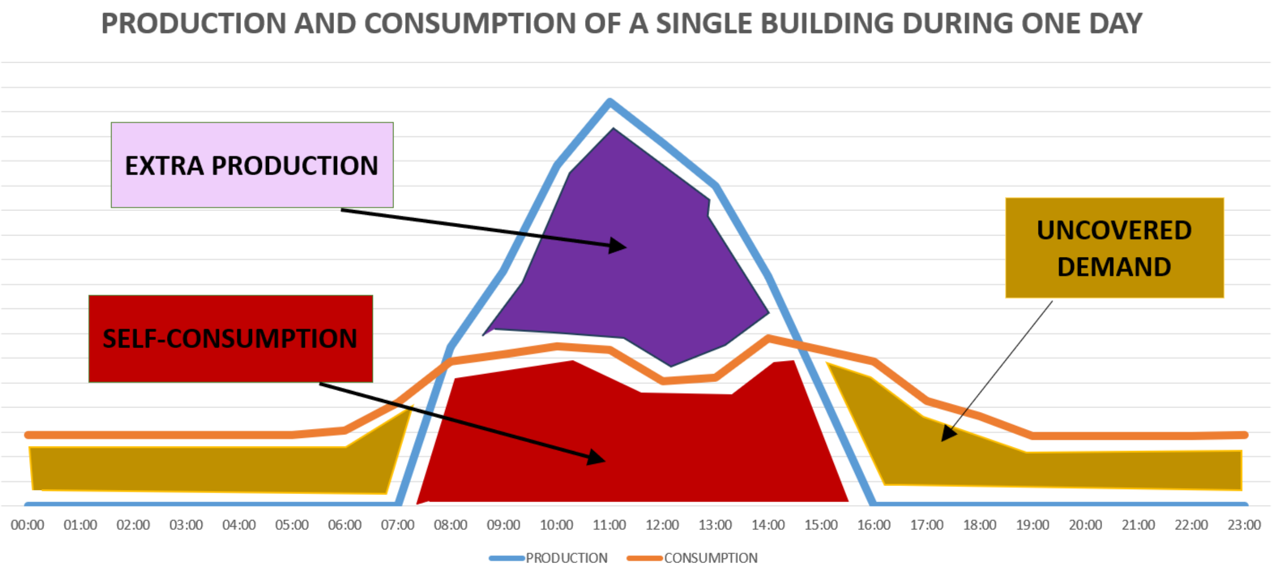


Figure 45: Production and consumption of a single building for one day (personal elaboration).

In Figure 46 the annual energy flows for a school are displayed to show the effect of seasonality on production and consumption. When the production is at its highest, the consumption is almost null so that most of the energy produced is fed into the grid and sold. By aggregating the single buildings, the single extra-productions are fed into the grid and shared among the REC's users. The more the energy is shared the more the REC's target is reached.

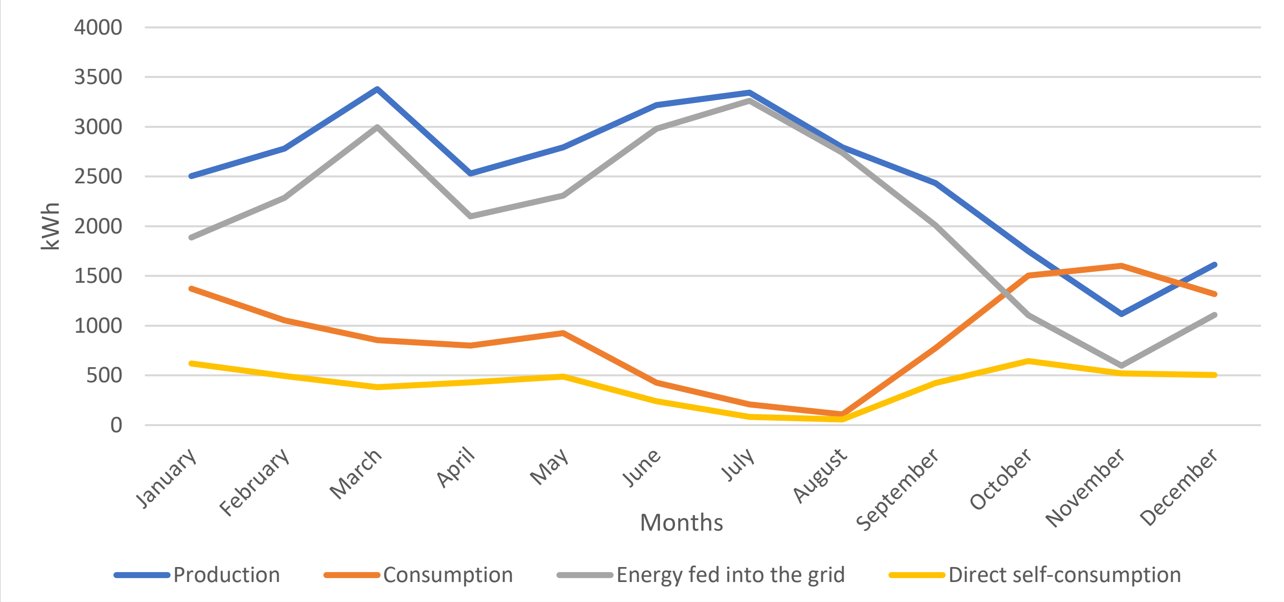


Figure 46: Annual energy flows.

From an energetic point of view, it becomes it is immediately clear that a REC cannot be energy independent using systems PV production not supported by storage systems. In order to cover night loads, or in case of absence of solar radiation, alternative generation systems should be taken into consideration. In relation to the municipal territory, and the installations present according to Atlaimpianti, a possible solution could be to include small-scale hydroelectric plants, but this is not addressed in this study.

4.2.1 Storage systems

At first glance, electrochemical storage systems are not considered for three main reasons. The first is the high cost that these present, which could be prohibitive for widespread diffusion among individual users in the current state of art. The second is automation and management of the charging and discharging processes, which are currently not so flexible as to be able to guarantee a perfect overlap between consumption and production. In the end, the issue of possible negative fluctuations on the network, due to storages, should not be overlooked. Besides, it is difficult to imagine that every single user could install a storage system and take charge of its correct management at the interface with the distribution network. The increase of distributed generation points and storage systems can cause, especially on low voltage networks, an imbalance in the minimum levels to be guaranteed on the voltage, due to the impossibility of insert reactive power into the grid capable of balancing the imbalance resulting from injection into the grid [33].

Nevertheless, storage systems play a crucial role in supporting renewable energy communities by addressing the intermittent nature of renewable energy sources. There are several ways in which storage systems can contribute to the success of renewable energy communities. RES like solar power is intermittent, meaning they don’t generate a consistent amount of energy throughout the day. Storage systems, such as batteries, can store excess energy when production is high and release it when production is low. This helps balance energy supply and demand, contributing to grid stability. Besides, storage systems allow communities to shift energy consumption from peak demand periods to off-peak times. This can help reduce strain on the grid during high-demand periods and make better use of renewable energy when it’s abundant.

Communities with reliable energy storage systems can become less dependent on the central grid. This can be especially valuable in remote or off-grid areas, where establishing and maintaining traditional power infrastructure may be challenging. Storage systems facilitate the integration of variable renewable energy sources into the grid. By storing excess energy during periods of high production, communities can ensure a continuous and reliable power supply even when renewable sources are not actively generating electricity.

Furthermore, advanced storage systems can provide grid services such as frequency regulation and voltage control. These services help stabilize the grid, making it more resilient to fluctuations in energy production and consumption. Energy storage systems empower local communities to have more control over their energy production and consumption. This can foster a sense of energy independence and community resilience.

Energy storage systems, as part of a REC, can encourage shared self-consumption among members. The GSE provides information on the configurations eligible for the integration of storage systems (e.g., electrochemical batteries) under a REC [34]. From a technical point of view, storage systems must essentially be subservient to a system of RES production so that the energy fed into the grid in a deferred manner (thanks to the storage system) can detect as shared energy. Clearly, a storage system can first of all be used to increase the share of onsite self-consumption, for the user to which it is connected.

From the point of view of the REC profitability, the battery must be within its scope investment thanks to the additional share of shared energy that it allows to achieve. To date, the costs of investment in batteries are still not fully competitive to provide good profitability. However, in the case of capital incentives on the storage system, and further reductions on the cost of technology, RES system configurations with integrated storage system could result advantageous.

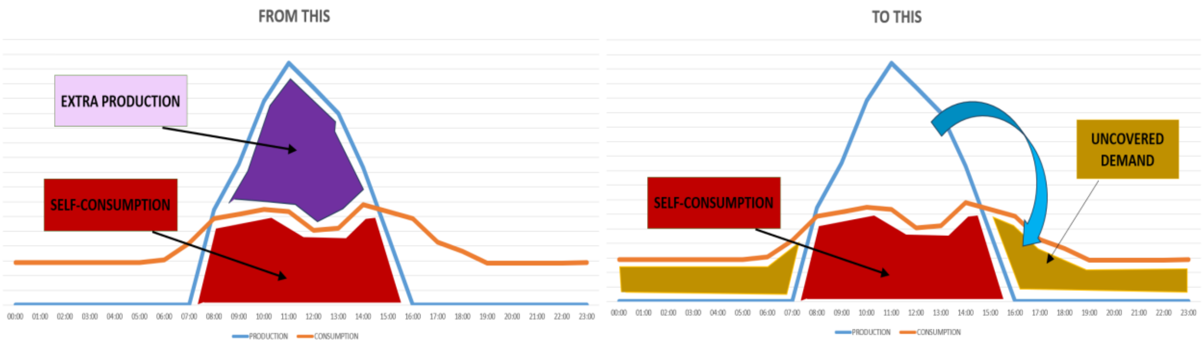


Figure 47: Storage of the surplus of the PV system (personal elaboration)

For this study, a battery charge/discharge (Figure 48) equation is hypothesized to evaluate the integration of a few storage systems in the REC.

$$Charge = 97{,}948 \cdot e^{-0{,}0009 \cdot t}$$

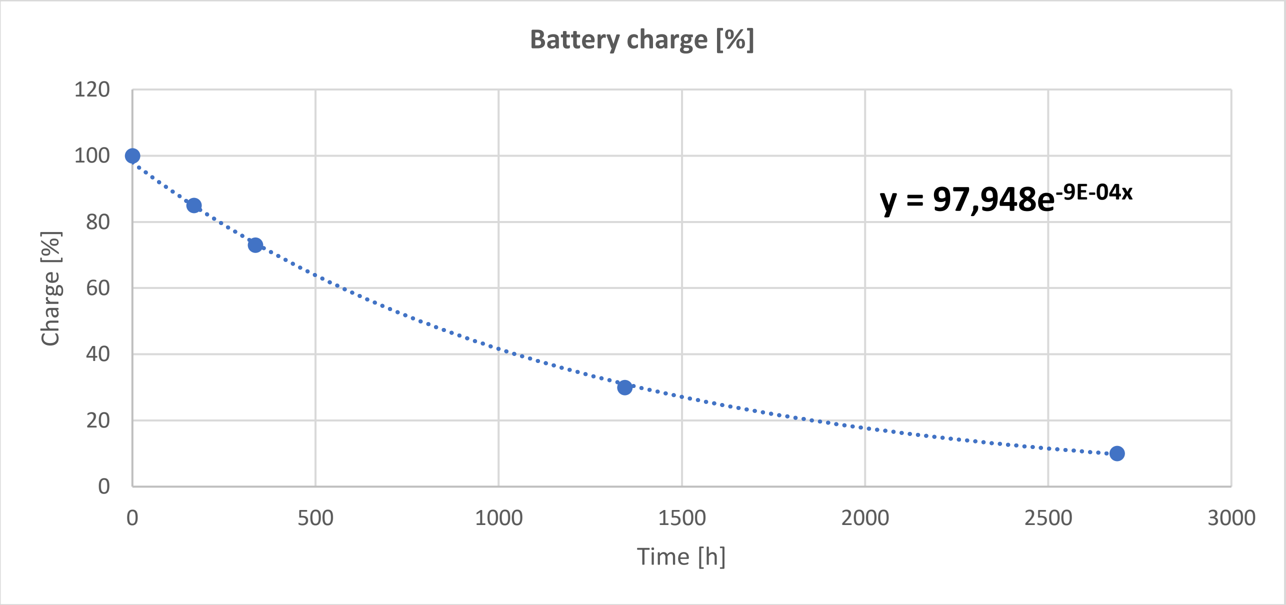


Figure 48: Battery charge/discharge equation.

To model the speed with which the battery charges and discharges the yearly time derivative is represented by Figure 49, with x and y representing time and battery charge.

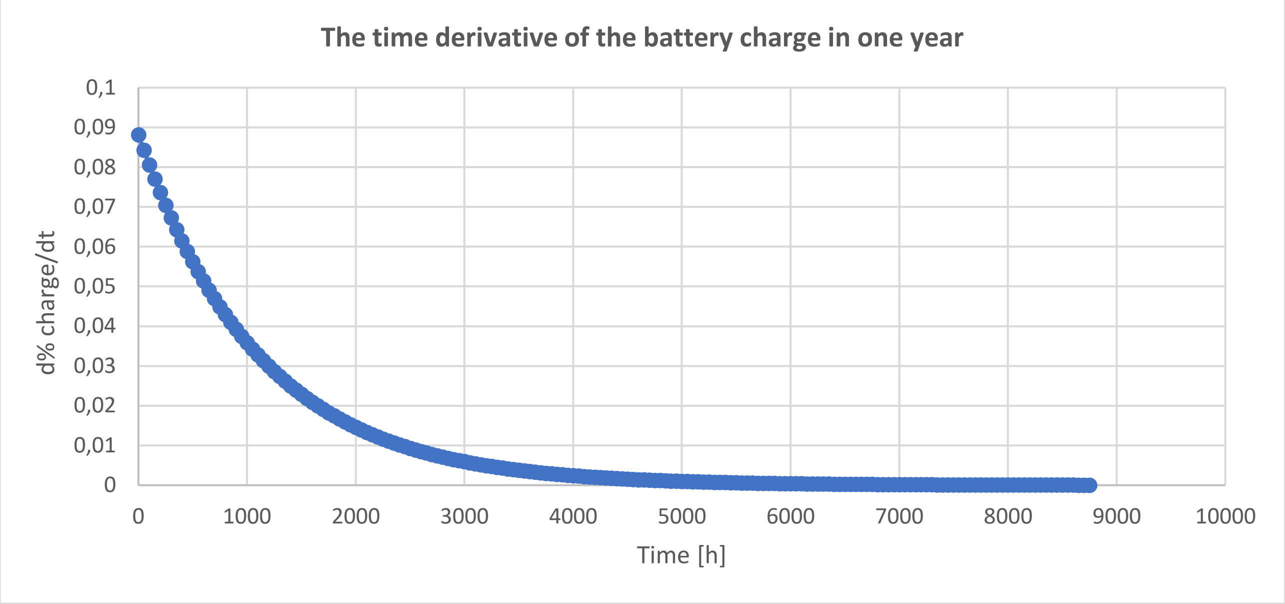


Figure 49: The time derivative of the battery charge in one year

4.3 REC's configurations: possible scenarios

This municipal REC study starts from a basic configuration, in which only photovoltaic systems and municipal electrical utilities are assumed to be present. To improve the REC's performance, in addition to this configuration, several potentially implementable scenarios are considered. It is hypothesized that:

- Domestic users can also join as members of the community (i.e. families), whose annual hourly load profile has been reconstructed considering the standard profile for domestic users proposed by the GSE [10];
- Municipal prosumers with higher consumption are combined with a storage system;
- PV systems are installed on all municipal buildings in order to charge stations for electric vehicles.

All these measures contribute to the primary REC's purpose, which is to maximize the instantaneous consumption of shared energy.

To comply with economic sustainability criteria, the REC's configurations must be able to maximize the incentives that GSE will recognize to the REC, based on the indications present in the MASE draft version of the Ministerial Decree. It is recognized that a REC configuration is well dimensioned if the energy fed into the grid by the RES plants is self-consumed every hour by other consumers belonging to the same configuration/REC for a value equal to 80%. In this chapter there are some possible RECs configurations different by number of PV systems and by type of consumer.

4.3.1 Scenario 1: REC with PV systems on all municipal buildings and household consumers

The base case consists of all the municipal buildings consuming the energy produced by PV plants installed on them. Because of their low annual consumption, the results of the base case show a low use of the energy fed into the grid by the plants. The percentage of shared energy is only of 2,7% for cabin 1317 and 1,7% for cabin 1319, quite far from the optimal value by 80%. 1.458 (for cabin 1317) and 1.233 (for cabin 1319) equivalent domestic end users (which simulate the consumption of a family unit of 2-3 people) are added to the energy analysis to increase the value of RECs' consumption and consequently get to a shared energy target value of 80%, which ensures the RECs' economic sustainability. The energy results of the target case will then be used for the economic-financial analysis in the next chapter.

The 1.458 domestic users have an aggregate equivalent consumption equal to 5.252 MWh/year while the 1.233 domestic users belonging to the other primary substation equal to 4.442 MWh/year. It is important to underline that these domestic end users have the same type of medium-low (1.393 kWh/year) per capita consumption. Consequently, involving users who have higher consumption (for example SMEs, little industries with higher daily consumption than domestic users) the number of users to be aggregated may also be reduced sensitively. In fact, using a commercial user with an annual consumption of 12.704 kWh/year as an equivalent user, the number of extra users to be aggregated tends to reduce (once the members' production and consumption indicated in the base case are fixed). Table 22 shows the percentage of shared energy in function of the number of domestic users together with Figure 50.

Table 22: Percentage of shared energy in function of the number of domestic users

NUMBER OF DOMESTIC USERS	SHARED ENERGY 1317	SHARED ENERGY 1319
150	15,7%	17,4%
500	40,5%	45,4%
750	54,3%	60,4%
1000	65,3%	71,7%
1250	74,0%	80,5%
1460	80,1%	86,0%

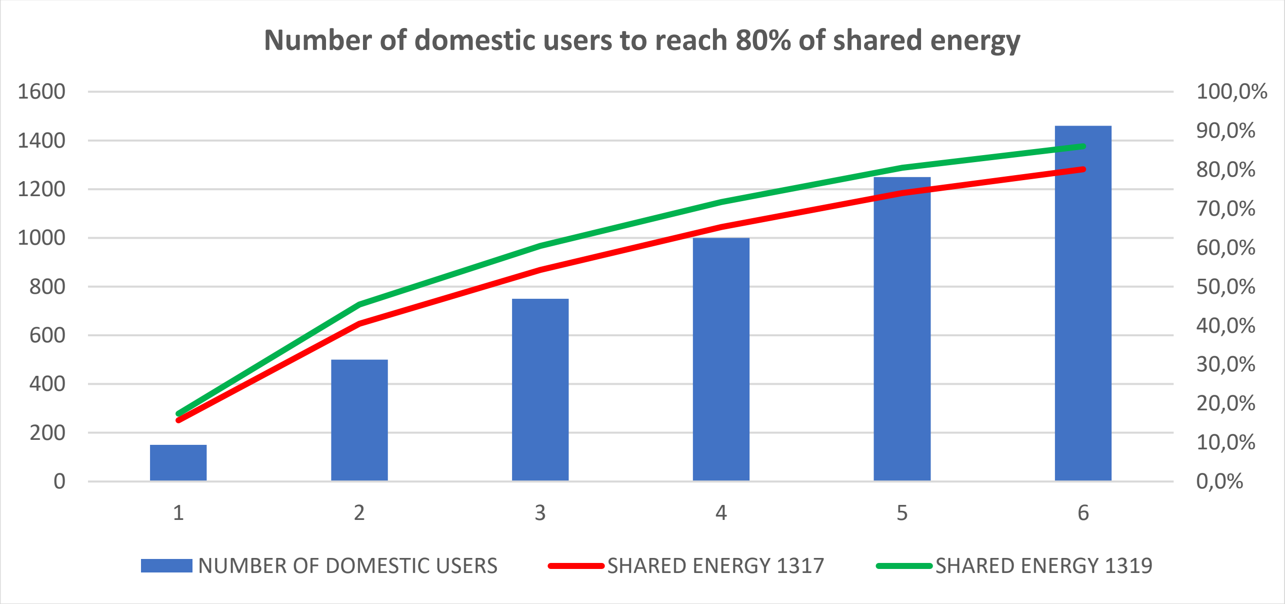


Figure 50: Number of domestic users to reach 80% of shared energy.

As an example, Table 23 shows some possible extra users (residential, commercial and SMEs) to aggregate to reach the shared energy target by 80%.

Table 23: Different users' aggregation in the RECs to reach the target of 80% of shared energy.

TYPE OF USERS	NUMBER OF USERS TO GET 80% SHARED ENERGY IN THE RECs		AGGREGATE EQUIVALENT USERS' CONSUMPTION *[MWh]*	
	AC001E01317	**AC001E01319**	**AC001E01317**	**AC001E01319**
Domestic	1.458	1.233	5.252	4.442
Commercial	270	230	3.434	2.925
SMEs	68	58	2.867	2.445

The results of the analysis for the first year are presented below, with an indication of the number of community members and on the total peak power installed serving the community.

Table 24: Energy analysis results (target case)

Target case REC (scenario 1)			
Item	**AC001E01317**	**AC001E01319**	**Unit of measure**
Installed peak PV power	1.189,8	994,2	kW
Number of RECs' members	1.458+Municipalities	1.233+Municipalities	-
Number of equivalent domestic users	1.458	1.233	-
Energy produced	1.409.444	1.105.842	kWh/year
Self-consumed energy	91.076	63.331	kWh/year
Energy fed into the grid	1.318.365	1.042.513	kWh/year
Consumption	228.898	156.664	kWh/year
Collective Self-Consumption (CSC)	1.054.960	834.102	kWh/year
Shared energy	80	80	%
Residential users aggregate consumption	5.252	4.442	MWh/year

The first scenario concerns RECs configuration in which PV systems are installed on all municipal buildings. To optimize a configuration in which the self-consumed and incentivized energy is at least equal to 80% of the energy fed into the grid by the municipal systems, it is necessary to provide for the adhesion to the REC by other final consumers underlying the same primary substation and not using municipal buildings. The type of final consumer assumed in this scenario is that of domestic users. Also, commercial and SMEs users were simulated as final consumers. Because of their higher aggregate consumption, a lower number of users is needed to reach the target of 80% of shared energy. The REC configuration was built starting from the data of energy fed into the grid by RES plants calculated thanks to the use of the PV GIS tool on an hourly basis to which equivalent extra users are added.

4.3.2. Scenario 2: Storage systems on a few Recs' buildings

It is possible to remedy the dis-matching of the hourly local energy demand and supply by introducing storage systems that allow to shift self-consumption over time. In this study only a few buildings with installable batteries are taken into consideration.

The buildings chosen for the installation of storage systems should have a high consumption and also a high PV production that can be stored during the day and to be used during night. The first one considered is the Town Hall in Chiaverano (10CH) with a yearly consumption of 27.393 kWh. After the onsite yearly self-consumption of 10.961 kWh, 13.949 kWh of extra production are available to be fed into the grid. In this first configuration the Town Hall's Self-Sufficiency is equal to 40%. To increase this value, a storage system can be installed. In function of the battery's capacity the Self Sufficiency value varies.

Table 25: Self-Sufficiency index in function of the storage battery capacity.

Battery's capacity *[kWh]*	**Self-Sufficiency 10CHI *[%]***	**Self-Sufficiency 13CHI *[%]***	**Self-Sufficiency 14 MO *[%]***	**Self-Sufficiency 5BO *[%]***	**Self-Sufficiency 7QUI *[%]***
None	40,04%	44,75%	45,51%	39,22%	47,57%
5	49,51%	62,57%	76,47%	47,92%	64,08%
10	53,88%	68,99%	83,25%	52,38%	69,50%
20	62,28%	76,68%	91,61%	59,74%	75,42%
50	71,24%	87,45%	97,84%	68,13%	80,81%
100	73,28%	91,34%	99,29%	70,12%	83,61%
200	74,77%	94,68%	100,00%	71,52%	84,94%
500	76,53%	98,03%	100,00%	74,00%	87,45%

Different battery size can be installed, but, since battery price increases with the size, the best solution is to minimize the capacity of the batteries. Besides, Self-sufficiency for 10CH building increases significantly until a battery capacity of 50 kWh, then by increasing more and more the storage size, SS tends to an asymptotic value also for the other buildings, as shown in Figure 51.

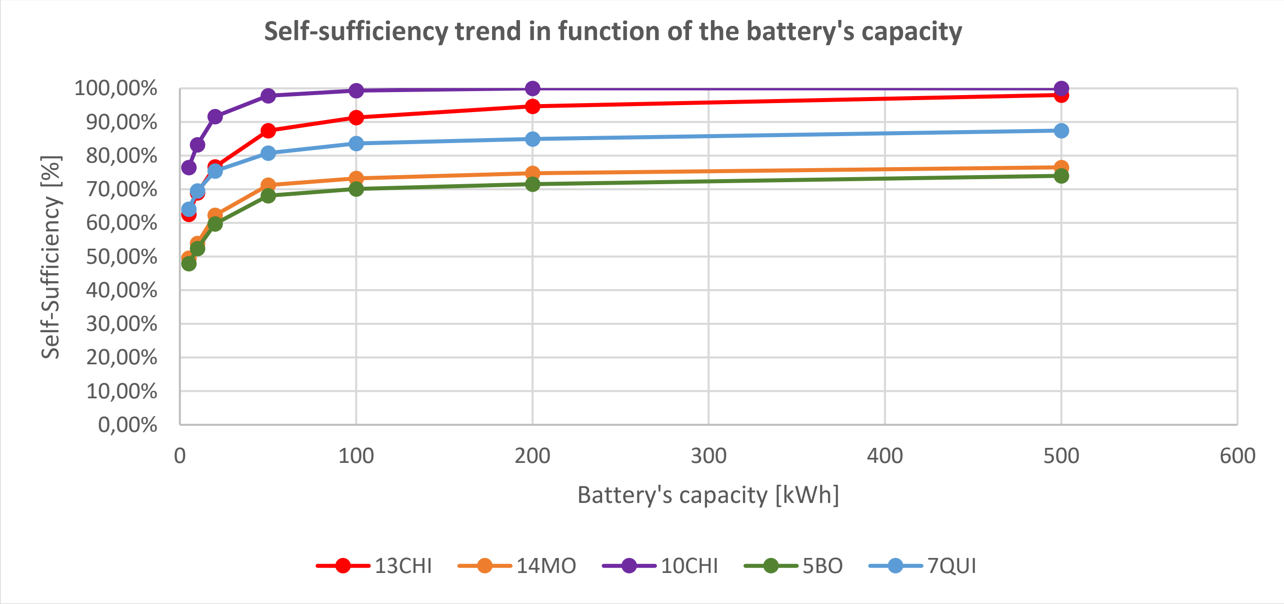
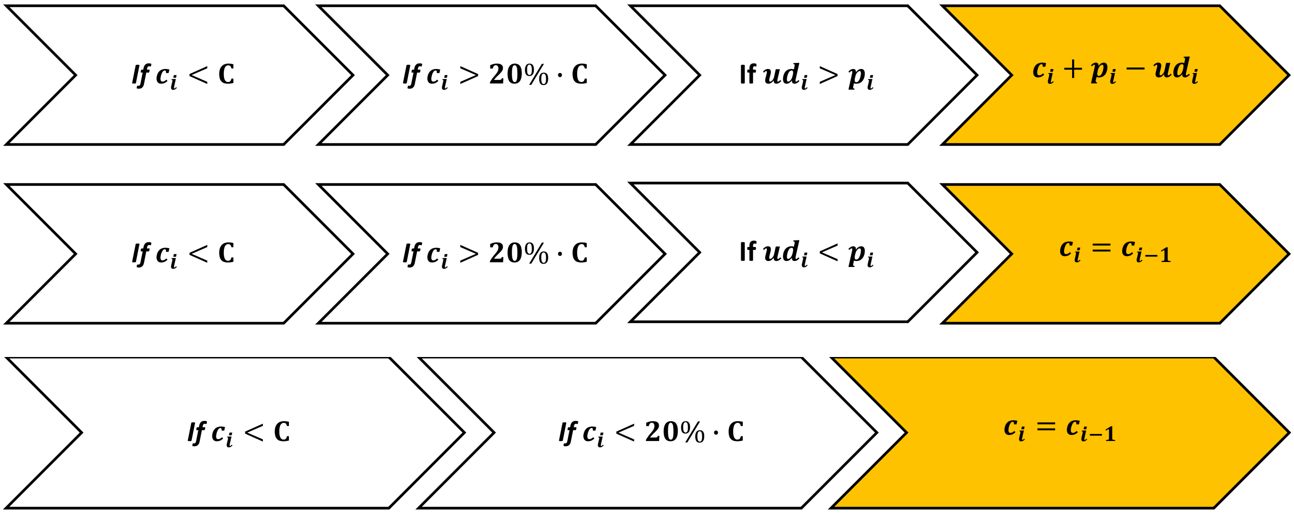


Figure 51: Self--Sufficiency trend in function of the battery's capacity.

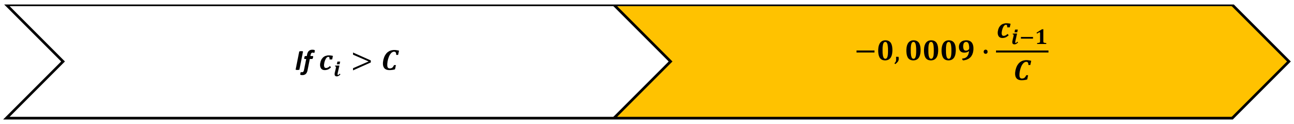
To evaluate the trend of a storage system once the hourly building uncovered demand and the hourly extra-production are defined, together with the battery capacity and the initial charge, the code below models the charging and the discharging throughout the year. The model used consists, for each hour, of the following assumptions:

- if the electrical energy produced is greater than the electrical energy consumed by the building, then the excess energy produced charges the electrical storage, up to when the maximum capacity is not reached.
- if the electrical energy produced is less than the electrical energy consumed by the building, then the energy accumulated in the batteries is used, until they are not empty.

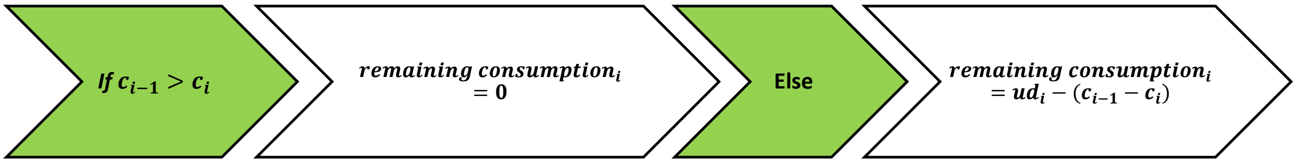
CASE 1: *If* $c_i < C$



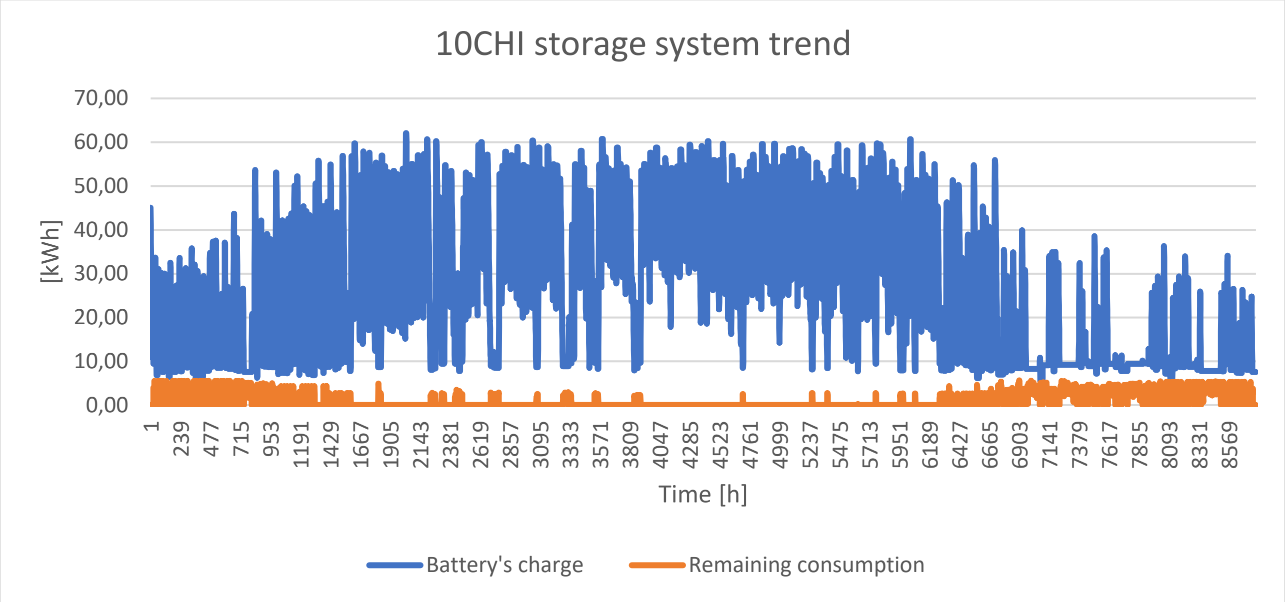
CASE 2: *If* $c_i > C$

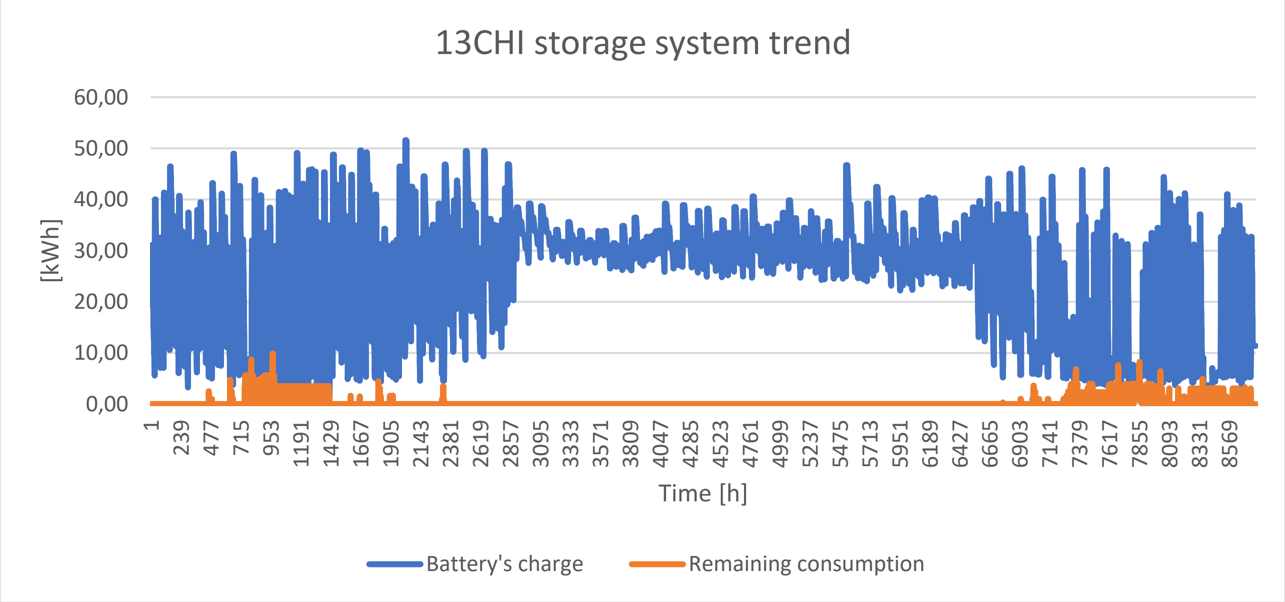


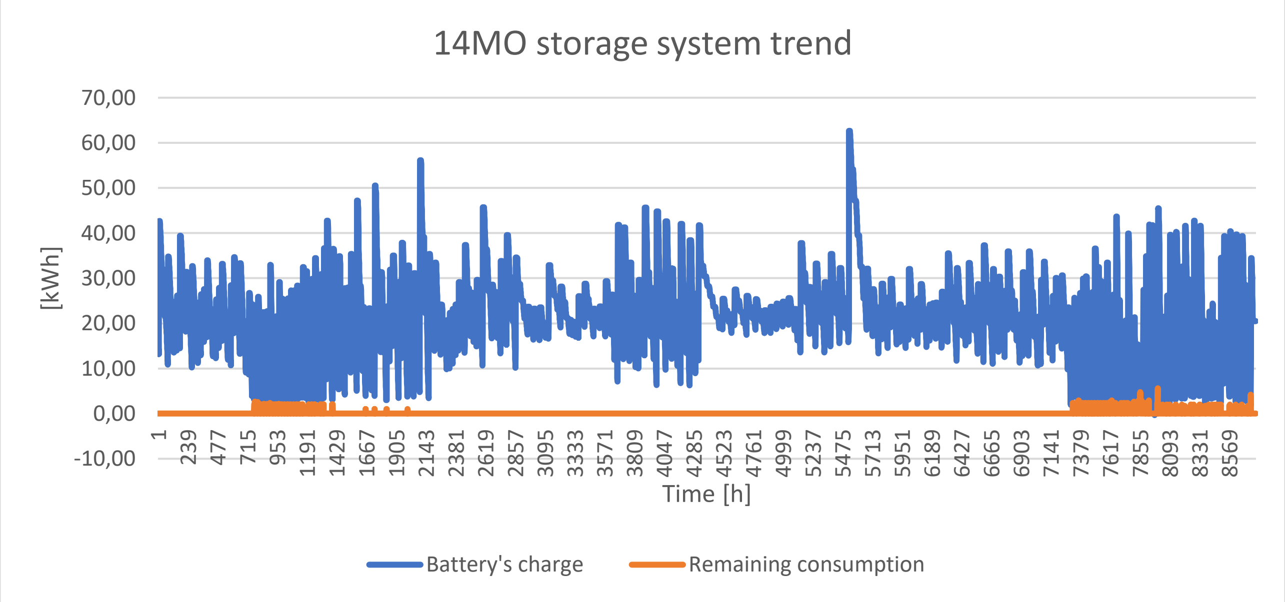
Once the storage algorithm is written, the remaining building consumption (the one uncovered also by the storage system) can be computed:



In the Figures below the storage system trend for 10CHI (50 kWh battery), 13CHI (30 kWh battery), 14 MO (20 kWh battery), 5BO (40 kWh battery) and 7QUI (30 kWh) is shown.


10CHI storage system trend
[kWh]
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
1
239
477
715
953
1191
1429
1667
1905
2143
2381
2619
2857
3095
3333
3571
3809
4047
4285
4523
4761
4999
5237
5475
5713
5951
6189
6427
6665
6903
7141
7379
7617
7855
8093
8331
8569
Time [h]
Battery's charge
Remaining consumption


13CHI storage system trend
[kWh]
60,00
50,00
40,00
30,00
20,00
10,00
0,00
1
239
477
715
953
1191
1429
1667
1905
2143
2381
2619
2857
3095
3333
3571
3809
4047
4285
4523
4761
4999
5237
5475
5713
5951
6189
6427
6665
6903
7141
7379
7617
7855
8093
8331
8569
Time [h]
Battery's charge
Remaining consumption


14MO storage system trend
[kWh]
70,00
60,00
50,00
40,00
30,00
20,00
10,00
0,00
-10,00
1
239
477
715
953
1191
1429
1667
1905
2143
2381
2619
2857
3095
3333
3571
3809
4047
4285
4523
4761
4999
5237
5475
5713
5951
6189
6427
6665
6903
7141
7379
7617
7855
8093
8331
8569
Time [h]
Battery's charge
Remaining consumption

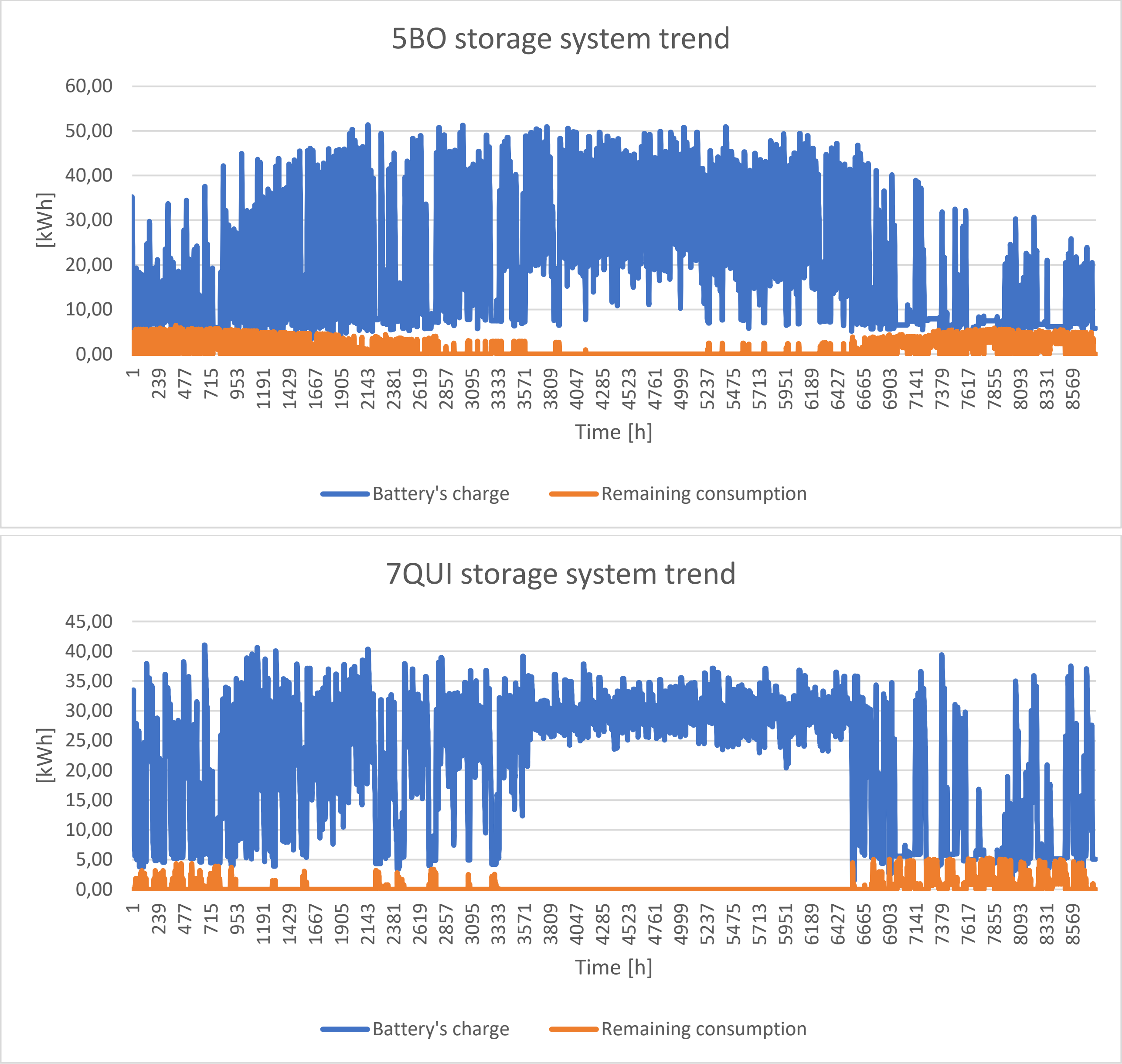


Figure 52: Buildings’ yearly storage system trend.

When the battery is low there is a few of remaining consumption while when its charge is completed or almost completed the remaining consumption is close to zero. During summer the battery is often charged because of the high PV extra production. In winter less PV extra production is available, so the battery is mostly discharged, and the uncovered demand isn’t covered by the storage system so that there is remaining consumption left.

In Figure 53 e Figure 54 daily and weekly storage trend is shown in winter and summer to show the seasonality of PV production and consequently the charging and discharging of the storage.

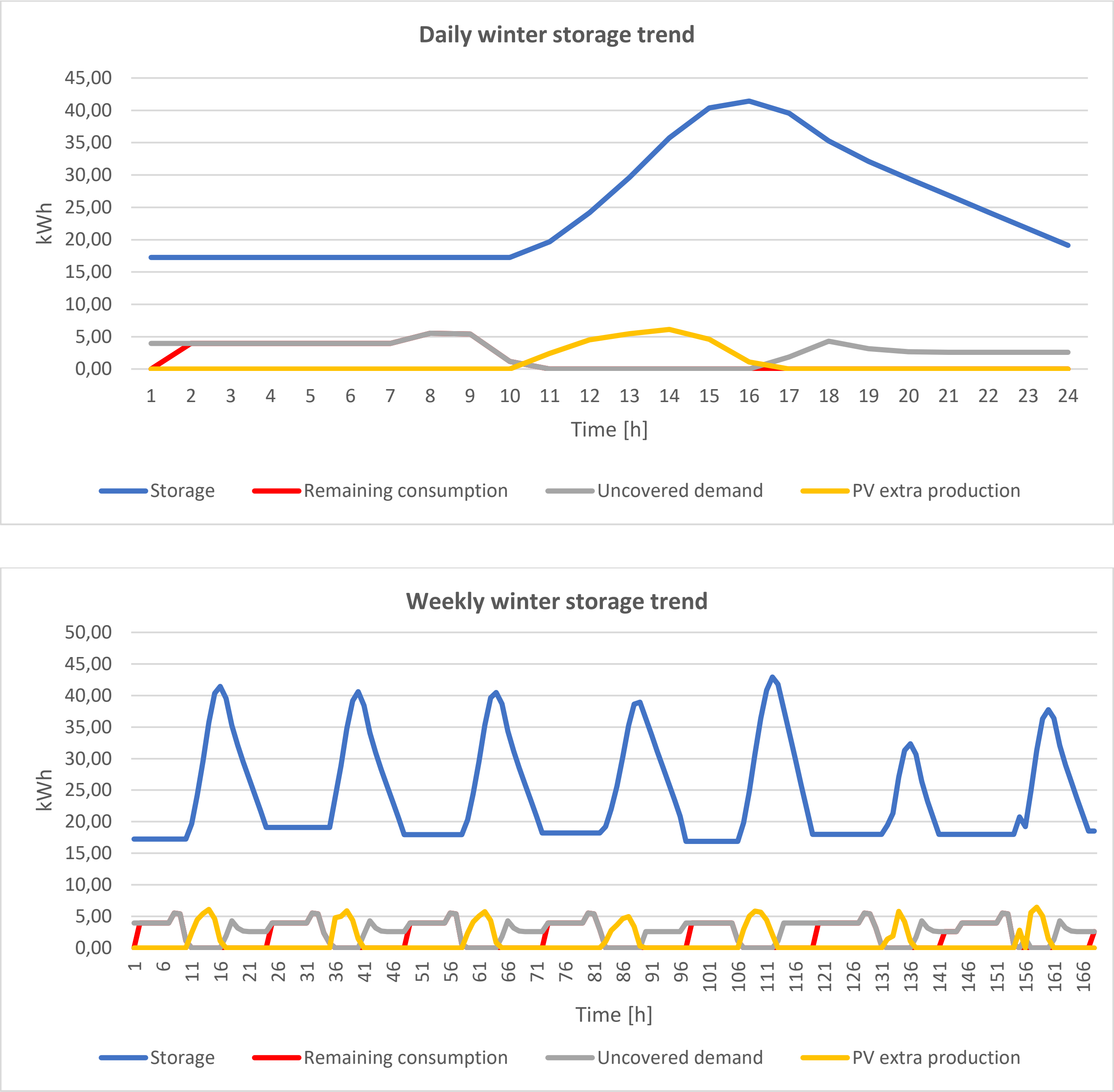
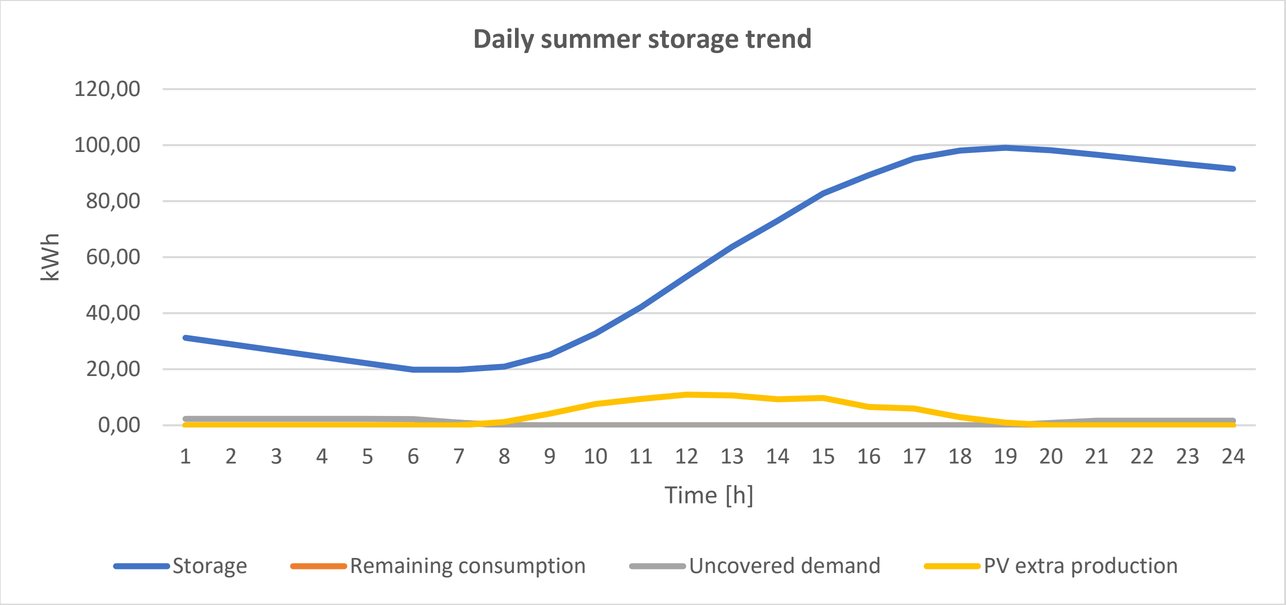


Figure 53: Daily and weekly winter storage trend



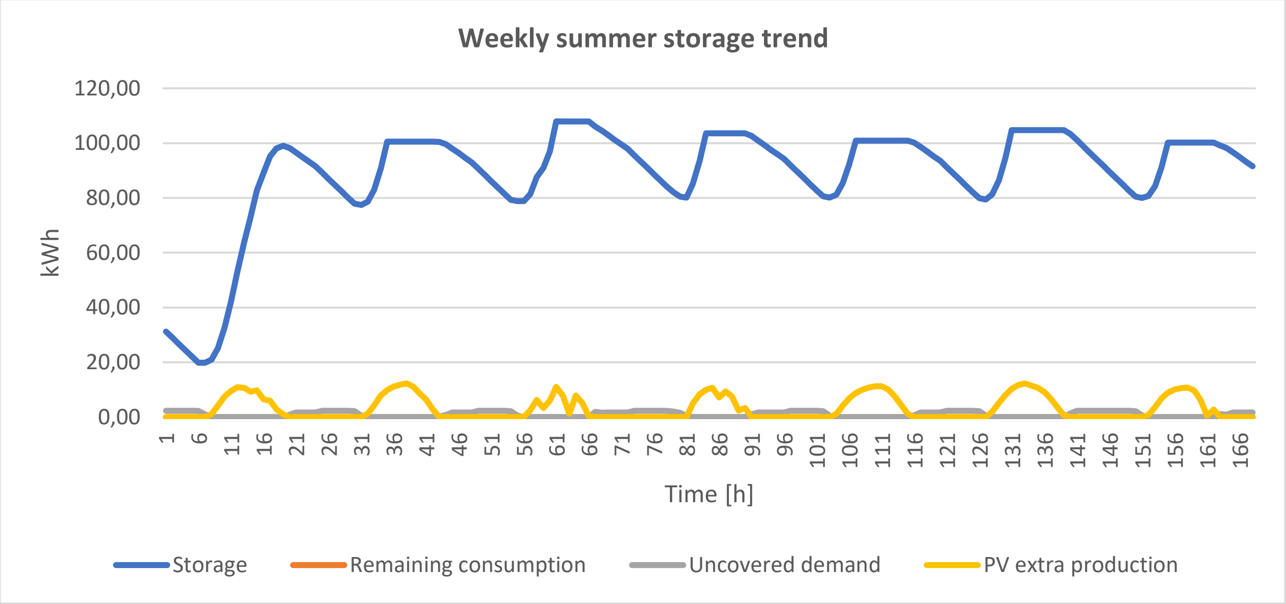


Figure 54: Daily and weekly summer storage trend

During winter the battery charge is lower than summer storage because the extra PV production is not that high as in summer. And also, the uncovered demand is higher in winter so the battery discharges faster with respect to summer. In the Figures it is clear that the remaining consumption is present in winter while during summer it is not there. That’s why it would be interesting to evaluate seasonal storages, but the evaluation is not going further for this study.

Energy storage systems play a pivotal role in making renewable energy communities more sustainable, resilient, and economically viable. They help overcome the challenges associated with the intermittent nature of renewable sources, contributing to a more reliable and efficient energy system.

4.3.3 Scenario 3: REC with PV systems on all municipal buildings charging stations for electric vehicles

The third scenario concerns a REC configuration in which PV systems are installed on all municipal buildings. The type of final consumer hypothesized in this scenario is that of charging stations for electric vehicles. The REC configuration was built starting from the energy data fed into the grid by the RES plants calculated thanks to the use of the PV GIS tool on an hourly basis to which the equivalent consumption of the charging stations for electric vehicles are added. To estimate the number of columns to be considered in this configuration, a recharge power of 7kW taking place during the day is assumed. This scenario therefore considers the recharging of electric cars used to go to the workplace and left parked for about 8/9 hours in the company car parking. The number of charges is equal to 94 for cabin AC001E01317 and equal to 84 for cabin AC001E01319. Table 26 shows the values of the configuration thus determined.

Table 26: Energy analysis values (scenario 3).

Third scenario REC			
Item	**AC001E01317**	**AC001E01319**	**Unit of measure**
Installed peak PV power	1.189,8	994,2	kW
Number of charges	94	84	-
One charge energy	49	49	kWh
Energy produced	1.409.444	1.105.842	MWh/year
Self-consumed energy	91.076	63.331	MWh/year
Energy fed into the grid	1.318.365	1.042.513	MWh/year
Consumption	228.897	156.665	MWh/year
Shared energy	1.054.692	834.010	MWh/year
Shared energy	80,1	80,1	%
Number of electric vehicles recharged	276	247	-
Average travelled distance per car	100	100	km
Specific vehicle consumption	6	6	km/kWh

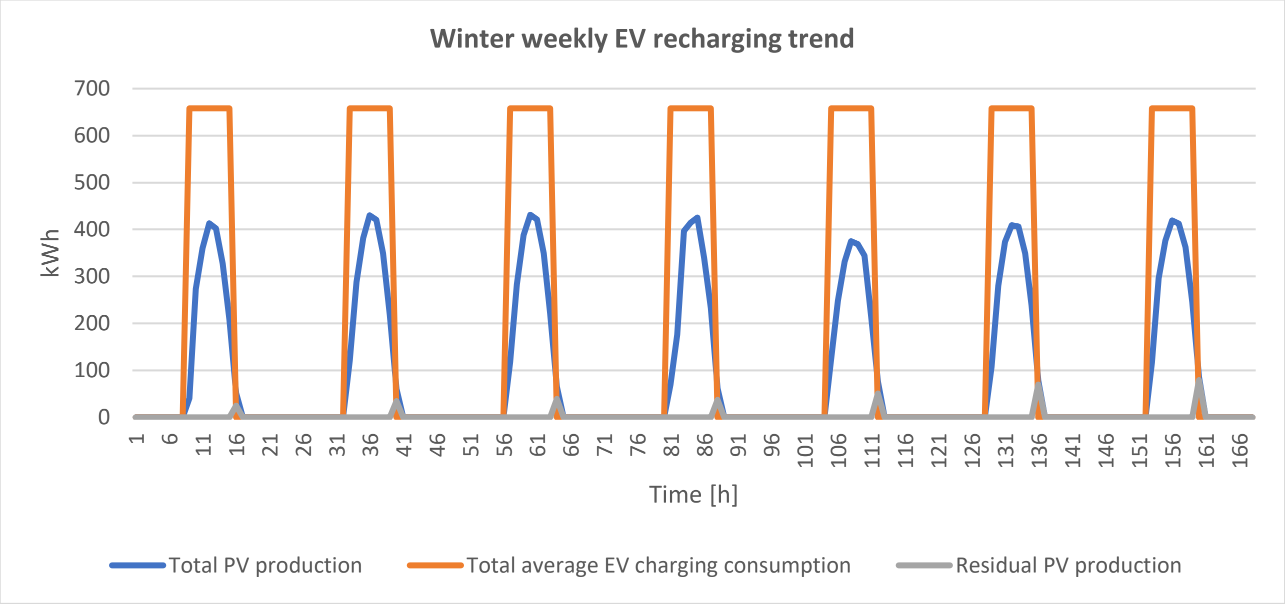


Figure 55: Winter weekly PV production with electric vehicles recharging during the day.

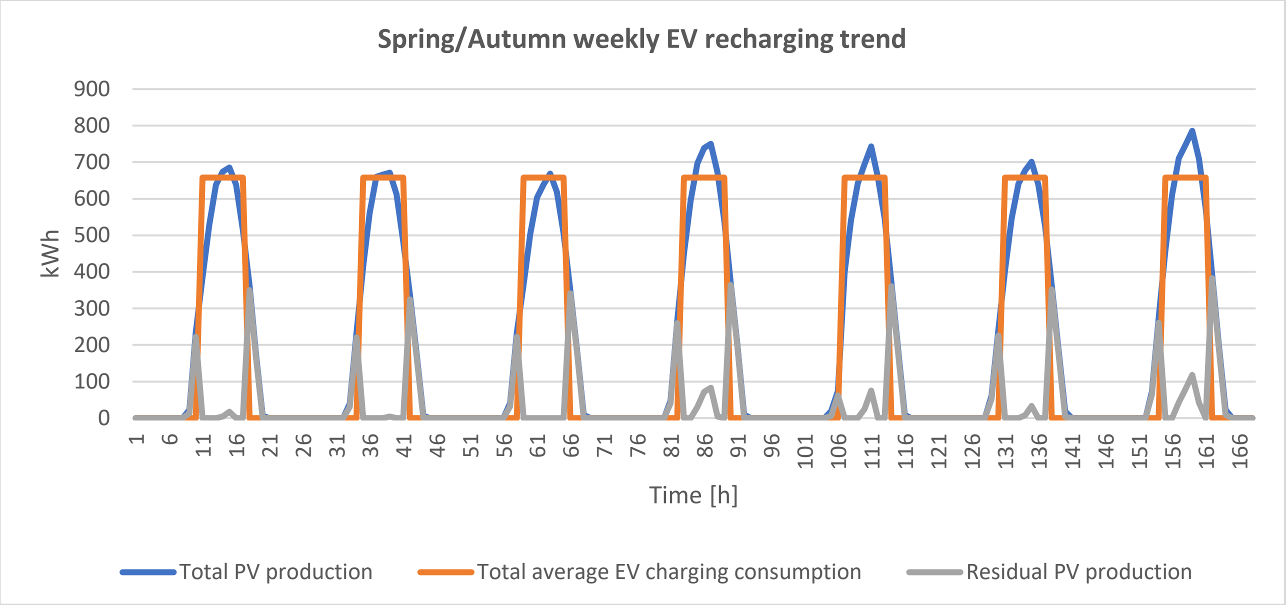


Figure 56:Spring/Autumn weekly PV production with electric vehicles recharging during the day.

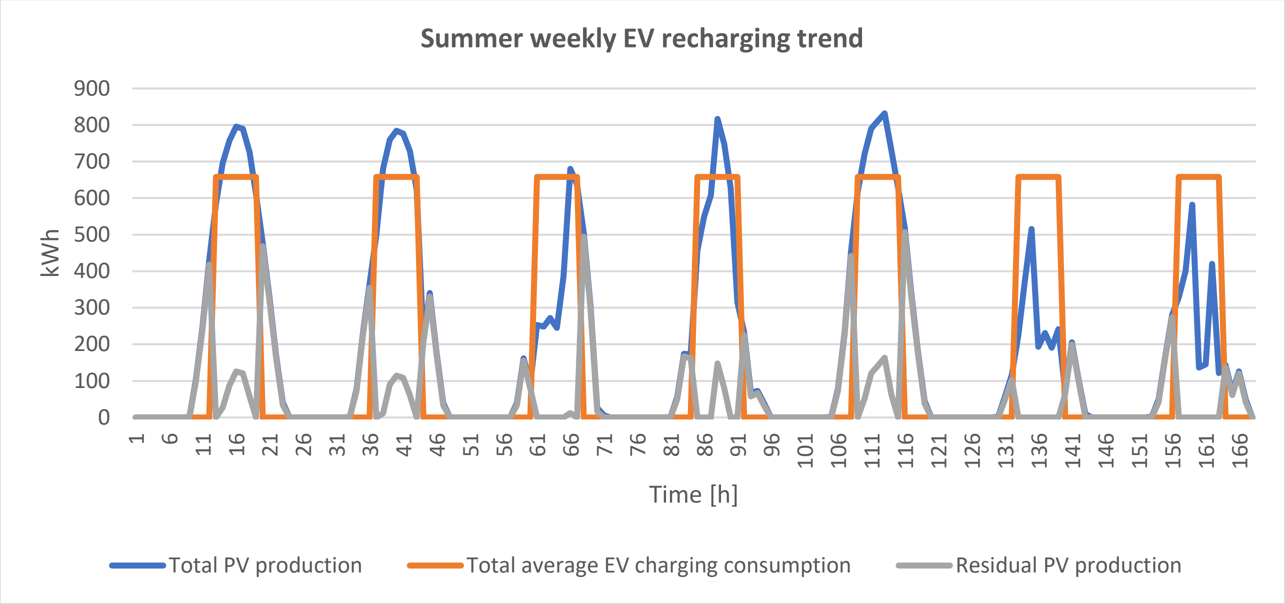


Figure 57: Summer weekly PV production with electric vehicles recharging during the day.

In the Figures it can be seen that in winter the charging EV consumption almost doubles PV production that is not able to cover the daily request. In fact, the residual PV production is almost null. In spring and in autumn PV production covers exactly the charging EV consumption with a bit of residual production early in the morning and late in the afternoon. While in summer, except for cloudy and rainy days, PV production can always cover and overcome the charging EV demand feeding its residual to the grid.

In Figure 58 the aggregate REC's profile is shown highlighting the shared energy (collective REC consumption in green) and the direct self-consumption throughout the day.

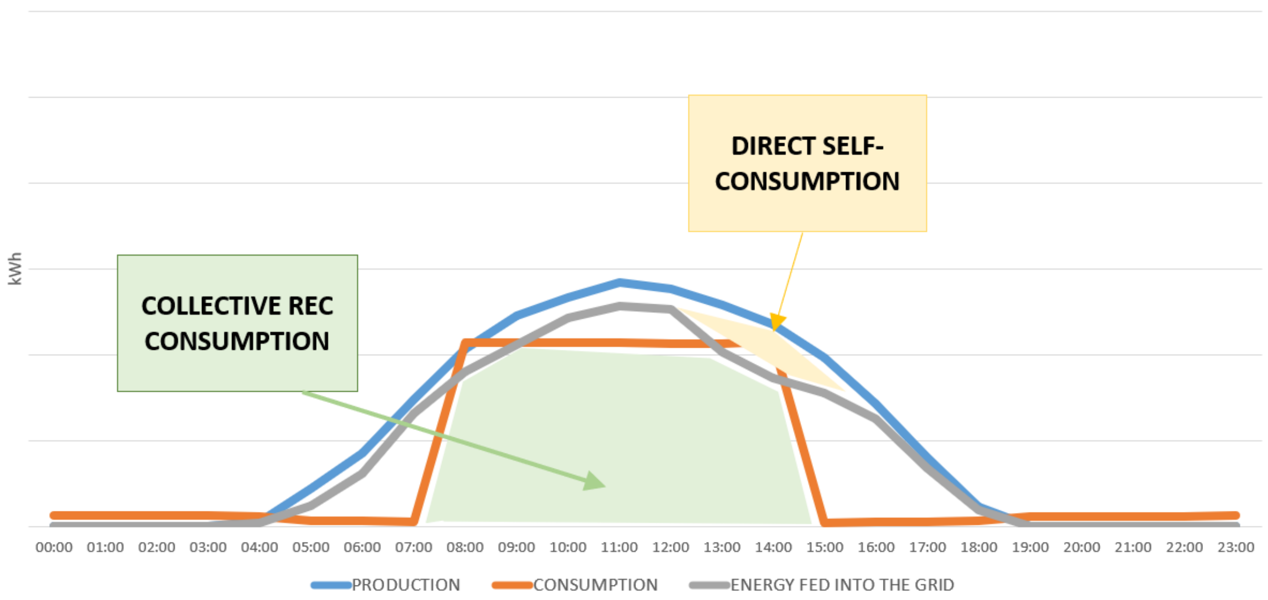


Figure 58: Third scenario trend.

4.4 Optimization method

The goal of optimization is to identify the configuration that from an energy point of view comes as close as possible to an optimal ideal point. The optimal configuration identifies which and how many PV plants should be installed to activate the REC. To be able to identify the ideal point and the optimum, energy performance indexes can be used: Self-consumption (SC), Self-sufficiency (SS) and Shared Energy (SE).

Considering the definition of the quantities self-consumption and self-sufficiency, the ideal point can be identified as the point where both are close to a unitary value. That is, the point at which all the energy produced is self-consumed and at which all the energy needs are covered by PV electricity production. This point can be reachable for the SC, especially in case of undersized systems linked to large-scale consumption, while it is virtually reachable for SS unless possible storage systems are considered. This is because loads are present at times when PV production is effectively zero (e.g., at night), and unless electrochemical batteries are considered, it is not possible to make the loads coincide perfectly with production.

The method here implemented considers the municipal buildings aggregated daily consumption from 7 am to 7 pm to be coupled with daily production. The daily consumption can be considered equivalent to the maximum PV production to theoretically guarantee 100% self-consumption. Given the REC target of sharing at least 80% of the production, to be conservative, a 120% of the daily consumption has been considered. The top ten most significant configurations differing for number of PV plants installed satisfying the REC’s criterion of maximizing the shared energy (at least 80%) have been evaluated and shown in Figure 59 and Figure 60.

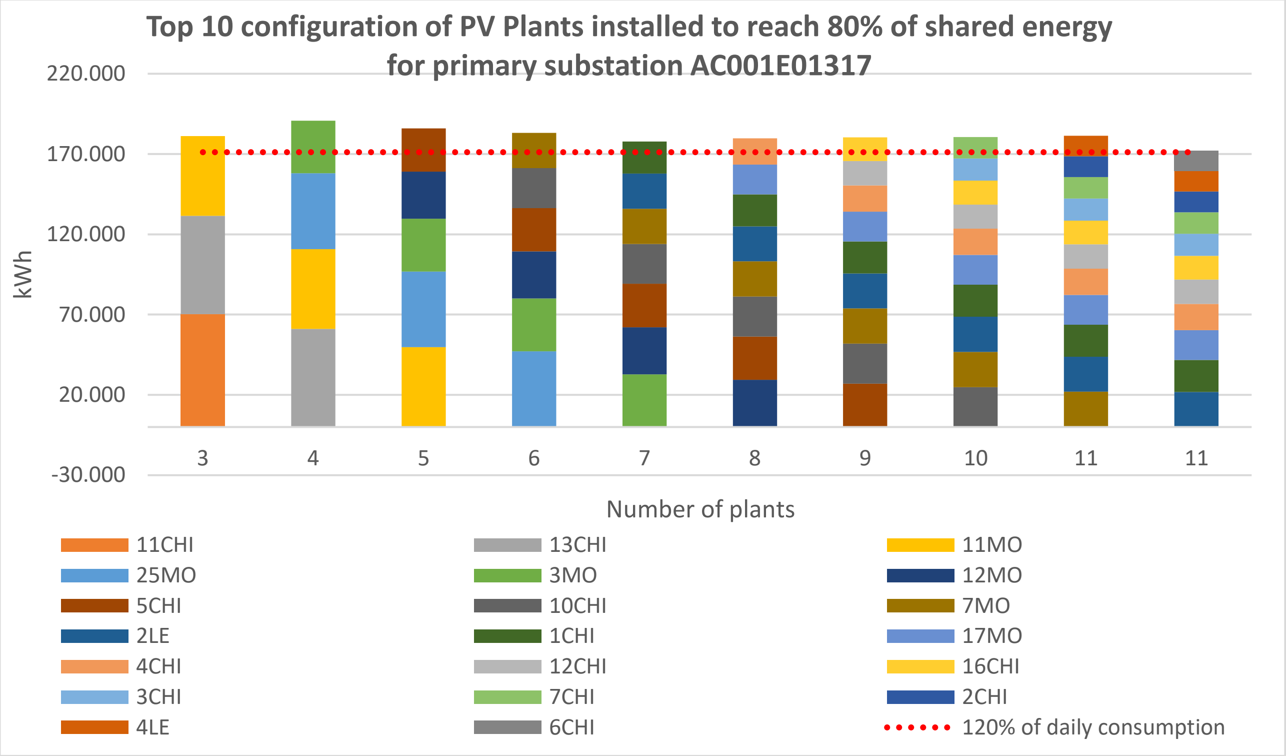


Figure 59: Top 10 configurations of PV plants installed to reach 80% of shared energy for primary substation AC001E01317.

With these ten top configurations the most valid plants' sizes are selected. The ones excluded are the too big ones (producing too much energy with respect to the consumption) because they immediately satisfy the building's needs feeding all the extra-production into the grid without satisfying the 80% REC's shared energy target. Also, the too little ones are taken out because they cost more due to the economy of scale.

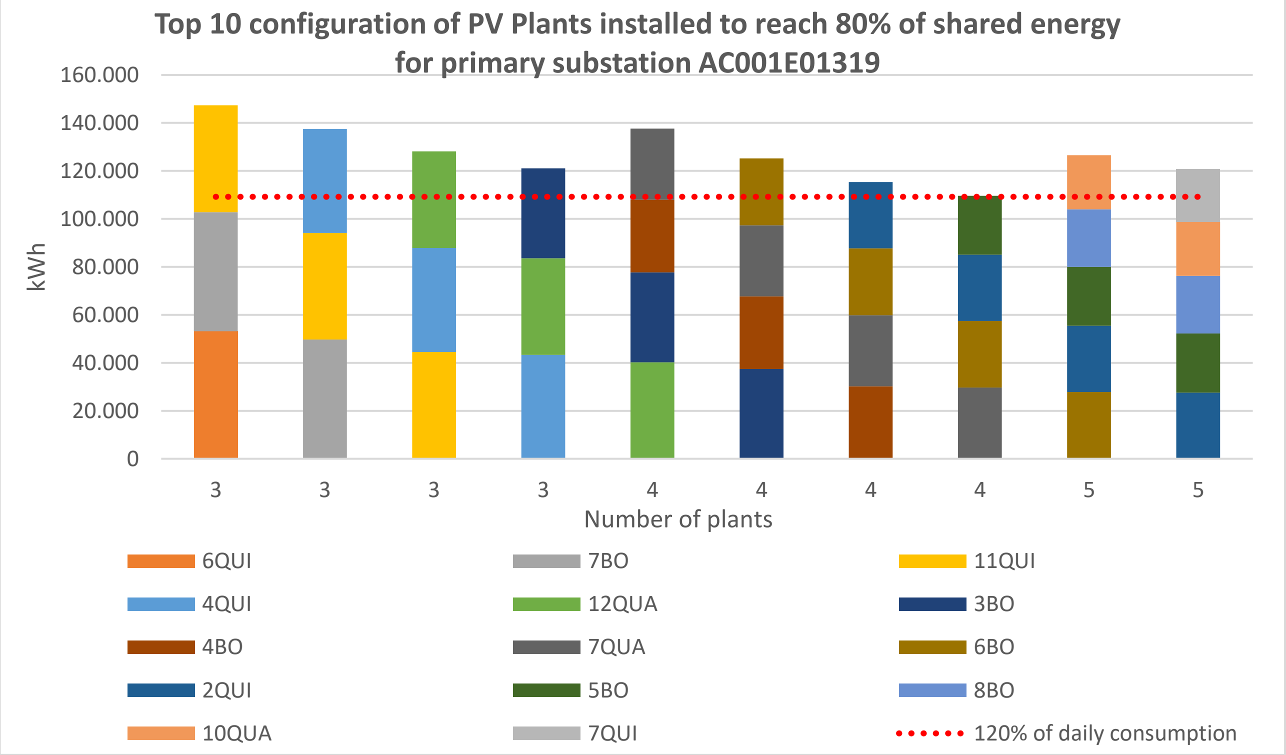


Figure 60:Top 10 configurations of PV plants installed to reach 80% of shared energy for primary substation AC001E01319.

This first constraint of maximizing the RECs' shared energy (80%) is primarily convenient for the REC targets. The second degree of freedom to choose the most energetically valid plants moves to an individual level. Among the PV plants chosen for the top 10 configurations, their individual self-sufficiency index is considered. The higher the SS, the higher is the incentive for direct self-consumption recognized by GSE. Given that, PV plants with descending order of self-sufficiency are selected until the REC aggregated daily consumption is covered.

Table 27: PV plants selected in order of self-sufficiency to cover the aggregated daily consumption for AC001E01317.

Building	Self-sufficiency	PV produced energy *[kWh]*	PV cumulative energy produced *[kWh]*	Daily consumption 7am-7pm *[kWh]*
11CHI	67%	70.368	70.368	172.144
1CHI	62%	61.158	131.526	
12MO	56%	49.683	181.209	
3CHI	56%	47.186		
12CHI	56%	32.812		
4LE	56%	29.366		
17MO	55%	26.971		
5CHI	53%	24.911		
2LE	52%	21.943		
6CHI	50%	21.780		
7MO	50%	19.946		
7CHI	50%	18.529		
3MO	50%	16.404		
4CHI	47%	15.079		
13CHI	45%	14.791		
10CHI	40%	13.776		
16CHI	38%	13.330		
25MO	38%	12.968		
2CHI	37%	12.829		
11MO	34%	12.737		

Table 28: PV plants selected in order of self-sufficiency to cover the aggregated daily consumption for AC001E01319.

Building	Self-sufficiency	PV produced energy *[kWh]*	PV cumulative energy produced *[kWh]*	Daily consumption 7am-7pm *[kWh]*
1QUA	63%	22.532	22.532	109.226
6QUI	62%	53.203	75.735	
8BO	61%	24.055	99.790	
2QUI	61%	27.602	127.392	
12QUA	56%	40.264		
4QUI	51%	43.347		
6BO	50%	27.819		
7QUI	48%	22.086		
7QUA	46%	29.633		
7BO	46%	49.663		
4BO	45%	30.263		
5BO	39%	24.609		
11QUI	38%	44.506		

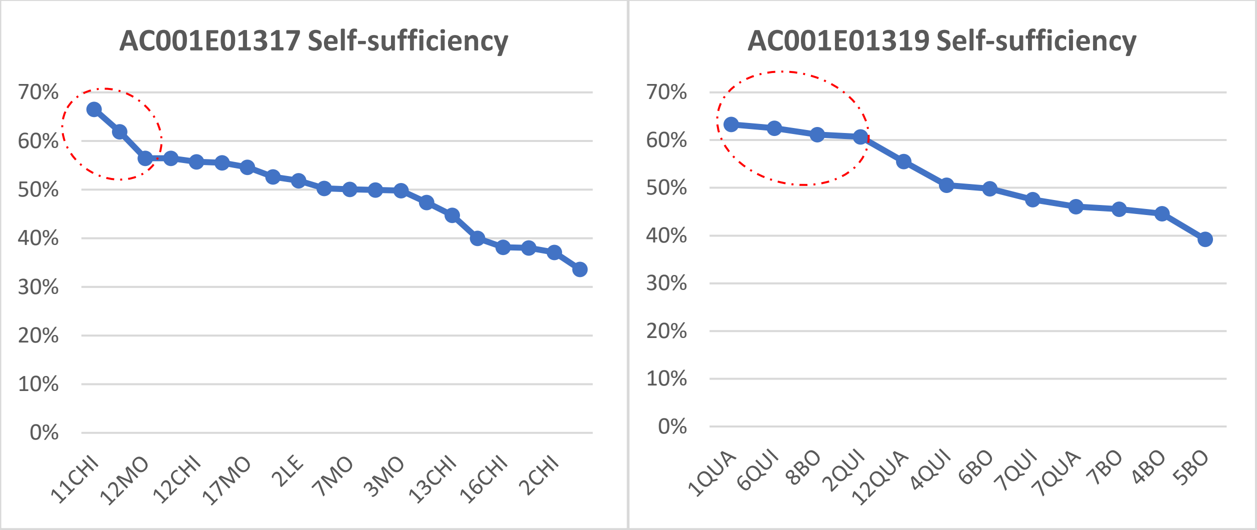


Figure 61: Self-sufficiency descending order comparison between the buildings in the two primary substations.

Once this energetic analysis is carried out, the economic analysis will follow in Chapter 5 to evaluate the goodness of the energy targets from an economic point of view.

4.5 Optimization results: optimized REC with PV systems on some municipal buildings only

The last hypothesized scenario concerns a REC configuration in which the RES plants are only those that the Municipalities will install on its buildings and where the consumers are the Municipalities itself. This type of configuration can be considered as the optimized one with a limited number of PV plants. Below are two initial scenarios for the REC configurations referring to the AC001E01317 and AC001E01319 substations. The configuration that optimizes the collective self-consumption includes the aforementioned PV systems.
The objective is to minimize as much as possible the share of surpluses released outside the configuration, trying to reduce the negative impact that this entry could have on network parameters.

Table 29: Optimized RECs configurations' results.

	AC001E01317	**AC001E01317 (target 80% shared energy)**	**AC001E01319**	**AC001E01319 (target 80% shared energy)**
Number of plants	3	2	4	2
Installed peak power *[kW_p]*	100,2	44,2	110	43
RES energy fed into the grid *[kWh]*	105.705	39.541	109.517	47.967
Energy consumption *[kWh]*	214.922	219.126	148.723	152.938
Collective self-consumption *[kWh]*	69.871	36.338	50.268	38.374
Shared energy *[%]*	66,1%%	91,9%	45,9%	80%

	AC001E01317	AC001E01317 (target 80% shared energy)	AC001E01319	AC001E01319 (target 80% shared energy)
Total REC self-sufficiency *[%]*	32,5%%	16,6%	33,8%	24,9%

Figure 62 shows the optimized REC's daily trend highlighting the shared energy among Municipal buildings in green and the aggregated Municipal buildings' direct self-consumption.

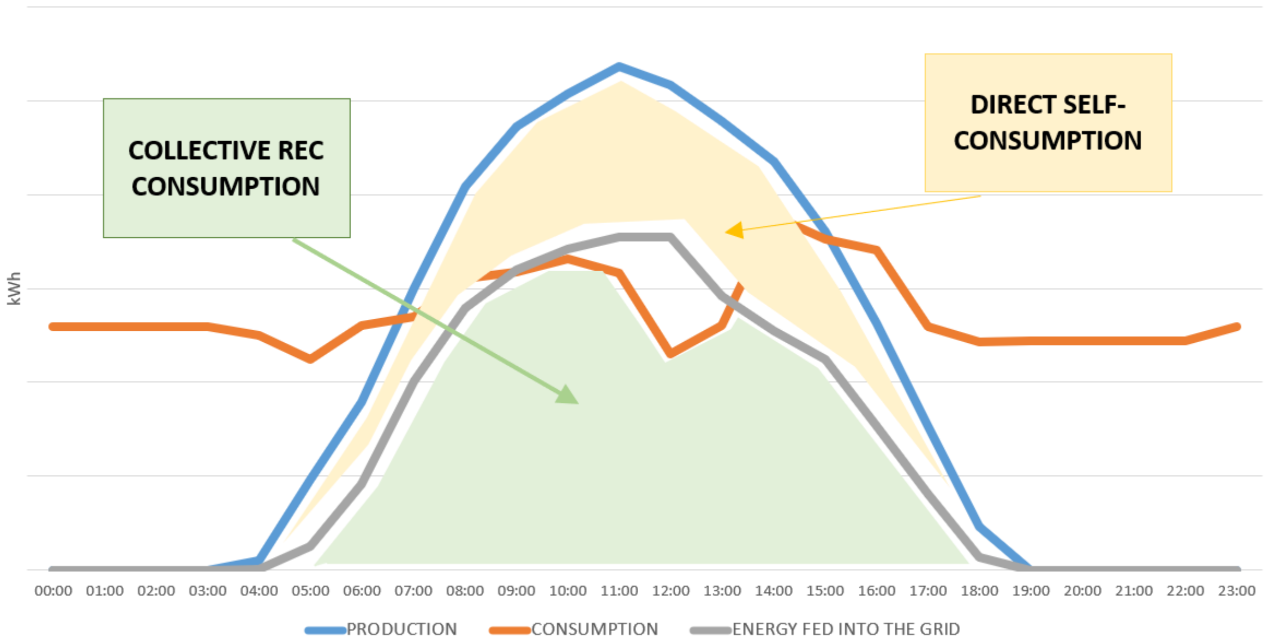


Figure 62: Optimized REC's daily trend.

In Table 30 and Table 31 the RECs' optimal configurations are summarized showing the Municipal buildings chosen for PV plants' installation, maximizing the collective REC's consumption.

Table 30: AC001E01317 target REC configuration.

AC001E01317			
PROSUMERS	**BUILDING**	**PV PLANT [KWP]**	**EXTRA PRODUCTION FED INTO THE GRID [KWH]**
Municipalities of Chiaverano, Montalto Dora, Lessolo	1CHI	17	17.658
	12MO	27,2	21.883
Total		**44,2**	**39.541**
CONSUMER	**BUILDING**	**ENERGY WITHDRAWN FROM THE GRID [KWH]**	**COLLECTIVE SELF-CONSUMPTION (INCENTIVIZED ENERGY) [KWH]**
Municipal buildings in Borgofranco d'Ivrea, Quassolo and Quincinetto	ALL	219.126	36.338
Percentage Collective REC's consumption (incentivized energy)			**91,9%**

Table 31:AC001E01319 target REC configuration.

AC001E01319			
PROSUMER	**BUILDING**	**PV PLANT [KWP]**	**EXTRA PRODUCTION FED INTO THE GRID [KWH]**
Municipalities of Borgofranco d'Ivrea and Quincinetto	8BO	20	21.969
	2QUI	23	25.998
Total		**43**	**47.967**
CONSUMER	**BUILDING**	**ENERGY WITHDRAWN FROM THE GRID [KWH]**	**COLLECTIVE SELF-CONSUMPTION (INCENTIVIZED ENERGY) [KWH]**
Municipal buildings in Borgofranco d'Ivrea, Quassolo and Quincinetto	ALL	152.938	38.374
Percentage Collective REC's consumption (incentivized energy)			**80%**

CHAPTER 5 Economic analysis

The economic analysis of a municipal 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 advantages of integrating renewable energy into the energy portfolio of a municipality. By conducting a comprehensive economic analysis that considers multiple factors, municipal 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 and compare the performances of the different scenarios from an economic point of view. The Net Present Value (NPV), the PayBack Time (PBT) and the Internal Rate of Return (IRR) will be computed for each configuration to find the more suitable one.

The following chapter will illustrate the economic-financial results for the two RECs, based on the energy analysis outputs for the different scenarios. In particular, the different cash flows related to the RECs will be presented and quantified and those relating to the *Dora5laghi* Municipalities.

5.1 Investment quantification: CAPEX

In the context of a renewable energy community, Capital Expenditure (CAPEX) refers to the funds allocated for the acquisition, development, and installation of infrastructure and assets associated with renewable energy generation and storage. The capital expenditures contribute to the establishment and growth of a sustainable and resilient renewable energy community. They represent long-term investments aimed at reducing dependence on non-renewable energy sources, minimizing environmental impact, and fostering energy independence within the community.

Based on the PV installation potential to be realised, the value of the investments that the Municipalities will have to mobilize to build the photovoltaic systems on the roofs of the previously described municipal buildings has been calculated. These investments would amount to approximately 3 million. That’s why only a few plants for each primary substation are considered, in order to constitute the RECs as soon as possible without burdening the Municipalities with a huge initial investment.

To determine the cost of each photovoltaic system, the unit prices published in the draft of the MASE decree were used as a reference, which will have to regulate the incentive methods for shared energy in self-consumption configurations for sharing renewable energy and the PNRR contributions for CER and collective self-consumption in municipalities of up to 5.000 inhabitants.
The unit prices considered were:

Table 32:Unit PV plants' prices in function of plants' size.

PLANT SIZE [kW_p]	CAPEX from MASE draft [$€/kW_p$]	CAPEX computed [$€/kW_p$]
0 kW_p < Plant size < 20 kW_p	1.500 $€/kW_p$	1.500 $€/kW_p$
20 kW_p < Plant size < 200 kW_p	1.200 $€/kW_p$	$20 \cdot 1.500 + \frac{(\text{Plant size} - 20) \cdot 1.200}{\text{Plant size}}$

PLANT SIZE [kW_p]	CAPEX from MASE draft [$€/kW_p$]	CAPEX computed [$€/kW_p$]
200 kW_p < Plant size < 600 kW_p	1.100 $€/kW_p$	$20 \cdot 1.500 + 180 \cdot 1.200 + \frac{(\text{Plant size} - 200) \cdot 1.050}{\text{Plant size}}$
600 kW_p < Plant size < 1.000 kW_p	1.050 $€/kW_p$	

Table 33: CAPEX for AC001E01319 primary substation's municipal buildings

AC001E01319			
PROSUMER	**SIZE [kWp]**	**UNITARY COST [€/kWp]**	**TOTAL COST [€]**
1BO	10	1.500 €	15.000 €
2BO	20,4	1.500 €	30.600 €
3BO	27	1.422 €	38.400 €
4BO	22	1.472 €	32.400 €
5BO	21,2	1.500 €	31.800 €
6BO	25,6	1.500 €	38.400 €
7BO	43,4	1.500 €	65.100 €
8BO	20	1.500 €	30.000 €
9BO	70	1.367 €	96.000 €
10BO	280	1.242 €	348.000 €
11BO	3,6	1.500 €	5.400 €
13BO	10	1.500 €	15.000 €
14BO	15	1.500 €	22.500 €
15BO	8,8	1.500 €	13.200 €
1QUA	19	1.500 €	21.000 €
4QUA	14	1.500 €	21.000 €
5QUA	16,4	1.500 €	24.600 €
6QUA	9	1.500 €	13.500 €
7QUA	26	1.500 €	37.200 €
8QUA	11	1.500 €	16.500 €
9QUA	9	1.500 €	13.500 €
12QUA	40	1.500 €	60.000 €
1QUI	58	1.303 €	75.600 €
2QUI	23	1.460 €	33.600 €
3QUI	3,6	1.500 €	5.400 €
4QUI	44	1.472 €	64.800 €
5QUI	6,6	1.500 €	9.900 €
6QUI	48	1.450 €	69.600 €
7QUI	18	1.500 €	28.500 €
8QUI	6	1.500 €	9.000 €
9QUI	8	1.500 €	12.000 €
10QUI	6	1.500 €	9.000 €
11QUI	42	1.343 €	56.400 €
1LE	9,6	1.500 €	14.400 €
TOTALE	**994,2**		**1.377.300 €**

Table 34:CAPEX for AC001E01317 primary substation's municipal buildings

AC001E01317			
PROSUMER	**SIZE [kWp]**	**UNITARY COST [€/kWp]**	**TOTAL COST [€]**
2MO	8,4	1.500 €	12.600 €
3MO	28	1.500 €	32.000 €
5MO	8,8	1.500 €	13.200 €
7MO	21	1.500 €	31.500 €
8MO	6	1.500 €	9.000 €
9MO	7,2	1.500 €	10.800 €
11MO	44	1.500 €	58.800 €
12MO	27,2	1.500 €	40.800 €
14MO	112	1.500 €	146.400 €
15MO	9,2	1.500 €	14.400 €
17MO	14	1.500 €	21.000 €
18MO	10	1.500 €	15.000 €
23MO	108	1.500 €	147.600 €
24MO	180	1.500 €	222.000 €
25MO	39,6	1.500 €	59.400 €
26MO	2,8	1.500 €	4.200 €
1CHI	17	1.500 €	25.500 €
2CHI	11,6	1.500 €	17.400 €
3CHI	11	1.500 €	16.500 €
4CHI	13	1.500 €	19.500 €
5CHI	24	1.500 €	36.000 €
6CHI	10	1.500 €	15.000 €
7CHI	10	1.500 €	15.000 €
8CHI	100	1.320 €	132.00 €
10CHI	19,4	1.500 €	29.100 €
11CHI	56	1.307 €	73.200 €
12CHI	12	1.500 €	18.000 €
13CHI	52	1.357 €	131.700 €
14CHI	76	1.357 €	103.200 €
15CHI	4,6	1.500 €	6.900 €
16CHI	12	1.500 €	18.000 €
2LE	17	1.500 €	14.400 €
4LE	**10**	1.500 €	25.500 €
8LE	**100**	1.260 €	126.000 €
10LE	**8**	1.500 €	12.000 €
TOTALE	**1.189,8**		**1.541.600 €**

Overall, the Capital Expenditure for the PV systems on the roofs of public buildings amount to €2.918.900, of which €1.377.300 on buildings under the AC001E01319 primary substation and €1.541.600 on the AC001E01317 primary substation.

In addition to photovoltaic systems as technological assets of the community, there can be storage systems. In the REC configuration (scenario 2), in which the pairing of the energy storage to PV production plants is considered, the expenses related to the purchase of the accumulation systems have been determined, considering the equation:

$$CAPEX_{BESS} = c_{BESS} \cdot P_{BESS}$$

Where P_{BESS} indicates the size of the storage system in kW. The cost coefficient c_{BESS} is assumed to be €$450/kW$ [39].

5.2 Revenues quantification

To draw up an economic analysis, it is necessary to estimate the future revenues generated by the photovoltaic systems that are assumed to be built on the roofs of municipal buildings. The revenues may concern the municipality directly or the energy community to which these plants are conferred. In the second case a part will then be returned to the municipality itself according to the methods indicated in the regulation of the Renewable Energy Community.

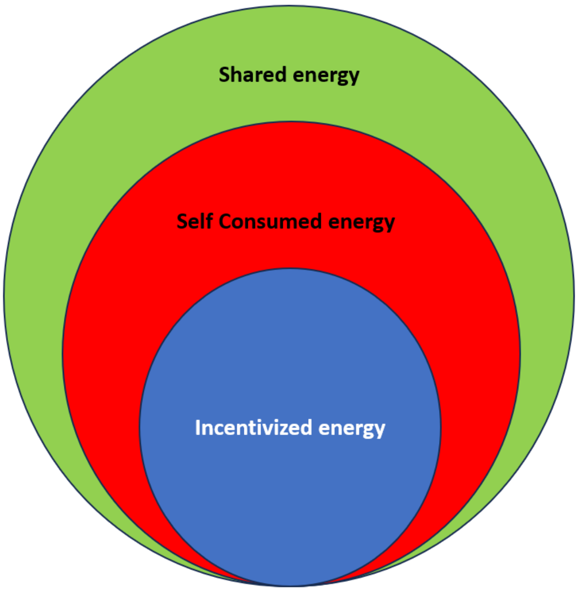


Figure 63: Shared energy division.

Shared energy is a definition by the legislation. It is possible to share energy in the market zone, which is wider than the primary substation perimeter. The self-consumed energy can be applied only to buildings underlying the same primary substation. The incentivized energy can only come from new plants with power under 1 MW.

The revenues are substantially differentiated into three energy-related items. The three energy voices are:

- revenues deriving from real self-consumption that depend on the electricity price;
- revenues deriving from dedicated withdrawal (input valorisation);
- revenues deriving from virtual self-consumption: linked to the premium rate defined on an hourly basis and to the reimbursement of the related costs.

Table 35: Revenues' incentives.

Energy related items	Incentive *[€/kWh]*
Direct self-consumption	0,35
Dedicated withdrawal	0,12
Premium tariff	0,13
Network avoided costs	0,0068

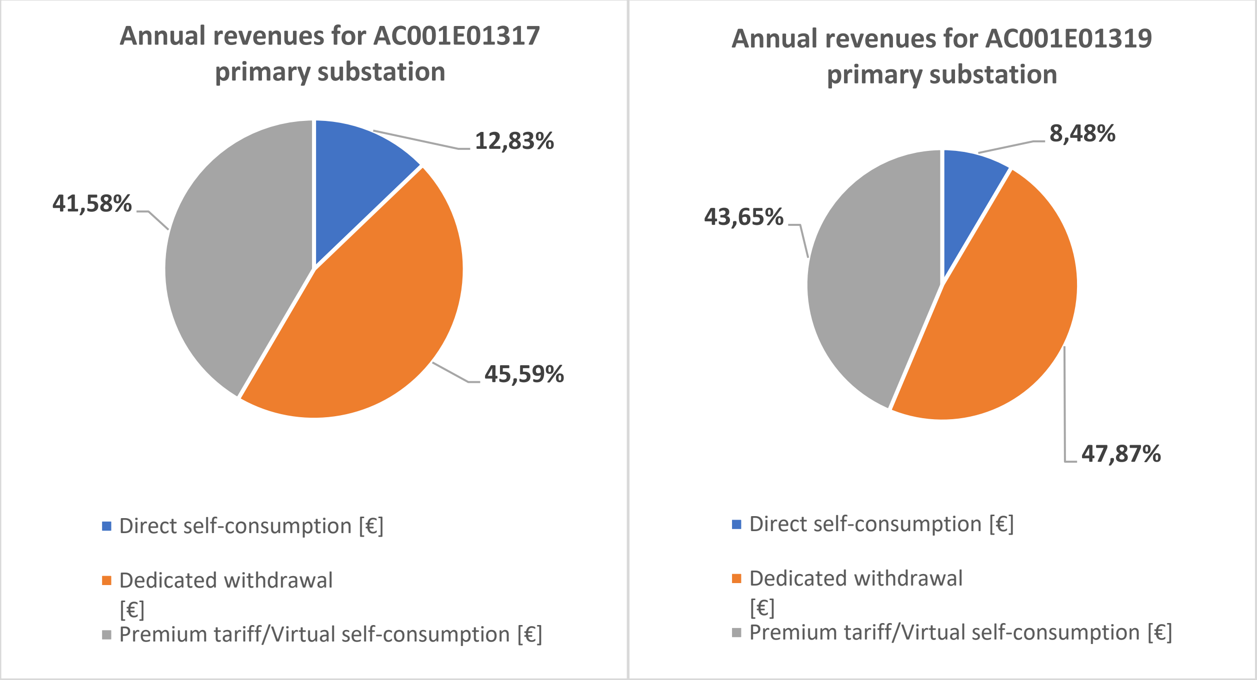


Figure 64: Distribution on annual revenues from energy-related items

5.2.1 Premium rate

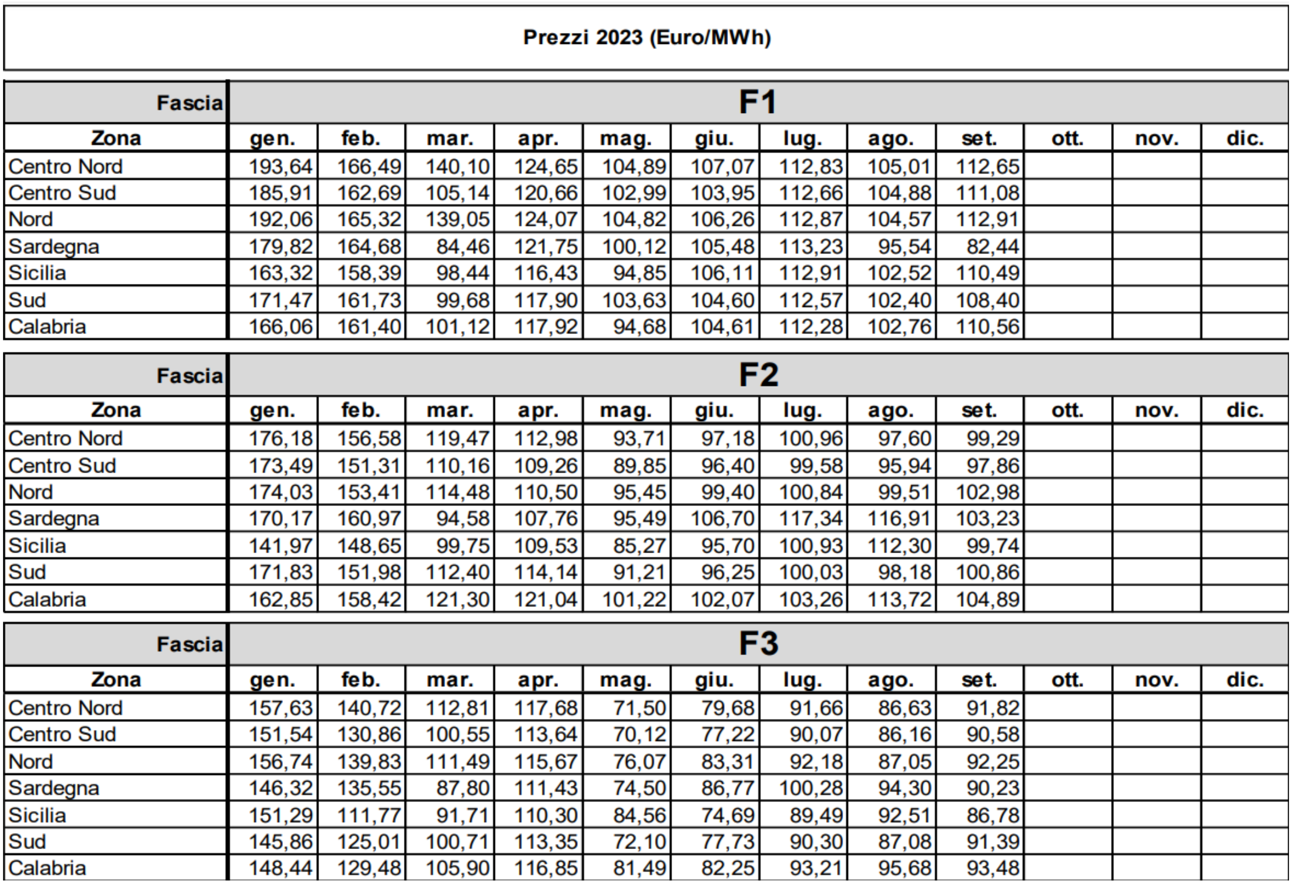
The REC revenues concern the enhancement of shared energy through the incentive determined by the TIP premium tariff. This tariff will be determined by the MASE Ministerial Decree to be published soon. The estimates shown here refer to what is indicated in the currently available draft of the decree.
As explained in the chapter 1.5 in the geographical area of the province of Turin the tariff varies according to the power of the plants. In this case study two different premium tariffs may be applied (Table 36).

Table 36: The two premium rates that can be applied to this case study.

Plant size P *[kW]*	Incentive *[€/MWh]*	Minimum incentive value *[€/MWh]*	Maximum incentive value *[€/MWh]*
P ≤ 200 kW	80 + max (0;180-Z_p)	80	120
200 kW < P < 600 kW	70 + max (0;180-Z_p)	70	110

The zonal price Z_p is periodically published by GSE. This price over the last few years has varied with significant percentages because of the COVID-19 pandemic and the Russian-Ukrainian war. Table 37 is updated to September 2023 and published by GSE [35].

Table 37: Zonal price updated to September 2023 and published by GSE.



Prezzi 2023 (Euro/MWh)

Fascia	F1											
Zona	**gen.**	**feb.**	**mar.**	**apr.**	**mag.**	**giu.**	**lug.**	**ago.**	**set.**	**ott.**	**nov.**	**dic.**
Centro Nord	193,64	166,49	140,10	124,65	104,89	107,07	112,83	105,01	112,65			
Centro Sud	185,91	162,69	105,14	120,66	102,99	103,95	112,66	104,88	111,08			
Nord	192,06	165,32	139,05	124,07	104,82	106,26	112,87	104,57	112,91			
Sardegna	179,82	164,68	84,46	121,75	100,12	105,48	113,23	95,54	82,44			
Sicilia	163,32	158,39	98,44	116,43	94,85	106,11	112,91	102,52	110,49			
Sud	171,47	161,73	99,68	117,90	103,63	104,60	112,57	102,40	108,40			
Calabria	166,06	161,40	101,12	117,92	94,68	104,61	112,28	102,76	110,56			

Fascia	F2											
Zona	**gen.**	**feb.**	**mar.**	**apr.**	**mag.**	**giu.**	**lug.**	**ago.**	**set.**	**ott.**	**nov.**	**dic.**
Centro Nord	176,18	156,58	119,47	112,98	93,71	97,18	100,96	97,60	99,29			
Centro Sud	173,49	151,31	110,16	109,26	89,85	96,40	99,58	95,94	97,86			
Nord	174,03	153,41	114,48	110,50	95,45	99,40	100,84	99,51	102,98			
Sardegna	170,17	160,97	94,58	107,76	95,49	106,70	117,34	116,91	103,23			
Sicilia	141,97	148,65	99,75	109,53	85,27	95,70	100,93	112,30	99,74			
Sud	171,83	151,98	112,40	114,14	91,21	96,25	100,03	98,18	100,86			
Calabria	162,85	158,42	121,30	121,04	101,22	102,07	103,26	113,72	104,89			

Fascia	F3											
Zona	**gen.**	**feb.**	**mar.**	**apr.**	**mag.**	**giu.**	**lug.**	**ago.**	**set.**	**ott.**	**nov.**	**dic.**
Centro Nord	157,63	140,72	112,81	117,68	71,50	79,68	91,66	86,63	91,82			
Centro Sud	151,54	130,86	100,55	113,64	70,12	77,22	90,07	86,16	90,58			
Nord	156,74	139,83	111,49	115,67	76,07	83,31	92,18	87,05	92,25			
Sardegna	146,32	135,55	87,80	111,43	74,50	86,77	100,28	94,30	90,23			
Sicilia	151,29	111,77	91,71	110,30	84,56	74,69	89,49	92,51	86,78			
Sud	145,86	125,01	100,71	113,35	72,10	77,73	90,30	87,08	91,39			
Calabria	148,44	129,48	105,90	116,85	81,49	82,25	93,21	95,68	93,48			

The tariff is made up of a fixed part depending on the size of the system, worth 60, 70 or 80 €/MWh, and a variable part that decreases as the zonal energy price increases, until it reaches zero for a zonal price equal to 180 €/MWh or higher. Figure 65 shows the trend of the premium rate as a function of the zonal price.

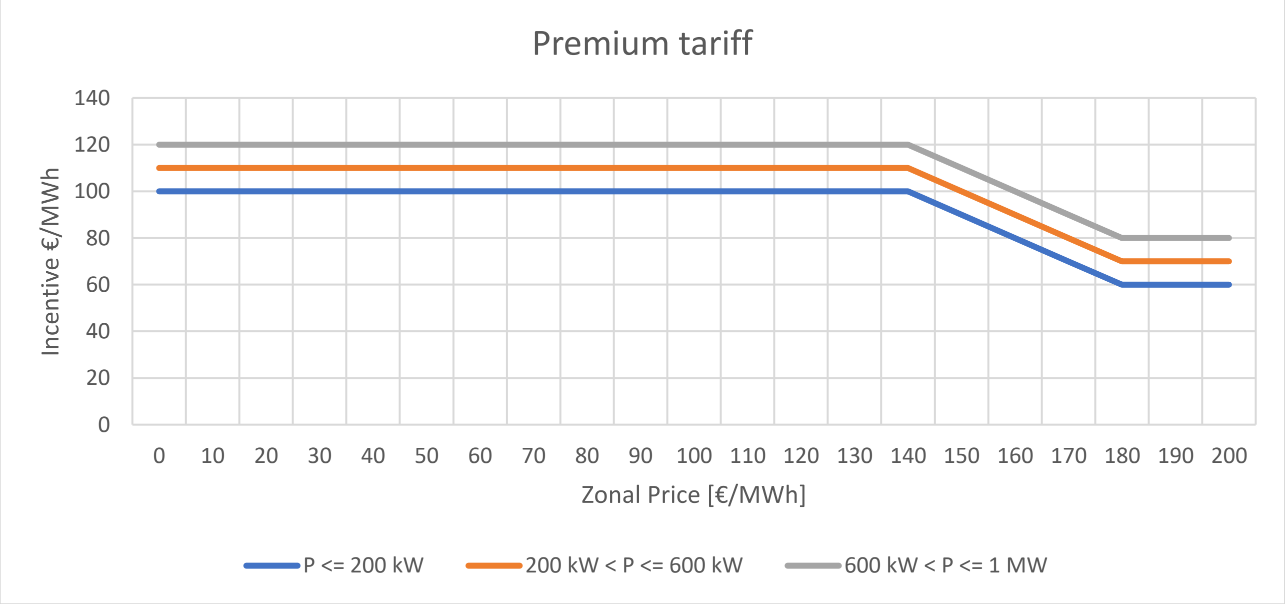


Figure 65: Trend of the Premium Rate as a function of the Zonal Price [36]

The current trend of reduction in the price of energy can lead us to assume that the Price of the Northern Zone can settle on a value lower than 140 €/kWh which would allow receiving the incentive at its maximum

value. A tariff of 110 €/MWh was therefore considered for plants with power higher than 200 kWp and 120 €/MWh for plants with power lower than 200 kWp.
The draft of the MASE Ministerial Decree provides a correction for premium rates to take into account the different levels of insolation of the various Italian regions. Plants built in the Piedmont region will receive a correction factor of +10 €/MWh.
Therefore, the premium rates considered in this study revenues are:

Table 38: Premium rates considered for this study.

Plant size P *[kW]*	Incentive *[€/MWh]*
P ≤ 200 kW	130 €/MWh
200 kW < P < 600 kW	120 €/MWh

5.2.2. Network avoided costs

The Integrated Text for Collective Self-Consumption (TIAD) published by ARERA with resolution 727/2022/R/EEL of December 27th, 2022, provides that the shared electricity relating only to the connection points located in the portion of the distribution network underlying the primary substation itself is valued through the return of the variable part of the transmission tariff which can be estimated at €6.8/MWh.

5.2.3 Dedicated withdrawal

The Dedicated Withdrawal is a simplified method available to producers to sell the electricity produced and fed into the grid, active since January 1st, 2008. It consists in the transfer to GSE of the electricity fed into the grid by the 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, GSE pays the producer a certain price for each kWh fed into the grid. The revenues deriving to producers from the sale of electricity to the GSE are therefore added to those achieved by any incentive mechanisms except for the case in which all-inclusive fixed prices are applied, including the incentive, for the withdrawal of the electricity fed into net. The value of the dedicated withdrawal injected into the network can be associated with the Zonal Price which, as we have seen in paragraph 1.5 today it is equal to about 120€/MWh.

5.2.4 Direct/real self-consumption

Photovoltaic systems built on the roofs of buildings allow producers to consume energy directly inside the buildings themselves, covering part of the consumption of the electrical utilities present there. Direct self-consumption translates into a reduction in the energy bill as it reduces the withdrawal of electricity from the grid.
As part of an economic plan, this saving can be valued at the unit price of the energy in the bill (including charges and taxes) that in September 2023 stood at approximately €350/MWh.

5.3 Operation and maintenance quantification (OPEX)

To draw up an economic analysis, it is necessary to estimate not only the future revenues generated by the photovoltaic systems that it is assumed to realize, but also the management costs necessary for the maintenance and management of the systems.

Operating Expenditure (OPEX) for a renewable energy community refers to the ongoing, day-to-day costs associated with the operation and maintenance of the community's renewable energy infrastructure. Unlike Capital Expenditure (CAPEX), which involves one-time investments in assets, OPEX represents the recurring expenses necessary to keep the renewable energy systems running efficiently. OPEX is critical for the continuous and efficient operation of a renewable energy community. Effective management of OPEX ensures the longevity, reliability, and sustainability of the renewable energy infrastructure while meeting the community's energy needs in an environmentally friendly manner.

5.3.1 Plant insurance and plant maintenance

Plant insurance is assumed that the annual insurance cost of photovoltaic systems is equal to 1% of the plant cost itself (CAPEX). While plant maintenance is assumed that the annual cost for the maintenance of photovoltaic systems is on average equal to 20 €/kW/year.

Table 39: Values for insurance and maintenance costs.

OPEX	Unit of measure	Value
Plant insurance	[€/year]	1% of the plant cost
Plant maintenance	[€/kW/year]	20

5.3.2. Taxes

Concerning taxes calculation, the IRES [37] and IRAP [38] rates were considered and published on the websites of the Revenue Agency and the Ministry of Economy and Finance. The following IRES and IRAP rates are used to calculate taxes:

Table 40: IRES and IRAP rates considered.

Name	Value
IRES	24.00 %
IRAP	8.50 %

5.4 Economic KPIs

The evaluation of costs and revenues allows the calculation of a series of economic KPIs. Through the discounted cash flow method (Discontinued Cashflows), the classic investments' valuation indices were calculated, such as:

- The Net Present Value, indicated with the acronym NPV;
- The Internal Rate of Return (IRR);

- The Pay-Back Time, indicated as PBT;

In the analysis the following financial and economic parameters are fixed:

- Interest rate *i* = 5%;
- Energy cost C_e= 0,35€/kWh;
- Lifetime of installation and basis for NPV calculation t= 20 years.

5.4.1 Net Present Value (NPV) and IRR

The Net Present Value (NPV) for a renewable energy community is a financial metric used to evaluate the profitability and attractiveness of an investment in renewable energy projects over time. NPV calculates the present value of all future cash flows generated by the project, discounted to their current value, and subtracts the initial investment cost. The result is a single figure that indicates the net value of the investment in today's euros. A positive NPV suggests that the investment is expected to generate a profit, while a negative NPV implies a potential financial loss.

In the context of a renewable energy community, the NPV would consider the costs and benefits associated with setting up and operating renewable energy infrastructure, such as solar panels, energy storage systems, and related facilities. The NPV analysis considers factors such as 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.

The NPV is calculated with the following formula:

$$NPV = -I + \sum_{t=0}^{N} \frac{R}{(1+i)^t}$$

Where I is the initial investment cost evaluated on the base of the plant sizing, i is the effective discount rate previously calculated and R is the total revenue of the plant. The revenues are computed following the formula:

$$REVENUES = Direct\ SelfC\ [kWh] \cdot 0{,}35 \left[\frac{€}{kWh}\right] + DedicatedWithd\ [kWh] \cdot 0{,}12 \left[\frac{€}{kWh}\right] + PremiumT\ [kWh] \cdot 0{,}1368 \left[\frac{€}{kWh}\right]$$

IRR represents the discount rate at which the net present value (NPV) of the investment becomes zero. In other words, it is the discount rate that equates the present value of the project’s cash inflows with the present value of its cash outflows. For a renewable energy community, the IRR would consider the costs associated with developing and operating PV panels and the revenue generated from energy production and distribution. The IRR is expressed as a percentage and provides insights into the project’s financial performance.

A higher IRR typically indicates a more attractive investment, as it implies that the project is expected to generate returns that exceed the cost of capital. Investors and decision-makers often use IRR to compare different investment opportunities and assess the financial feasibility of renewable energy projects within a community. If the IRR is greater than the project's cost of capital, the project is considered financially viable.

$$-I - OPEX + \sum_{t=0}^{N} \frac{R}{(1+i)^t} = 0$$

All the data is summarized in the table below.

Table 41: NPV and IRR for the optimal RECs' configuration.

RECs' optimal configuration	AC001E01317	AC001E01319
Total cost *[€]*	73.695 €	71.694 €
Total annual revenues *[€]*	12.429 €	12.297 €
Discount rate	5%	5%
20 years NPV	62.702 €	62.803 €
20 years IRR	14%	15%
Profit index over 20 years	5,02	5,11

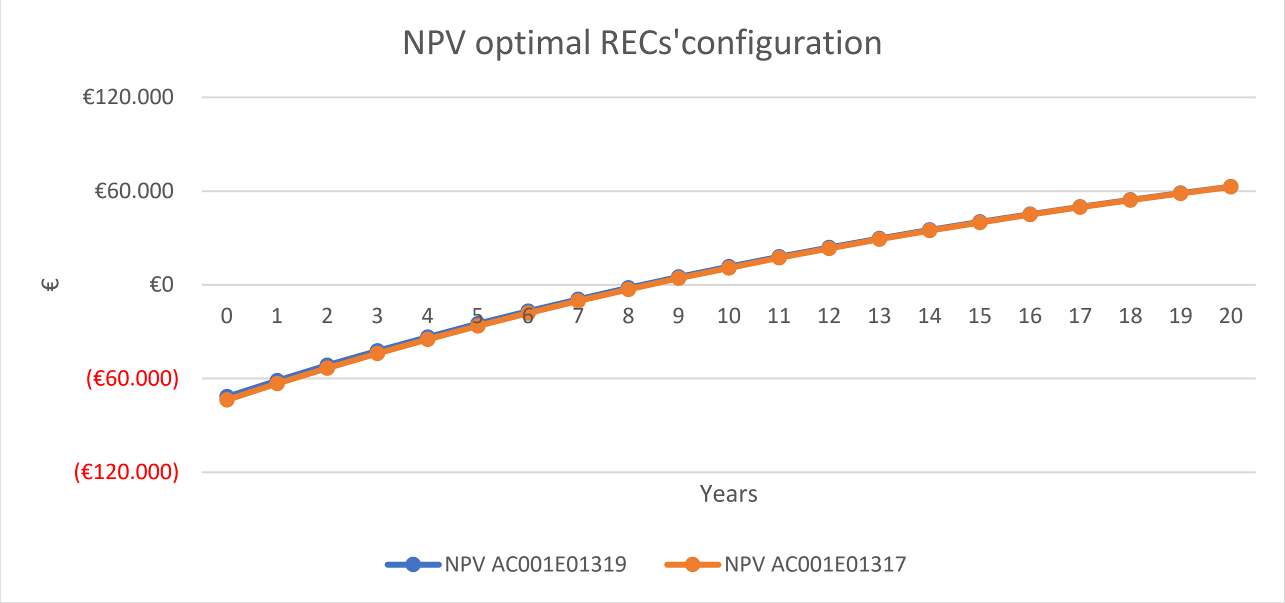


Figure 66: NPV for optimal REC's configuration.

The Net Present Value for both RECs' optimal configurations are between 60.000€ and 70.000 € while the IRR is around 15%.

5.4.2 Pay Back Time (PBT)

In this section the payback time is computed for the optimal configuration found in the previous paragraph. The PBT is the corresponding year in which the NPV reaches the zero and so the plant starts to generate incomes.

Payback time, also known as the payback period, is a financial metric that measures the time it takes for the initial investment in a project to be recovered through the project's generated cash flows. It represents the duration it takes for the cumulative net cash inflows to equal the initial investment. In simpler terms, payback time indicates how long it will take for an investment to recoup its initial costs.

The payback time is often expressed in years and is a useful metric for assessing the risk and return of an investment. A shorter payback time is generally considered more favourable, as it implies a quicker recovery of the initial investment. However, payback time is a relatively straightforward metric and may not account for the time value of money or provide a comprehensive assessment of the project's long-term profitability.

Table 42: Pay Back Time (PBT) for the optimal RECs' configuration.

RECs' optimal configuration	AC001E01317	AC001E01319
Simple Pay Back Time	5,9	5,7
Pay Back Time	9	8

5.4.3 Sensitivity analysis of the investment

The sensitivity analysis is a financial modelling technique used to assess how changes in key variables or assumptions affect the outcomes of the investment. In the context of a renewable energy community, sensitivity analysis can help identify the most critical factors influencing the project's financial performance and sustainability. Here's how sensitivity analysis might be applied to a renewable energy community:

1. Varying Electricity Prices: evaluate how changes in energy prices impact the project's financial viability. Lower or higher energy prices can affect revenue generation and, consequently, the project's profitability.
2. Discount Rate: assess the impact of changes in the discount rate on the Net Present Value (NPV) and Internal Rate of Return (IRR) of the project. The discount rate reflects the time value of money and the project's risk.
3. Storage Battery Size and Costs: if the renewable energy community incorporates energy storage, analyse the sensitivity of the project to changes in battery storage efficiency and costs. This is crucial for understanding the impact on grid stability and energy storage economics.

Through a sensitivity analysis it is possible to evaluate how the net present value would change in case of discount rate variation between 2% and 7%.

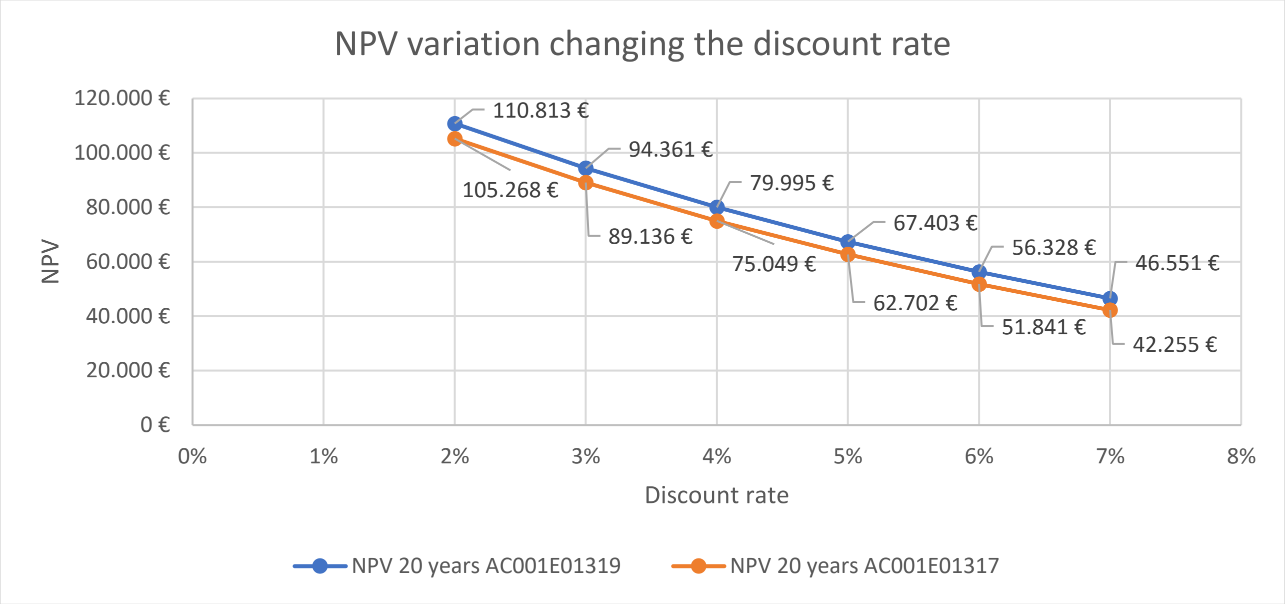


Figure 67: NPV variation changing the discount rate.

As expected, by increasing the discount rate, the Net Present Value decreases with an exponential trend.

In Figure 68 annual revenues are computed varying the electricity cost between 0,15€/kWh and 0,45 €/kWh.

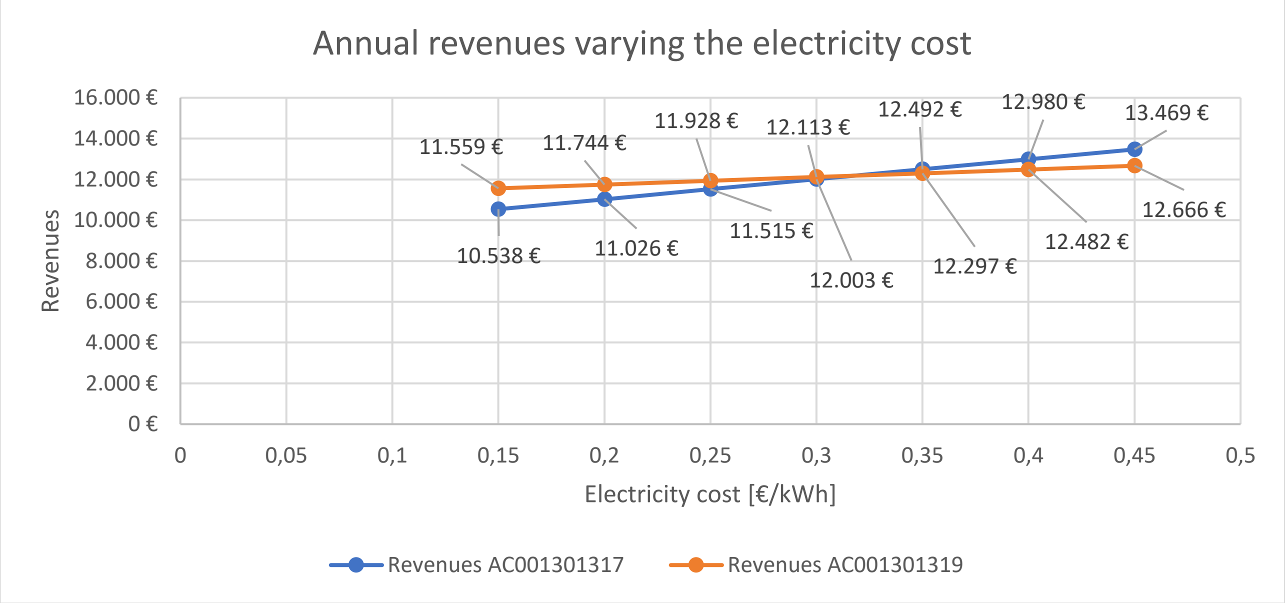


Figure 68: Annual revenues varying the electricity cost.

Revenues increase by the electricity price increasing because of the direct self-consumption incentive, dependant on the energy cost.

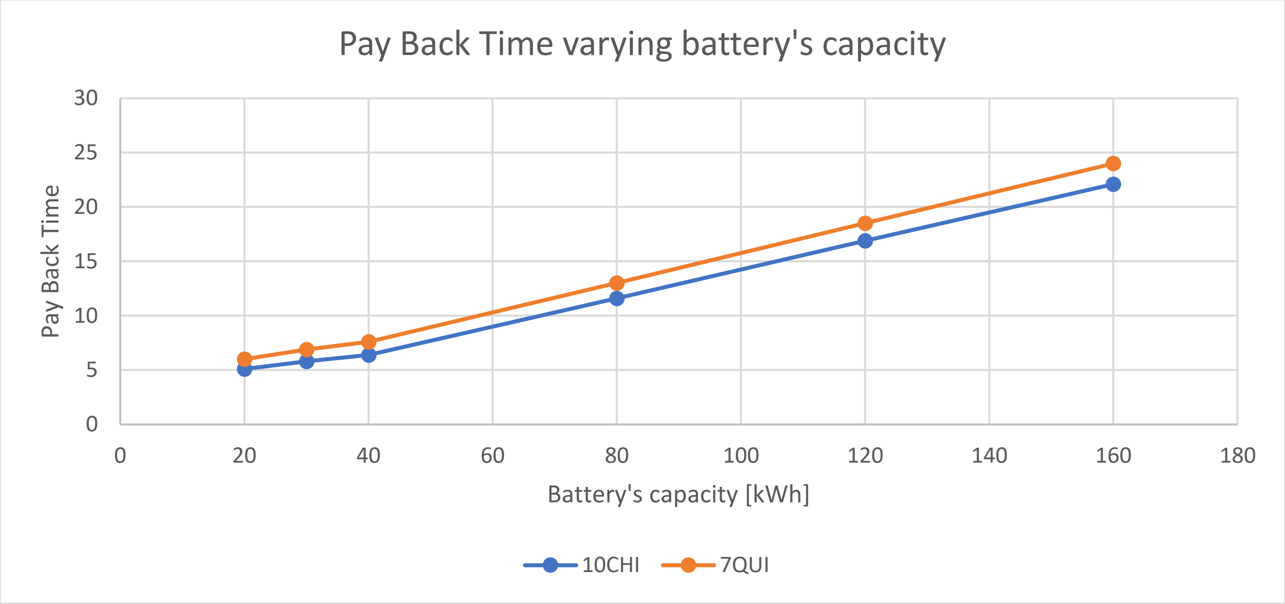


Figure 69: Pay Back Time varying battery's capacity.

In Figure 69 it emerges that by increasing the battery’s capacity for two different buildings the pay Back Time increases almost with a linear trend.

Sensitivity analysis helps to understand the resilience and flexibility of a renewable energy community project in the face of uncertainties and changes in key variables. It provides valuable insights for risk management and strategic decision-making, allowing for a more robust and adaptive approach to project planning and implementation.

5.5 Cash flows

Therefore, for the calculation of the annual cash flows (of the *i*-th year), indicated as Cfi the following equation was adopted:

$$CF_i = \begin{cases} -CAPEX & at\ t = 0 \\ -OPEX_i + R_t & at\ t = 1, \dots n \end{cases}$$

Where:

- the time variable t indicates the reference year, while n is the duration in years of the investment, set equal to 20 years;
- $CAPEX$ are the total capital costs linked to the purchase of photovoltaic systems and REC storage systems;
- $OPEX_i$ are the REC operating costs, in year t;
- R_t are the REC revenues, in year t;

In Figure 70 cash flows are shown for the optimized configurations.

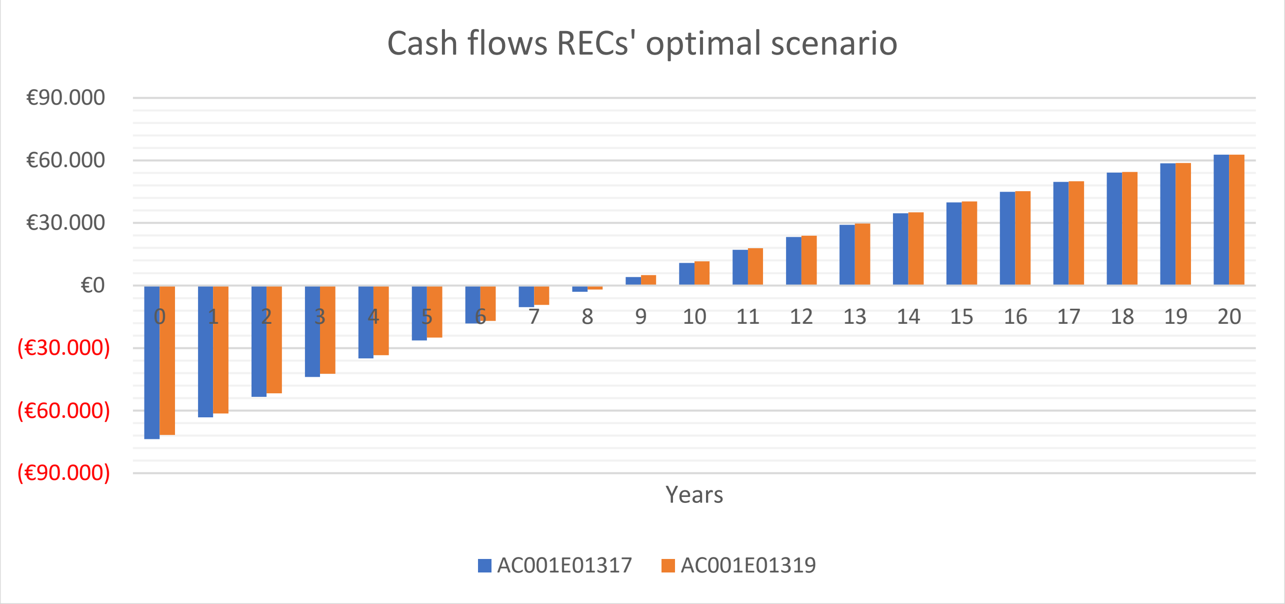


Figure 70: RECs' optimal scenario cash flows.

In Table 43 and Table 44 cashflows' values are evaluated for the optimal configurations in both the primary substations.

Table 43: AC001E01317 primary substation optimal configuration cashflows.

Capital Expenditure (CAPEX)			
PV Plants construction			**66.300 €**
Revenues			
	Energy [kWh]	Unit price [€/kWh]	Total [€/y]
Direct Self-consumption	5.560	0,35	1.946 €/y
Dedicated withdrawal	39.541	0,12	4.745 €/y
Premium tariff plants < 200kW$_p$	36.338	0,1368	4.971 €/y
Total			**11.662 €/y**
Operational Expenditure (OPEX)			
Plants' insurance	Tariff [%]	CAPEX	Total [€]
	1%	66.300€	663€/y
Maintenance	Tariff [€/kW$_p$]	Installed power	
	20	44,2	884€/y
Taxes	Tariff [%]	CAPEX	
	8,5%	66.300€	5.636€
	Tariff [%]	Maintenance	
	24%	884€	212€/y
Total			**7.395€**

Table 44:AC001E01319 primary substation optimal configuration annual cashflows.

Capital Expenditure (CAPEX)			
PV Plants construction			**63.600 €**
Revenues			
	Energy [kWh]	Unit price [€/kWh]	Total [€/y]
Direct Self-consumption	3.691	0,35	1.292€/y
Dedicated withdrawal	47.967	0,12	5.756€/y
Premium tariff plants < 200kW$_p$	38.374	0,1368	5.250€/y
Total			**12.297€/y**
Operational Expenditure (OPEX)			
Plants' insurance	Tariff [%]	CAPEX	Total [€]
	1%	63.600€	636€/y
Maintenance	Tariff [€/kW$_p$]	Installed power	
	20	43	860€/y
Taxes	Tariff [%]	CAPEX	
	8,5%	63.600€	5.406€
	Tariff [%]	Maintenance	
	24%	860€	206€/y
Total			**7.108€**

5.6 Distribution of revenues

The criteria for dividing the REC proceeds among its members are to be agreed between the members themselves according to private law agreements and may involve complex algorithms. Some examples are:

- Pro User Subdivision;
- Algorithms on social economic well-being indicators (e.g., ISEE);
- Subdivision based on the self-consumption of each member (thanks to which the incentive is accrued).

The problem with the last method is allocating self-consumption to each member when, on an hourly basis, the community's consumption is higher than the energy fed into the grid by the REC's plants.

According to the proportional methodology all the self-consumption attributable to the REC for the time slot in which the production fed into the network was exceeded is taken as a reference, and the percentage of this value attributable to each consumer member is calculated: this percentage will be the one used to attribute the contributions accrued in the time slot to the consumer member. Instead, according to the progressive methodology each consumer member is attributed, in the hour considered, the self-consumption corresponding to that of the consumer member who consumed the least (“Minimum Self-Consumption”). The allocation occurs recursively and progressively until the share of shared energy is exhausted. By attributing this Minimum Self-Consumption to all consumer members, the value of the energy injected and shared can be exceeded or not.

If by attributing the Minimum Self-Consumption the total value of the energy injected into the grid (and shared) by the CER plants for the hour considered is exceeded, then this shared energy is divided equally among all those who participated in the same hour.

If by attributing the Minimum Self-Consumption the total value of the energy injected into the grid (and shared) by the CER plants in the considered hour is not exceeded, proceed as follows: contributions corresponding to the Minimum Self-Consumption are attributed to all members who contributed; the Delta Contributions not yet attributed is calculated and the further minimum self-consumption is calculated net of that already considered and attributed in the previous point ("Further Minimum Self-Consumption"); the value of the contributions produced by the Further Minimum Self-Consumption is attributed to all consumer members who have carried out self-consumption greater than or equal to the Minimum Self-Consumption. If by doing so the Delta Contributions is exceeded, the latter is attributed equally to all those who contributed. However, if by doing so the value of the Delta Contributions is not exceeded, the above procedure is repeated until the Delta Contributions are completely extinguished.

The ‘proportional’ methodology (the first presented above) tends to benefit the most energy-intensive users, if they are synchronous with production of the plants owned by the CER. The second methodology, with attribution ‘progressive’, tends instead to divide the shared energy equally between those who make the same minimum consumption, only based on synchrony of self-consumption with solar production. Basically, with progressive attribution: small consumers are favoured over large one’s consumers as they have a higher percentage recognition of contributions.

Since the investment in the systems would be entirely the responsibility of the Municipalities, as most of the electricity consumption, it is expected that the Municipalities will be entitled to a portion of the revenues generated by the energy produced, directly self-consumed, fed into the grid, shared, and incentivized necessary to recoup investments incurred over ten years and to support the operational costs of maintaining the plants. The remaining part of the revenues may remain available to the REC and may be used for financing policies to combat energy poverty.

In Table 45and Table 46 the hypothesis of revenues distribution between Municipalities and RECs is computed. Considering that the Pay Back Time for both RECs is 9 years, the Municipalities in AC001E01317 primary substation will have to receive annual revenues equal to 9.126€, net of operating costs equal to 7.367€. While the Municipalities in AC001E01319 primary substation will have to receive revenues equal to 8.769€, net of operating costs equal to 7.067€.

Table 45: Hypothesis of revenues' distribution between municipalities and AC001E01317 REC.

Hypothesis of revenues’ distribution between municipalities and REC			
	Direct Self-consumption	Dedicated withdrawal	Premium tariff
Municipalities	100%	100%	49%
REC	0%	0%	51%
Municipalities’ annual revenues			
	Total [€]	Percentage distribution	Municipalities’ revenues
Direct Self-consumption	1.946 €	100%	1.946 €
Dedicated withdrawal	4.745 €	100%	4.745 €
Premium tariff plants < 200kW_p	4.971 €	49%	2.436 €
Total			**9.127 €**
AC001E01317 REC’s annual revenues			
	Total [€]	Percentage distribution	Municipalities’ revenues
Direct Self-consumption	1.946 €	0%	0 €
Dedicated withdrawal	4.745 €	0%	0 €
Premium tariff plants < 200kW_p	4.971 €	51%	2.535 €
Total			**2.535 €**

Table 46: Hypothesis of revenues' distribution between municipalities and AC001E01319 REC.

Hypothesis of revenues’ distribution between municipalities and REC			
	Direct Self-consumption	Dedicated withdrawal	Premium tariff
Municipalities	100%	100%	33%
REC	0%	0%	67%
Municipalities’ annual revenues			
	Total [€]	Percentage distribution	Municipalities’ revenues
Direct Self-consumption	1.292 €	100%	1.292 €
Dedicated withdrawal	5.756 €	100%	5.756 €
Premium tariff plants < 200kW$_p$	5.250 €	33%	1.732 €
Total			**8.780 €**
AC001E01317 REC’s annual revenues			
	Total [€]	Percentage distribution	Municipalities’ revenues
Direct Self-consumption	1.292 €	0%	0 €
Dedicated withdrawal	5.756 €	0%	0 €
Premium tariff plants < 200kW$_p$	5.250 €	67%	3.517 €
Total			**3.517 €**

5.7 Business model hypothesis

The municipalities of Borgofranco d’Ivrea, Quassolo, Quincinetto, Montalto Dora, Chiaverano and Lessolo are responsible for the purchase and management of photovoltaic systems installed on their roofs, which are made available to the communities. Two cases of plant financing are analysed, i.e., 60% Equity (capital invested by the municipalities) with 40% non-refundable capital from the PNRR and 60% Debt (borrowed capital) with 40% non-refundable capital from the PNRR.

5.7.1 60% Equity and 40% PNRR

The revenues for the Municipalities are represented by the sale of energy, the direct self-consumption, and the Premium Tariff. The expenses are linked to the purchase of PV systems (only for the 60% of their cost because 40% is covered by PNRR), to the plants’ insurance and maintenance and to taxes.

Using the results of the energy analysis and the quantities just introduced we arrive at the quantification of cash flows. Annual income and annual expenditure are computed.

The net cash flow is negative (around -1 million euros for scenario 1 and -€45.000 for the RECs’ optimal configuration), which increases in the second year and then decreases in subsequent years until reaching a minimum value in year 20 (approximately €100.000 for scenario 1 and €10.000 for the RECs’ optimal configuration), while remaining positive, as can be seen in the following graphs:

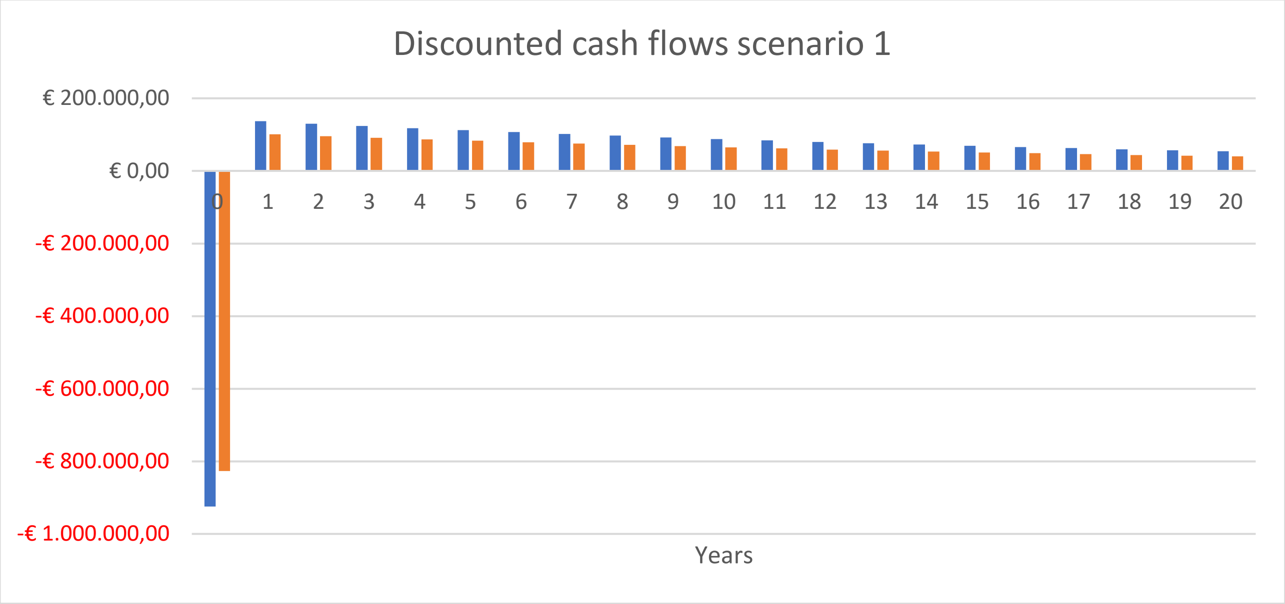


Figure 71: Net cashflows 60% equity 40% PNRR (scenario 1).

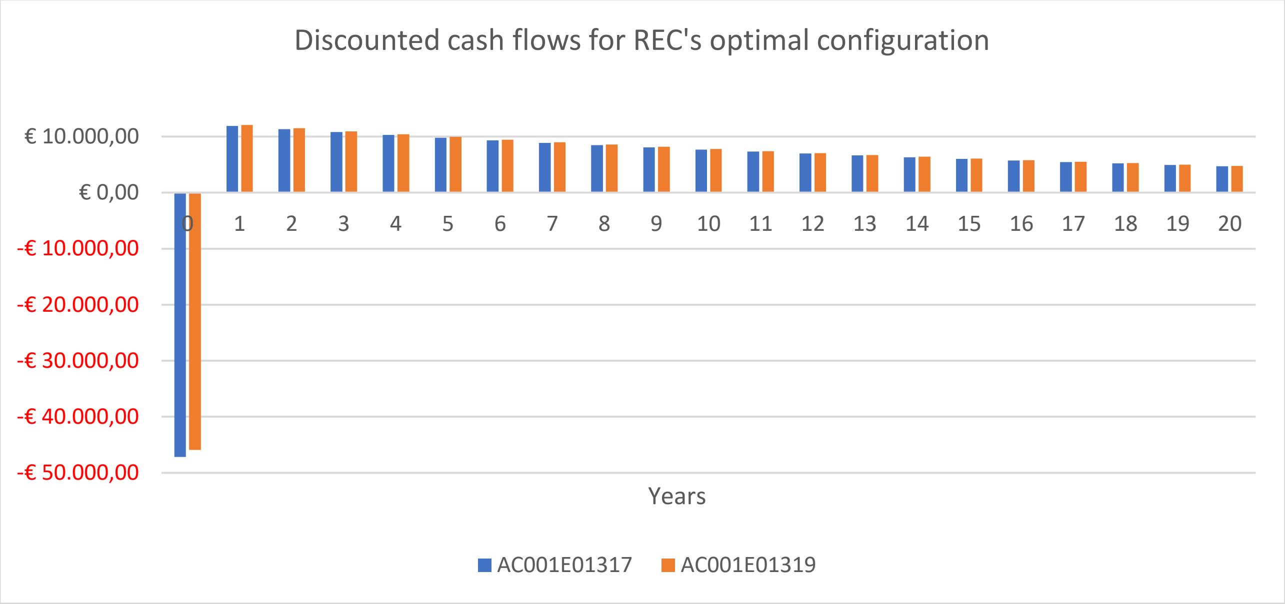


Figure 72: Net cashflows 60% equity 40% PNRR (optimal configuration).

From an economic point of view, the return on the investment (supported upstream of the creation of the community) is obtained after approximately 10 years for scenario 1 and after 4 years for the RECs' optimal configuration, with a total return after 20 years of €2.000.000 for scenario 1 and €100.000 for RECs' optimal configuration.

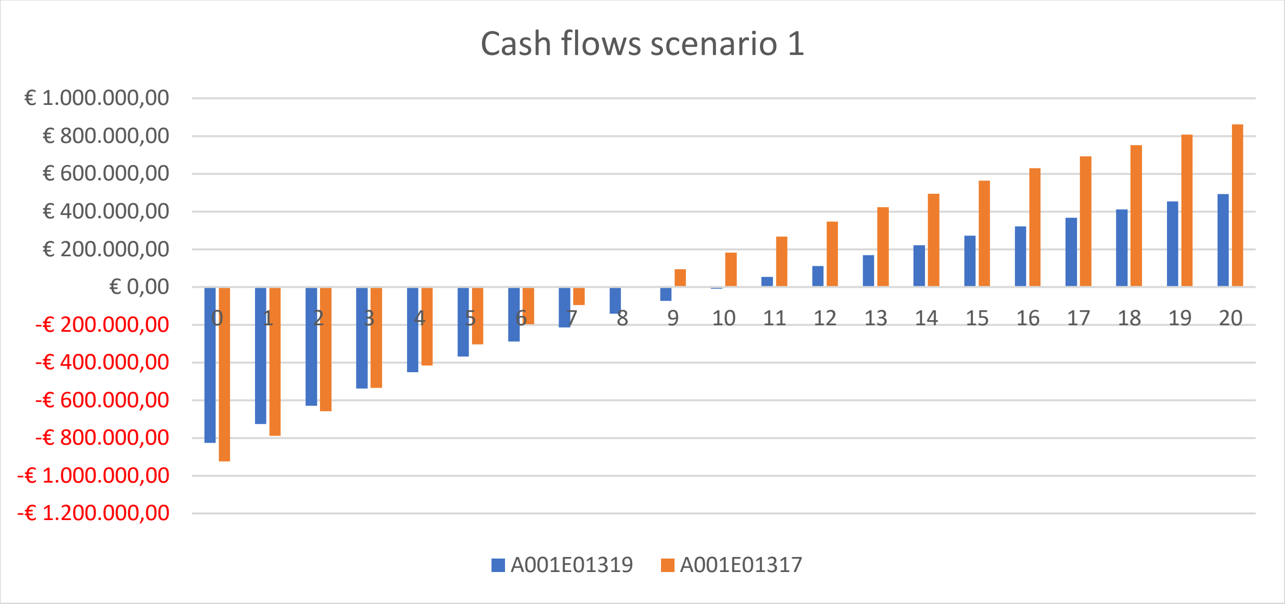


Figure 73: Cash flows 60% equity and 40% PNRR (scenario 1)

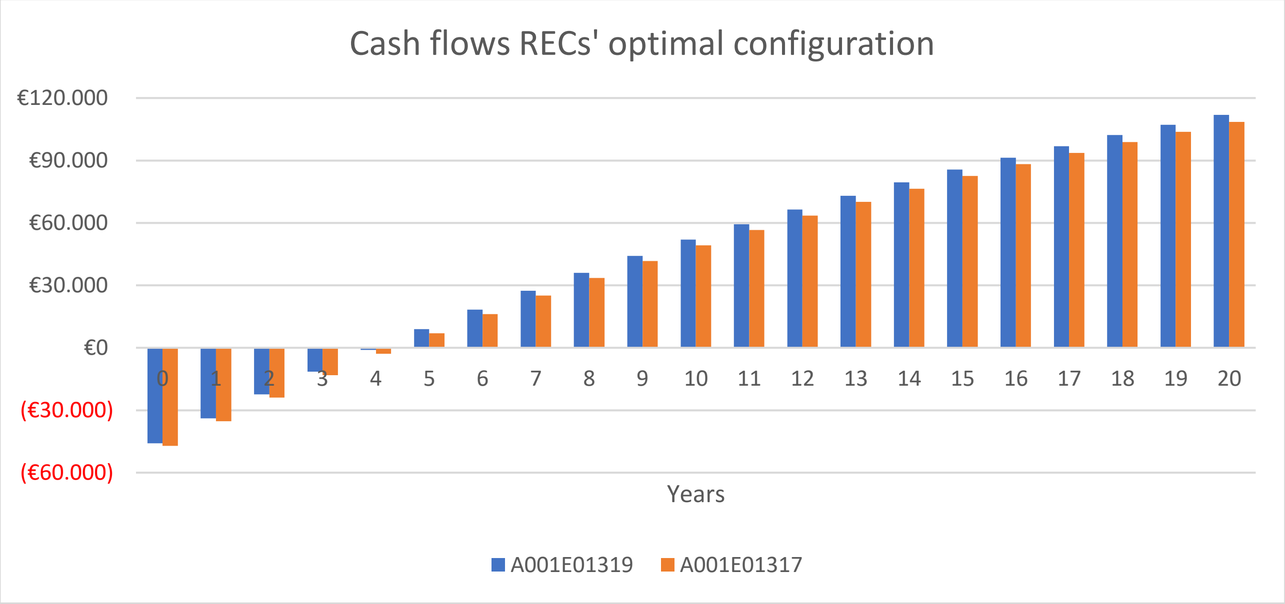


Figure 74: Cash flows 60% equity and 40% PNRR (optimal configuration).

5.7.2 60% Debt and 40% PNRR

In this case the cost of the photovoltaic systems is covered for 60% by the capital taken in loan, with a fixed interest rate of 5% and repayment over 15 years with annual instalments. The cost of the systems is the same as the previous case (40% covered by the PNRR), with the difference that the monetary output for the municipalities will not be concentrated at the initial moment of the plants' construction. It will be spread over the years of financing and burdened by the interest related to the loan. Considering that the total cost of the plants in the optimal scenario is 60% of total CAPEX equal to 39.780€ (AC001E01317) or 38.700€ (AC001E01319) and assuming financing subsidized over 15 years at a fixed rate of 5%:

Financing installment (AC001E01317) = 2.785 €/year

Financing installment (AC001E01319) = 2.709 €/year

OPEX operating costs (plant insurance/maintenance) and taxes are equivalent to the previous case.

The net cash flow is positive since the first year and lower than in case 60% Equity as this is affected by the presence of the financing instalment, which represents 27% of the outgoings annually incurred.

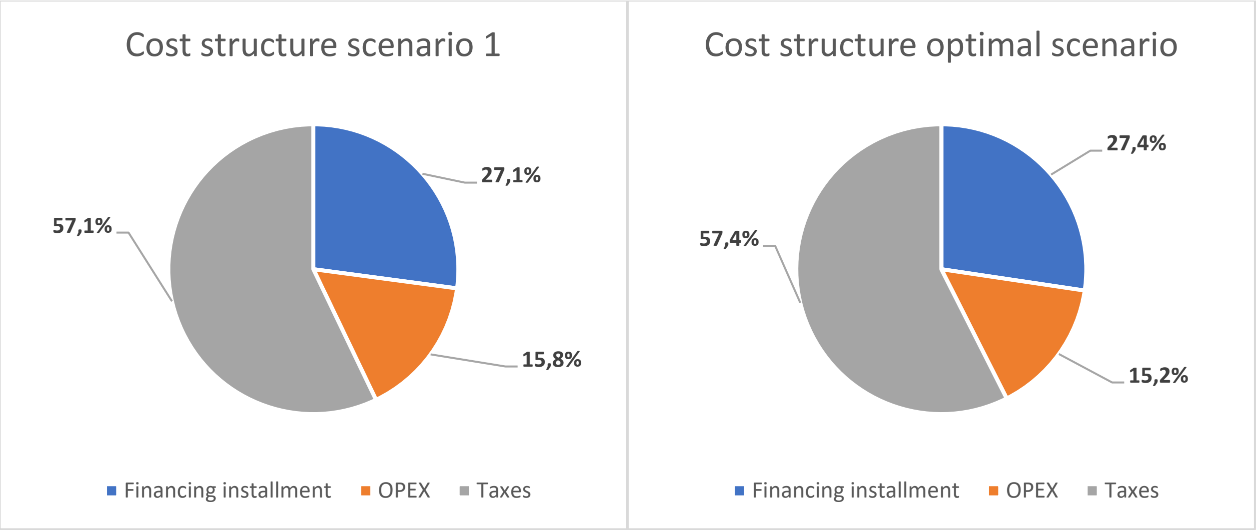


Figure 75: Cost structure 60% debt and 40% PNRR.

Cash flows tend to reduce over the years but always remain positive, and then increase from year 16, that is, the year after having paid the last loan instalment, as can be seen in the following graphs:

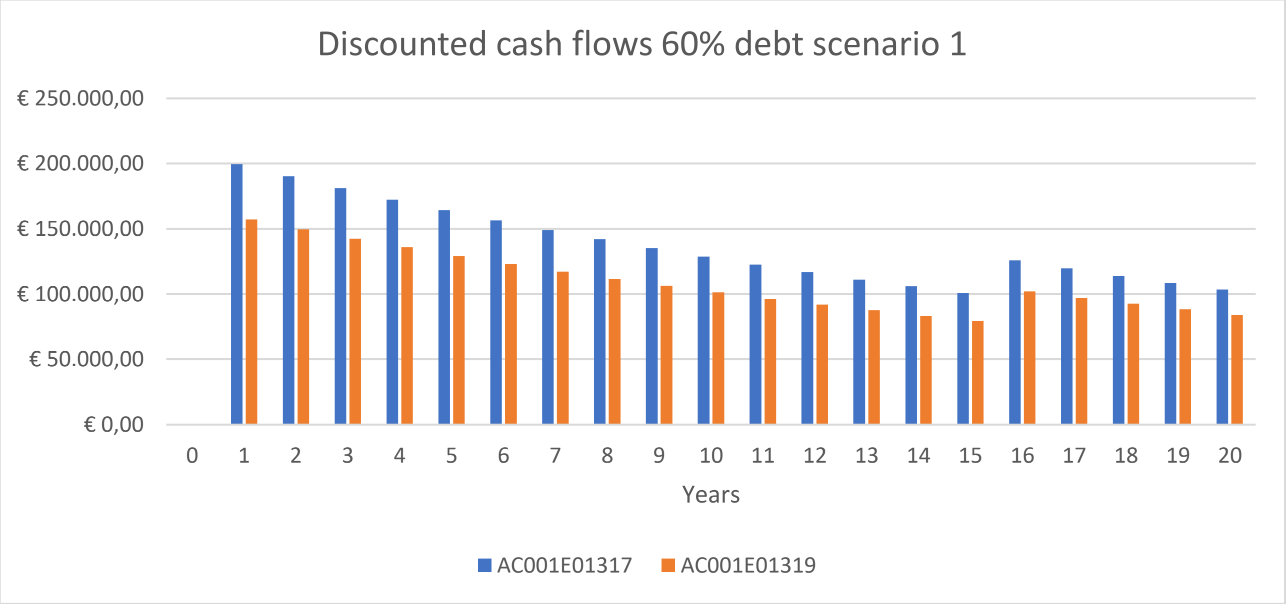


Figure 76: Discounted cash flows 60% debt and 40% PNRR (optimal configuration).

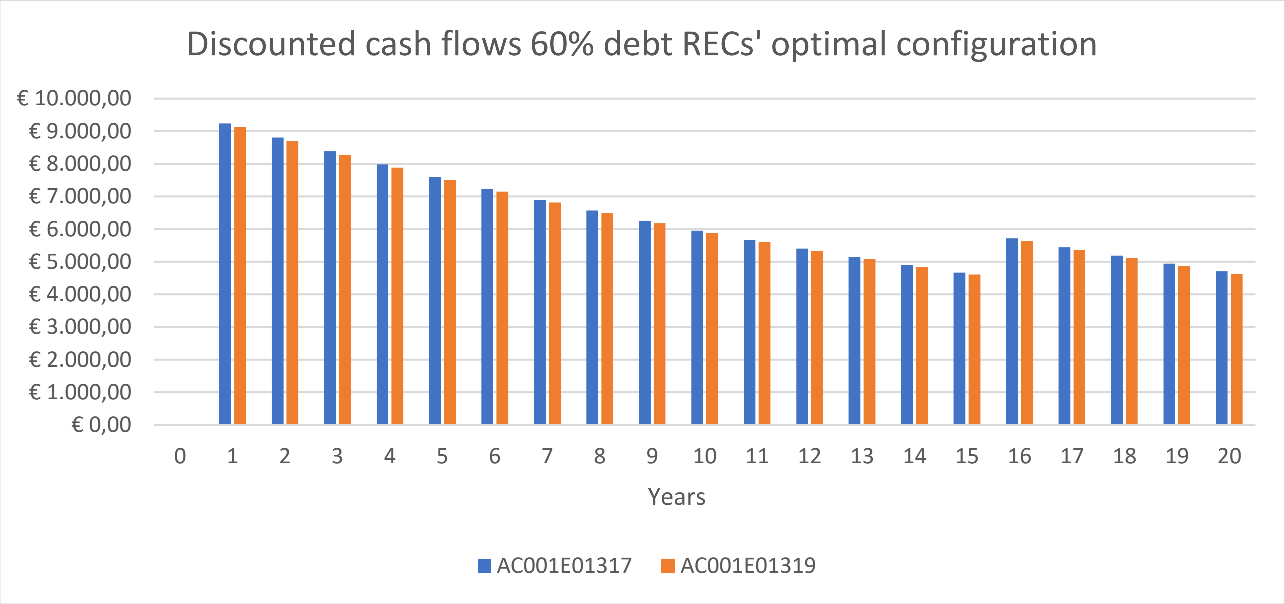


Figure 77: Discounted cash flows 60% debt and 40% PNRR (optimal configuration).

From an economic point of view, the return on investment is immediate given that the capital used is borrowed entirely, and the instalment is supported by positive annual cash flows generated by the plants. The overall return on investment after 20 years is lower than the 60% Equity case due to the interest paid on the loan taken.

5.8 Cost-optimal analysis

The aim of the cost-optimal analysis (COA) is to compare the economic implication of the different installed PV plant, defining the optimal level of performance as a function of costs [40]. The term cost-optimal points out the energy performance level, which leads to the lowest global cost during the estimated economic lifecycle [41]. The main steps of the COA methodology are represented in Figure 78.

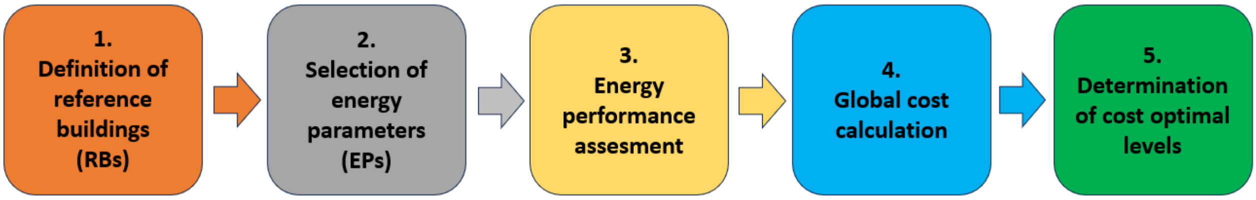


Figure 78: The multi-step methodology adopted for COA applications (personal elaboration)

Reference buildings (RBs) are the ones chosen in chapter 4.5 belonging to the top ten configurations for both primary substations. Energy parameters are assessed for the RBs as the PV produced energy, the energy fed into the grid, the real self-consumed energy, and the electricity energy baseline consumption. In this study the energy performance assessment entails the definition of self-sufficiency and self-consumption indexes. The economic performance ensures a gain for each energy user. To assess cost-optimal analysis, the Global Cost approach (Standard EN 15459:2007) has been applied to each scenario. The Global Cost assessment is performed based on the net present values standard approach for financial evaluation of long-term projects. The cost evaluation should include all energy-related lifecycle costs and not only the usually considered investment cost.

The Global Cost includes the initial Investment Cost and the present values of Energy Costs implemented with the Excel function VA (discount rate, years, consumption in kWh multiplied by the energy cost in €/kWh) to calculate the energy cost over the years. It also includes the plants' insurance equal to 1% of the Initial Investment and the plants' maintenance equal to 20€/kW$_p$. The annual Energy Costs considers the aggregation of all the expenses (for the withdrawal of energy incurred by users) and the aggregation of all the revenues generated by the sale profit of the energy shared and fed into the grid, and savings from the Self-Consumption, as they correspond to a lack of expenditure. Concerning revenues, the dedicated withdrawal over the years is evaluated with the Excel function NPV (discount rate, years, self-consumption in kWh multiplied by the energy cost in €/kWh plus energy fed into the grid in kWh multiplied by the incentive for dedicated withdrawal in €/kWh).

$$Annual\ energy\ cost = \sum Expenses - \sum Revenues$$

$$Expenses = Uncovered\ demand \cdot Withdrawal\ energy\ price$$

$$\begin{aligned} Revenues = {} & (Overproduction \cdot Sales\ energy\ price) + (CSC_{RECinc}) \\ & + (SelfConsumption \cdot Withdrawal\ electricity\ price) \end{aligned}$$

It is important to note that the global cost, as intended for cost-optimal calculations, takes into account only energy-related costs. Therefore, the concept of global cost as intended in the EBPD recast is not in compliance with a full life cycle assessment, where the environmental impacts are also considered.

Finally, the procedure results in a cost-optimal graph where the energy parameter is on the horizontal axis and the global cost is on the vertical axis, as in Figure 79 and Figure 80.

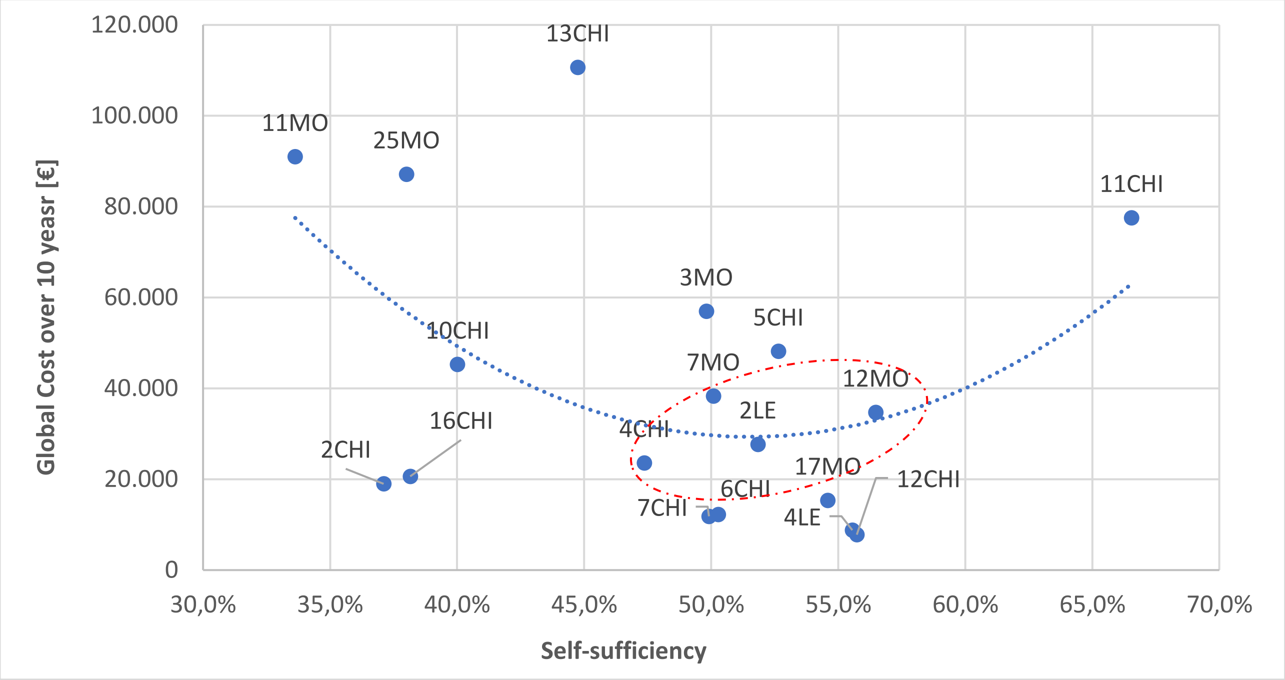


Figure 79: Cost-Optimal A001E01317 aimed at improving Self-Sufficiency Index.

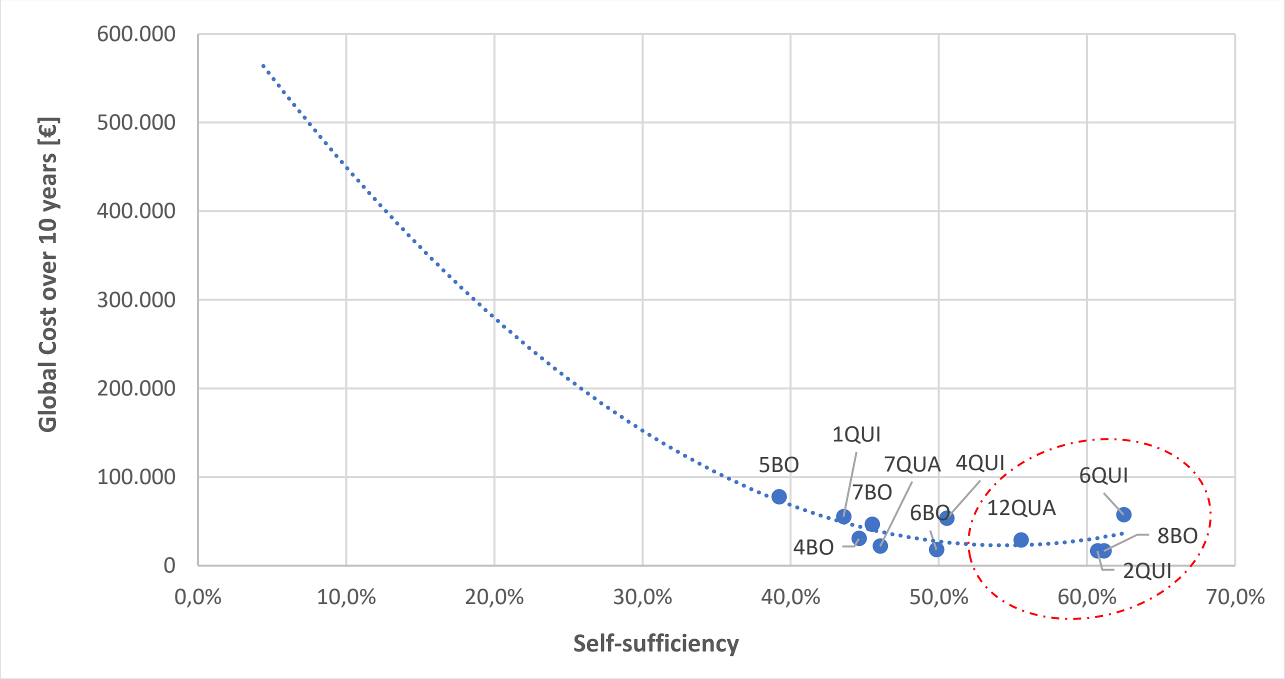


Figure 80: Cost-Optimal A001E01319 aimed at improving Self-Sufficiency Index.

In Figure 79 and Figure 80 the optimal buildings where it is convenient to install PV plants are shown. Instead, in Figure 81 the global Cost-Optimal Analysis has been carried out considering all the different scenarios.

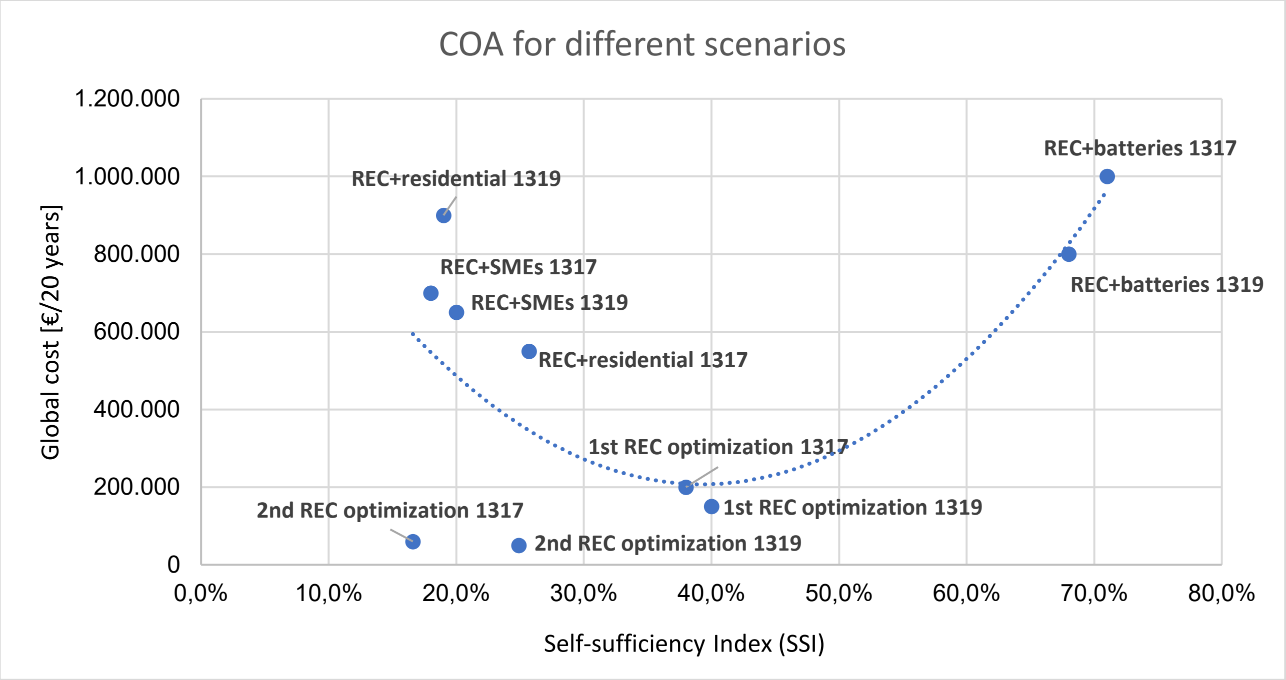


Figure 81: Global Cost-Optimal Analysis for different scenarios.

CHAPTER 6 Benefits and impact on the territory

The establishment of the *Dora5Laghi* Renewable Energy Community have multiple positive repercussions and impacts on the territory from an environmental, economic, and social point of view. The establishment of a REC encourages the diffusion of production plants from renewable sources and the citizens' and SMEs' awareness towards a virtuous use of their energy systems, thanks to the economic incentives deriving from the sharing of energy between municipal and private users and the mobilization of economic resources foreseen by PNRR.

6.1 Environmental sphere: CO_2 emissions avoided

Given the strong push towards the use of renewable energy sources, the advantages of RECs are first of environmental nature, in terms of reducing CO_2 emissions from electricity production. RECs allow small/medium sized renewable source plants to be spread across the territory, with the specificity of placing the plants close to consumers, with the effect of reducing transport costs and energy dispersion. The RECs, therefore, contribute to the objectives of the National Integrated Plan for Energy and Climate (PNIEC) [42] with:

- reduction of CO_2 emissions (more precisely, a reduction in emissions is expected by 2030 of greenhouse gases equal to 40% compared to 1990 levels);
- penetration of RES (the share of energy from RES in Gross Final Energy Consumption must reach 30% by 2030).

And therefore, it contributes significantly to the country's ecological and energy transition. In terms of technical benefits, the self-consumption generated by RECs represents a significant increase in efficiency for the electricity grid as it allows, first of all, to:

- reduce transport/distribution losses;
- mitigate imbalance between supply and demand.

For a perfect calculation we should know with certainty from which fossil sources the energy is purchased, whether the latter is produced by a thermal, hydroelectric, wind or nuclear power plant, but obviously this is not possible. Therefore, to obtain an estimate, we use the "emission factor of the electricity mix" which represents the average value of CO_2 emissions due to the production of electricity used in Italy. The data is made public by the Ministry of the Environment, which updated to date is 0.531Kg of CO_2/kWh.

Let's go back to the explanation of the Ministry of the Environment itself:
"To produce 1 kWh of electricity, the equivalent of 2.56 kWh is burned on average in the form of fossil fuels, consequently around 0.53 kg of carbon dioxide is emitted into the air. It can therefore be said that every kWh produced by the photovoltaic system avoids the emission of 0.53 kg of carbon dioxide. To quantify the benefit that this substitution has on the environment it is appropriate to refer to a practical example ".

The carbon dioxide emission avoided in a year is calculated by multiplying the value of the electricity produced by the system by the emission factor of the electricity mix. To estimate the emissions avoided over the plants' life it is sufficient to multiply the annual emissions avoided by the 20 years of the plants' estimated life.

A rough analysis of the environmental benefits has been carried out calculating the carbon dioxide (CO_2) emissions linked to the consumption of electricity by users, in absence and in presence of the Renewable Energy Community project. In the first case the calculation is relatively simple, as it is it is sufficient to multiply the total annual requirement of the users' electricity ($E_{\mathrm{withdrawn}}$), expressed in kWh, for the CO_2 emission factor, linked to the consumption of electricity from the national electricity grid.

Therefore, the following equation is computed for the calculation of carbon dioxide emissions, if it is not present the REC initiative:

$$\in_{CO2}^{0}=\in_{network}\cdot E_{withdrawn}$$

where $\in_{network}$ is the CO_2 emission factor. The $E_{withdrawn}$ considered is 21.785 MWh, that is the Municipalities aggregate electrical energy consumption according to the SECAP.

In the presence of the Renewable Energy Community, it is always necessary to calculate emissions linked to energy consumption from the electricity grid, multiplying the same carbon dioxide emission factor, for the energy actually withdrawn from the grid. The latter is obtained by subtracting the REC self-consumed energy and the Collective REC's consumption from the total REC consumption, e.g., the uncovered demand, both in an instantaneous way or through energy storage systems, within the REC. However, for a more complete analysis, it is necessary also consider the CO_2 emissions linked to the manufacturing of PV modules and batteries (in case of Scenario 2) used as storage systems. Therefore, the scenario 1 and optimal scenario REC's CO_2 emissions can be calculated as:

$$\in_{CO2}^{REC}=\in_{network}\left(E_{withdrawn}-(E_{self-c}+E_{share})\right)+\left(\in_{PV}\cdot E_{prod}\right)$$

While scenario 2 REC's CO_2 emissions are evaluated in this way:

$$\in_{CO2}^{REC}=\in_{network}\left(E_{withdrawn}-(E_{self-c}+E_{shared})\right)+\left(\in_{PV}\cdot E_{prod}+\frac{\in_{BESS}\cdot C_{BESS}}{N}\right)$$

where C_{BESS} is the energy storage capacity (expressed in kWh) and where $\in_{PV}$ and $\in_{BESS}$ are the CO_2 emission factors linked to photovoltaic modules production and electrochemical batteries disposal. N are the storage system's years of life (N=20). Energy quantities refer to the respective annual quantities.

The emission coefficients introduced are expressed in $kgCO_2/kWh$. $\in_{network}$ [43] and $\in_{PV}$ [44] refer respectively to the energy consumed and produced, while $\in_{BESS}$ [43] refers to the storage system size (C_{BESS}). The emission factors considered values can be found in literature [45] (ISPRA). In this study the values considered are shown in Table 47.

Table 47: CO_2 emission factors.

EMISSION FACTOR	**VALUE** [$kgCO_2$/kWh]
$\in_{network}$	0,256
$\in_{PV}$	0,050
$\in_{BESS}$	175

Furthermore, the saved (negative) emissions linked to the electricity production avoided thanks to the introduction of renewable energy into the grid produced locally, which does not go into physical self-consumption, and which does not come shared. These emissions were set equal to 0 because the analysis focuses on local consumption.

In the end, an environmental performance indicator can be calculated, which allows to evaluate the percentage reduction of CO_2 emissions, compared to the case in which the RECs do not exist. In percentage terms the index can be calculated according to the following expression:

$$\Delta CO2_{\%} = \frac{\in_{CO2}^{0} - \in_{CO2}^{CER}}{\in_{CO2}^{0}} \cdot 100$$

The indicator is equal to 0 in the absence of the community initiative and reaches 100% in the ideal case in which all CO_2 emissions are cancelled. Because of emissions linked to the life cycle of the renewable source plant and the storage system, despite reaching 100% self-sufficiency, emissions do not become zero, as can be seen from equation $\in_{CO2}^{REC}$. Table 48 summarizes the avoided CO_2 emissions' results for the different scenarios.

Table 48: Avoided CO_2 emissions' results.

	Value	Unit of measure
$\in_{CO2}^{0}$	5.576.960	$KgCO_2$
$\in_{CO2}^{REC}$ scenario 1	2.183.004	$KgCO_2$
$\in_{CO2}^{REC}$ scenario 2	2.175.104	$KgCO_2$
$\in_{CO2}^{REC}$ scenario opt	82.258	$KgCO_2$
$\Delta CO2_{\%}$ scenario 1	39,14	%
$\Delta CO2_{\%}$ scenario 2	39,00	%
$\Delta CO2_{\%}$ scenario opt	1,5	%

By installing only a few plants as in the optimal configuration the CO2 emissions avoided are a low value while by installing PV plants on all the Municipal buildings the result is significant but to reach this configuration (scenario 1 and 3) as well as the configuration with batteries (scenario 2) a huge initial investment is needed.

6.2 Energy sphere

RECs certainly constitute a driving force for the promotion of energy from renewable sources but also an opportunity to attract economic resources to an area and generate value for the local economy. In fact, PNRR plans to distribute 2.2 billion euros by 2026 to carry out interventions relating to Energy Communities. These funds can be used by the REC to create new plants involving local professionals and businesses and generating direct economic impacts on the territory.

Furthermore, the construction of new plants will increase the energy produced and shared within the CER, generating greater economic benefits for the community itself and its members. Finally, the greater availability of PV systems will make it possible to reduce the energy spending of new prosumers (with particular attention to vulnerable consumers), mitigating the effects of the current energy crisis.

6.3 Social sphere: use of RECs' revenues

The project to establish the REC on this territory has multiple social impacts. In fact, the energy community can become a tool for triggering collective actions starting from themes such as sustainability and common goods to revitalize the local community, mitigate depopulation and promote inclusion. The participation in the RES of different local actors (citizens, businesses, professionals, commercial activities, and local authorities) makes possible to build mutually beneficial relationships between stakeholders who will be able to promote the development of the local economy, train local resources in energy management for the purpose to create job opportunities. In the following Tables a summary of the revenues' distribution hypothesis between Municipalities and REC is evaluated for scenario 1, scenario 3 and the optimal one for both the primary substations.

Table 49: Evaluation of revenues remaining to AC001E01317 REC (scenario 1 and 3).

AC001E01317			
Number of plants	Installed PV power [kW$_p$]	N. of domestic users	N. of EV charging
35	1.189,8	1.458	94
CAPEX			
PV plants construction			1.541.600€
REVENUES			
Total annual revenues (self-consumption, dedicated withdrawal, incentive)			334.362€
OPEX			
Total annual operational costs (maintenance, insurance, and taxes)			44.923€
Hypothesis revenues' distribution between Municipalities and REC			
Revenues to be destinated to Municipalities (investors)			198.737€
Revenues remaining to the REC			144.282€

Table 50: Evaluation of revenues remaining to AC001E01319 REC (scenario 1 and 3).

AC001E01319			
Number of plants	Installed PV power [kW$_p$]	N. of domestic users	N. of EV charging
34	994,2	1.233	84
CAPEX			
PV plants construction			1.377.300€
REVENUES			
Total annual revenues (self-consumption, dedicated withdrawal, incentive)			261.360€
OPEX			
Total annual operational costs (maintenance, insurance, and taxes)			38.429€
Hypothesis revenues' distribution between Municipalities and REC			
Revenues to be destinated to Municipalities (investors)			176.931€
Revenues remaining to the REC			114.093€

Table 51: Evaluation of revenues remaining to AC001E01317 REC (scenario opt).

AC001E01317	
Number of plants	Installed PV power [kW_p]
2	44,2
CAPEX	
PV plants construction	66.300€
REVENUES	
Total annual revenues (self-consumption, dedicated withdrawal, incentive)	11.662€
OPEX	
Total annual operational costs (maintenance, insurance, and taxes)	1.759€
Hypothesis revenues' distribution between Municipalities and REC	
Revenues to be destinated to Municipalities (investors)	9.127€
Revenues remaining to the REC	2.535€

Table 52: Evaluation of revenues remaining to AC001E01319 REC (scenario opt).

AC001E01319	
Number of plants	Installed PV power [kW_p]
2	43
CAPEX	
PV plants construction	63.600€
REVENUES	
Total annual revenues (self-consumption, dedicated withdrawal, incentive)	12.297€
OPEX	
Total annual operational costs (maintenance, insurance, and taxes)	1.702€
Hypothesis revenues' distribution between Municipalities and REC	
Revenues to be destinated to Municipalities (investors)	8.870€
Revenues remaining to the REC	3.517€

It is suggested to use the resources remaining to the REC, net of the resources allocated to the producer to recover of the investment and support operating expenses, and equal to approximately 3.000€ for the optimal configuration and 100.000 for scenario 1 and 3 as follows:

- Recognition of an Energy Bonus to consumers participating in the REC equal to a maximum of 100 EUR. The sum of the Energy Bonuses must not exceed 50% of the value of the revenues remaining to the REC, in the event that the sum of the €100 Energy Bonuses exceeds 50% of the revenues remaining to the REC, the value of the individual bonuses will be reduced based on the ISEE value of the end users' consumers up to reach the overall value of 50%
- The remaining part of the proceeds will feed a fund with which the REC will finance a series of services intended partly for people in conditions of energy poverty and identified by social services of the Municipalities and partly to REC members not in a condition of energy poverty.

Table 53 summarizes the REC's benefits and who can beneficiate.

Table 53: RECs' Benefits and beneficiaries.

SERVICES	BENEFITS	BENEFICIARIES
Provision of digital services: • **purchase of IT media** • **wireless networks**	• Contrast of the digital divide • Social inclusion • Greater work and training opportunities	People and families residing in municipalities in conditions of energy poverty and identified by the Municipality (REC-s members and otherwise)
Provision of energy services: • **purchase more efficient devices/appliances** • **installation of energy monitoring devices** • **implementation of energy efficiency measures on properties** • **construction of PV systems**	• Increase in energy efficiency and reduction in energy expenditure • Improvement of comfort (adequate heating/cooling) and healthiness of homes (reduction of mold and humidity) • Widespread production of clean and renewable energy • Greater awareness of one's energy expenditure and the tools for its containment	People and families residing in municipalities in conditions of energy poverty and identified by the Municipality (REC-s members and others)
Provision of social welfare services: • **Psychological support** • **cultural and social mediation services** • **socio-educational support** • **training courses**	• Greater social and personal autonomy of subjects at risk of marginalization and their families • Equal access to scholastic, social and work environments for foreign people • Management of social conflicts between citizens (condominium conflicts, street conflicts) to promote tolerance, integration and civil life • Re-employment • Greater social inclusion	People and families residing in municipalities in conditions of energy poverty and identified by the Municipality (REC-s members and otherwise)
Agreements with local commercial activities and sponsors	• Support and development of the local economy • Purchase of goods and services at convenient and competitive prices	• REC-s members (citizens, SMEs and PAs) • Local businesses
Creation of purchasing groups (energy, food, essential goods)	• Purchase of goods and services at convenient and competitive prices • Development of a responsible, aware and sustainable local community • Promote sociality and communication between local realities	REC-s members (citizens, SMEs and PAs)
Discounts on municipal services (TARI relief, discounts on public services and bike-sharing)	• Reduction of costs associated with municipal services and contributions	REC-s members (citizens and SMEs)
Energy Manager Consulting	• Greater awareness of one's energy expenditure and the tools for its containment	REC-s Members (citizens, SMEs and PAs)

It is proposed to apply the following formulas to be included in the regulation. The share of REC's revenues to be paid to the private producer (supposing private producer Pay Back time equal to 8 years) are:

$$Share_{private\ producer} = \frac{P_{FV} \cdot UP_{MASE}}{8} + P_{FV} \cdot 20 + (P_{FV} \cdot UP_{MASE}) \cdot 0{,}01$$

The share of REC revenues to be paid to the public producer (supposing public producer Pay Back time equal to 10 years) are:

$$Share_{public\ producer} = \frac{P_{FV} \cdot UP_{MASE}}{10} + P_{FV} \cdot 20 + (P_{FV} \cdot UP_{MASE}) \cdot 0{,}01$$

Where:

- P_{FV} is the nominal PV plant power in kW_p
- UP_{MASE} is the unit price indicated in the MASE Decree [13] that may vary depending on the installed power;
- 20 is the annual labour cost per kW_p installed;

The share of REC revenues to be recognized as an Energy Bonus to the consumer member is:

$$Share_{EB} = \frac{RECR_{tot} \cdot 0{,}50}{N_{cons}}$$

Where:

- $RECR_{tot}$ is the sum of revenues minus the sum of the quotas to be paid to producers
- N_{cons} is the number of consumers participating in the community

In the case of:

- $Share_{EB} > 100$ the value will be reset to 100;
- $Share_{EB} < 100$ a distribution will be proposed based on the ISEE of the members so that the lowest ISSE will be recognized 100 euros while the others will be recognized a value in proportion to their ISEE.

6.4 Economic sustainability: Levelized Cost Of Energy (LCOE)

To determine from a strictly economic point of view whether the Energy Community is a solution more advantageous than simply purchasing from the electricity grid, the total LCOE (Levelized Cost of Energy) has been computed. The LCOE is the price per unit of generated electricity necessary to recover the operating costs of a generation plant within the assumed life cycle (in our case equal to 20 years) [39].

To determine which solution is more economically advantageous between self-consumption and simple purchase from the electricity grid, three LCOE have been carried out:

- $LCOE_{\text{grid}}$ for simple purchase from the electricity grid;
- $LCOE_{\text{self-c}}$ for self-consumption;
- Total $LCOE_{tot}$ which takes into consideration both self-consumption and purchase from the network.

The $LCOE_{\text{grid}}$ is given by the average purchase price $p(t)$ of energy from the electricity grid over the course of the year 2023.

$LCOE_{\text{self-c}}$, is computed with the formula:

$$LCOE_{self-c} = \frac{\sum_{t=1}^{n} \frac{CAPEX_t + O\&M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

- C$APEXt$ is the total expense for the purchase and installation of systems on an annual basis;
- $O\&Mt$ is total expenditure for the plants' management and maintenance on an annual basis;
- r is the discount rate, equal to 5%;
- Et is the total energy produced during the year.

The $LCOE_{\text{grid}}$ is much lower than $LCOE_{\text{self-c}}$, this indicates that producing and consuming energy renewable is cheaper than simply purchasing. In the formula above, only the energy produced is considered (given by the discharge of the battery and the system photovoltaic). To determine the total price, therefore also considering the purchased power $P\ buy$ we need to calculate the $LCOE_{tot}$.

The $LCOE_{tot}$ takes into consideration both the production of energy and the purchase from the electricity grid via coefficients c_1 and c_2. It is calculated with the following equation:

$$LCOE_{tot} = c_1 \cdot LCOE_{grid} + c_2 \cdot LCOE_{self-c}$$

Where:

- c_1 = is given by the ratio between the total power produced and the total consumption Lc
- c_2 = is given by the ratio between the uncovered loads $Lc\ miss$ total and total consumption Lc

$LCOE_{tot}$ is higher than $LCOE_{\text{grid}}$. Consequently, the Energy Community self-consumption configuration is more convenient compared to the simple purchase with a supply contract.

CONCLUSIONS

The case study examined is in the area called *Dora 5 Laghi* and consists of the Municipalities of Borgofranco d'Ivrea, Quassolo and Quincinetto for the REC underlying AC001E1319 primary substation and the Municipalities of Montalto Dora, Chiaverano and Lessolo for the REC underlying AC001E01317 primary substation. Photovoltaic systems have been sized, with different levels of installed capacity, and their producibility was calculated by the software QGIS and PVGIS tool. The integration of electrical consumptions with PV production has let the evaluation of self-consumed energy at the individual buildings' level of and the quantification of the shared energy at the Renewable Energy Community level. The contribution of the Renewable Energy Community brings an advantage in terms of self-consumption and of satisfied needs especially for the optimized scenario in which photovoltaic is installed only on a few buildings. In fact, it emerged that lower levels of PV allow the achievement of percentages of higher self-consumption.

Furthermore, the potential of storage batteries for some individual buildings was considered to further encourage community self-consumption and self-sufficiency. Simulations show that the increase in SCI and SSI grows with the increasing of the battery size. The best-case scenario is with 200 kWh of batteries, where they can reach self-consumption levels close to 100%. It also emerged that the batteries' optimal installed capacity ranges from 20 to 50 kWh on a few single buildings.

The addition of photovoltaic brings an additional gain or saving that is more convenient if the installed power is not too high. The Renewable Energy Community increases the economic benefit of photovoltaics, thanks to the higher remuneration of energy shared. A target of 80% of shared energy in the community was considered due to the main RECs purpose of sharing energy and not selling it. This benefit can be divided differently, depending on the model of business adopted, considering that all the six Municipalities can have access to the PNRR contribution for 40% of the CAPEX non repayable fund. Electric storage brings greater savings for single users, but it is not economically advantageous for those who support the investment. In fact, in a REC promoted by Public Administrations the energy benefit does not justify the high economic expense for batteries.

A Cost-Optimal analysis compares different intervention scenarios to identify the one that can ensure the more economic benefits coupled with the energy parameter which is the Self-Sufficiency index. The results obtained in this work can provide technical support to policy makers and the applied methodology can be replicated and adapted to other context and case studies.

The benefits of Renewable Energy Communities are manifold. Firstly, they promote energy democracy by enabling citizens to actively engage in the energy transition and have a say in energy-related matters. Additionally, RECs can enhance energy security by diversifying energy sources and reducing reliance on centralized grids. Moreover, the establishment of RECs can boost the local economy, create jobs, and support community development.

The integration of renewable sources for the supply of electricity to residential buildings is one of the main objectives of policies aimed at decarbonising the energetic system. To this end, some general trends such as decentralization are found in energy production and in the electrification of consumptions. In the building sector, these trends are represented by a significant penetration of municipal and domestic photovoltaic systems into the electric energy production national mix. Energy Communities are a tool recently introduced to increase the share of electricity produced and self-consumed locally at the level of single building with multiple residential units, at the level of a municipality or urban district. In this study, some models are integrated in order to analyse a set of municipal and residential buildings, to verify the advantage of the presence of a REC from an energy, environmental and economic point of view. In fact, the presence of a REC allows that the energy produced by some PV plants is consumed by other buildings and enables the aggregation of electrical loads with different profiles, in such a way as to maximize the community's self-consumption.

This work concludes with a look into the future prospects of Renewable Energy Communities. As governments and societies increasingly prioritize sustainability, RECs are expected to play a crucial role in scaling up renewable energy deployment and fostering a more inclusive, resilient, and green energy landscape. Renewable Energy Communities present a promising model for accelerating the adoption of renewable energy sources and achieving sustainable energy goals at local level. By empowering communities to actively participate in the energy transition, RECs have the potential to drive positive change and contribute significantly to a cleaner and more sustainable future. By 2030, distributed generation will involve at least two-thirds of the population of European Union. In Northern Europe (such as Denmark, the Netherlands, and Germany) the configurations of self-consumption are already a reality. In Italy Energy Communities are slowly taking shape. There are already cases scattered throughout Italy, but it remains clear that politics and the economy are now pointing towards transition. Energy Communities present enormous growth potential internationally, and this allows to test countless solutions that allow greater competitiveness on the market electricity and above all innovation in the technological sector.

Future implementations on the study done could include the integration of intelligent control systems and energy retrofit of buildings scenarios. Renewable energy communities represent a promising model for the future of sustainable energy. They embody the principles of collaboration, self-reliance, and environmental stewardship. By enabling individuals and communities to take control of their energy consumption and production, renewable energy communities are leading the way toward a cleaner, more resilient, and inclusive energy future.

Bibliography

[1] "The 17 goals," United Nations, Department of Economic and Social Affairs, 2015. [Online]. Available: https://sdgs.un.org/goals. [Accessed October 2023].

[2] E. U. law, "Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources," 11 December 2018. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32018L2001. [Accessed October 2023].

[3] E. Commission, "Clean energy for all Europeans package," [Online]. Available: https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en. [Accessed October 2023].

[4] "Renewable Energy Directive," European Commission, 2019. [Online]. Available: https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en. [Accessed October 2023].

[5] "Official Journal of the European Union Directives," 5th June 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0944. [Accessed October 2023].

[6] "REPoweEU," European Commission, May 2022. [Online]. Available: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_it#investire-nelle-energie-rinnovabili. [Accessed October 2023].

[7] M. Krug, M. Di Nucci, M. Caldera e E. De Luca, «Mainstreaming Community Energy: Is the Renewable Energy Directive a Driver for Renewable Energy Communities in Germany and Italy?,» *Sustainability,* vol. 7181, p. 14, 2022.

[8] E. U. Law, "Directive (EU) 2019/944 on common rules for the internal market for electricity," 2019. [Online]. Available: https://eur-lex.europa.eu/legal-content/EN/LSU/?uri=CELEX%3A32019L0944. [Accessed October 2023].

[9] Terna, "HOW THE ELECTRICITY SYSTEM WORKS," [Online]. Available: https://www.terna.it/en/electric-system/terna-role/how-electricity-system-works. [Accessed October 2023].

[10] D. d. finanze, "Decreto-legge del 30/12/2019 n. 162 - articolo 42bis modificato da legge del 28/02/2020 n. 8 Allegato," 28 Febbraio 2020. [Online]. Available: https://def.finanze.it/DocTribFrontend/getArticoloDetailFromResultList.do?id={A2557794-4998-45AB-BF7F-AE6003C9DDE1}&codiceOrdinamento=200004200000200&idAttoNormativo={74782FF5-8835-4235-BFE0-F8D4DA1A7AB4}. [Accessed October 2023].

[11] GSE, "COMUNITÀ ENERGETICHE E GRUPPI DI AUTOCONSUMATORI," [Online]. Available: https://www.gse.it/servizi-per-te/autoconsumo/gruppi-di-autoconsumatori-e-comunita-di-energia-rinnovabile. [Accessed October 2023].

[12] "DECRETO LEGISLATIVO 8 novembre 2021, n. 199: Attuazione della direttiva (UE) 2018/2001 del Parlamento europeo e del Consiglio, dell'11 dicembre 2018, sulla promozione dell'uso dell'energia da fonti rinnovabili," 8 November 2021. [Online]. Available: https://www.gse.it/normativa_site/GSE%20Documenti%20normativa/ITALIA_DLGS_n199__08_11_2021.pdf. [Accessed October 2023].

[13] M. d. e. d. s. energetica, "Consultazione pubblica: Attuazione della disciplina per la regolamentazione degli incentivi per la condivisione dell'energia di cui all'articolo 8 del decreto legislativo 8 novembre 2021, n.199," 28 November 2022. [Online]. Available: https://www.mase.gov.it/bandi/consultazione-pubblica-attuazione-della-disciplina-la-regolamentazione-degli-incentivi-la. [Accessed October 2023].

[14] ARERA, "TESTO INTEGRATO AUTOCONSUMO DIFFUSO – TIAD," Dicembre 2022. [Online]. Available: https://www.arera.it/it/com_stampa/23/230104.htm. [Accessed Ottobre 2023].

[15] M. d. e. d. s. energetica, «Bozza MASE,» February 2023. [Online]. [Consultato il giorno October 2023].

[16] GSE, "MAPPA INTERATTIVA DELLE CABINE PRIMARIE," Settembre 2023. [Online]. Available: https://www.gse.it/servizi-per-te/autoconsumo/mappa-interattiva-delle-cabine-primarie. [Accessed October 2023].

[17] D. d. finanze, "Decreto legislativo 3 luglio 2017, n. 117," Luglio 2017. [Online]. Available: https://www.bosettiegatti.eu/info/norme/statali/2017_0117_terzo%20settore.htm. [Accessed October 2023].

[18] "Decreto Ministeriale - Individuazione della tariffaincentivante per la remunerazione degli impianti a fonti rinnovabili inseriti nelle configurazioni sperimentali di autoconsumo collettivo e comunità energetiche rinnovabili," 16 Settembre 2020. [Online]. Available: https://www.mimit.gov.it/it/normativa/decreti-ministeriali/decreto-ministeriale-16-settembre-2020-individuazione-della-tariffa-incentivante-per-la-remunerazione-degli-impianti-a-fonti-rinnovabili-inseriti-nelle-configurazioni-sperimentali-di-autoconsumo-c. [Accessed October 2023].

[19] GSE, «Ritiro dedicato,» [Online]. Available: https://www.gse.it/servizi-per-te/fotovoltaico/ritiro-dedicato. [Consultato il giorno October 2023].

[20] "Scambio sul posto," GSE, [Online]. Available: https://www.gse.it/servizi-per-te/fotovoltaico/scambio-sul-posto. [Accessed October 2023].

[21] R. De Lotto, C. Micciché, E. Venco, A. Bonaiti and R. De Napoli, "Energy Communities: Technical, Legislative, Organizational, and Planning Features," *Energies,* vol. 1731, p. 15, 2022.

[22] P. Borowski, "Zonal and nodal models of energy market in European union.," *Energies,* vol. 4182, p. 13, 2020.

[23] E. Espe, V. Potdar and E. Chang, "Prosumer communities and relationships in smart grids: A literature review, evolution and future," *Energies,* vol. 2528, p. 11, 2018.

[24] R. Piemonte, "Il Programma Regionale FESR Piemonte 2021-2027," [Online]. Available: https://www.regione.piemonte.it/web/temi/fondi-progetti-europei/fondo-europeo-sviluppo-regionale-fesr/programma-regionale-fesr-2021-2027/programma-regionale-fesr-piemonte-2021-2027. [Accessed October 2023].

[25] “Piano Nazionale di Ripresa e Resilienza (PNRR),” 2021. [Online].

[26] H. J. e S. M., «The solar radiation model for Open source GIS: implementation and applications. International GRASS users conference in Trento, Italy,,» Trento, 2022.

[27] S. M., H. T.M., D. E.D. and O. H.A., “Potential of solar electricity generation in the European Union member states and candidate countries,” *Solar Energy ,* vol. 81, pp. 1295-1305, 2007.

[28] “Geoportale Piemonte,” 2023. [Online]. Available: (https://www.geoportale.piemonte.it/visregpigo/?action-type=dwl&url=https://geomap.reteunitaria.piemonte.it/ws/taims/rp01/taimsscaricogp/wms_scaricogp?service=WMS&version=1.3&request=getCapabilities&title=Scarico%20-. [Accessed October 2023].

[29] “ATLAIMPIANTI,” [Online]. Available: https://www.gse.it/dati-e-scenari/atlaimpianti. [Accessed OCTOBER 2023].

[30] C. europea, “Joint research centre,” EU science hub, [Online]. Available: https://joint-research-centre.ec.europa.eu/index_en. [Accessed 27 Ocotber 2023].

[31] J. r. c. (. b. E. Commission, “PVGIS Tool,” [Online]. Available: https://re.jrc.ec.europa.eu/pvg_tools/en/. [Accessed 27th October 2023].

[32] “Global Solar Atlas,” Energydata.info, [Online]. Available: https://globalsolaratlas.info/map?c=45.52439,7.833939,11. [Accessed October 2023].

[33] GSE, “GRUPPI DI AUTOCONSUMATORI DI ENERGIA RINNOVABILE CHE AGISCONO COLLETTIVAMENTE E COMUNITÀ DI ENERGIA RINNOVABILE,” 4th April 2022. [Online]. [Accessed October 2023].

[34] G. Chicco, “Slide Smart electricity systems,” 2023.

[35] IEA-PVPS, “T1-28,” 2023. [Online]. [Accessed October 2023].

[36] e-distribuzione, “Le Comunità Energetiche,” February 2023. [Online]. Available: https://www.e-distribuzione.it/a-chi-ci-rivolgiamo/casa-e-piccole-imprese/comunita-energetiche.html. [Accessed October 2023].

[37] V. S. I., B. P. N. and B. A. G., “Market-based TSO-DSO coordination for enhanced flexibility services provision,” *Electric Power Systems Research,* vol. 208, no. 107883, 2022.

[38] GSE, “Sistemi di accumulo,” [Online]. Available: https://www.gse.it/documenti_site/Documenti%20GSE/Servizi%20per%20te/SISTEMI%20DI%20ACCUMULO/regole%20e%20procedure/REGOLE%20TECNICHE%20SISTEMI%20ACCUMULO.pdf. [Accessed October 2023].

[39] T. V, M. P., M. G., L. A. and S. M., “Towards Energy Self-consumption and Self-sufficiency in Urban Energy Communities,” *IIETA,* pp. 1-11, 2020.

[40] GSE, “Prezzi medi mensili per fascia oraria e zona di mercato,” 23rd October 2023. [Online]. Available: https://www.gse.it/servizi-per-te/fotovoltaico/ritiro-dedicato/documenti. [Accessed November 2023].

[41] RSE, «DOSSIER: CER e Autoconsumo collettivo: alcune simulazioni numeriche alla luce della nuova regolazione,» [Online]. Available: https://dossierse.it/19-2023-cer-e-autoconsumo-collettivo-alcune-simulazioni-numeriche-alla-luce-della-nuova-regolazione/. [Consultato il giorno October 2023].

[42] A. entrate, "Imposta sui redditi delle società - Ires - Che cos'è," [Online]. Available: https://www.agenziaentrate.gov.it/portale/imposta-sui-redditi-societa-ires/infogen-imposta-sui-redditi. [Accessed 26 October 2023].

[43] M. d. e. d. finanze, "Imposta Regionale IRAP: aliquote applicabili," [Online]. Available: https://www1.finanze.gov.it/finanze2/dipartimentopolitichefiscali/fiscalitalocale/aliquoteirap/dettaglio_irap.php?id=1225&reg=13&year=2023. [Accessed 26 October 2023].

[44] M. G., S. S. and B. S., "Indicators and Representation Tools to Measure the Techical-Economic Feasibility of a Renewable Energy Community. The case study of Villar Pellice (Italy)," *International journal of Sustainable Development and Planning,* vol. 16, no. 1, pp. 1-11, 2021.

[45] E. Parliament, "EPBD Recast: Directive 2010/31/EU of the European Parliament and of Council of 19 May 2010 on the energy performance of buildings," May 2010. [Online]. Available: https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF. [Accessed October 2023].

[46] M. d. i. e. d. m. i. Italy, "Piano Nazionale integrato per l'energia e il clima," [Online]. Available: https://www.mimit.gov.it/it/notizie-stampa/pniec2030. [Accessed 27th October 2023].

[47] C. A., M. P., L. P., M. I. and R. M., "Renewable Energy Communities business models under the 2020 Italian regulation," *Journal of Cleaner Production,* vol. 316, no. 128217, pp. 53-60, 2021.

[48] J. o. I. Ecology, "Life cycle greenhouse gas emissions from solar," 2012. [Online]. [Accessed October 2023].

[49] ISPRA, " Rapporto ISPRA 2020 – Fattori di emissione atmosferica di gas effetto serra nel settore elettrico nazionale e nei principali Paesi Europei," 2020. [Online]. Available: https://www.isprambiente.gov.it/files2020/pubblicazioni/rapporti/Rapporto317_2020.pdf. [Accessed October 2023].

[50] Wikipedia, "Levelized Cost of Energy," [Online]. Available: https://en.wikipedia.org/wiki/Levelized_cost_of_electricity. [Accessed October 2023].

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