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Energy Community on the Island of Ischia

Advantages of establishing a renewable energy community to maximize shared energy and promote energy savings

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Abstract

This thesis explores the establishment of a Renewable Energy Community (REC) on the island of Ischia, focusing on the environmental, economic and social benefits of shared renewable energy use among local members. The project aligns with the European Union's efforts to reduce greenhouse gas emissions and promote a sustainable energy transition by actively involving citizens, businesses and institutions in the production and consumption of renewable energy generated locally.

The Italian regulatory framework supporting renewable energy communities was analyzed, with particular focus on key legislation, including the transposition of the European RED II Directive. Recent regulations provide incentives and operational guidelines for self-consumption, facilitating the financial sustainability of communities. The technical planning for Ischia's renewable community includes the project of new photovoltaic systems, optimised to balance energy production with the demand of each community member.

The study includes a detailed analysis of the energy consumption patterns of various community users, such as a school, a supermarket, a bus station, a hotel, residential households and electric vehicle charging stations. Energy data for each member was carefully collected and analyzed, enabling an in-depth understanding of individual and collective energy needs throughout different hours of the day and periods of the year. To highlight opportunities for optimizing self consumption, each member consumption has been categorized according to main time bands: peak hours (F1), intermediate hours (F2) and off-peak hours (F3).

Additionally, an economic analysis was conducted to evaluate the financial incentives available to the community and to estimate the return on investment for the REC community. This section considers government incentives, such as subsidies for shared energy use, which improve the economic appeal of the REC. The analysis also includes an estimate of the community's investment payback period, supporting the project's financial sustainability.

This thesis illustrates how RECs contribute to European renewable energy goals by promoting decentralised energy systems. The results emphasize the potential of RECs to reduce dependence on large energy providers and centralised systems, lower costs and foster resilience and sustainability, offering a replicable model for other communities aiming to adopt renewable energy and to achieve a greater reliance on the energy self-sufficiency.

Abstract (Italian version)

Questa tesi esamina la costituzione di una Comunità Energetica Rinnovabile (CER) sull'isola di Ischia concentrandosi sui benefici ambientali, economici e sociali dell'uso condiviso di energia rinnovabile tra i diversi membri locali. Il progetto è in linea con gli sforzi dell'Unione Europea per ridurre le emissioni di gas serra e promuovere una transizione energetica sostenibile, coinvolgendo attivamente cittadini, imprese e istituzioni nella produzione e nel consumo di energia rinnovabile generata localmente.

È stato analizzato il quadro normativo italiano a supporto delle CER, con un focus sulla legislazione chiave, inclusa la trasposizione della Direttiva Europea RED II. Le normative recenti offrono incentivi e linee guida operative per l'autoconsumo, facilitando la sostenibilità finanziaria delle CER. La pianificazione tecnica della CER di Ischia include la progettazione e l'installazione strategica di sistemi fotovoltaici (PV), ottimizzati per bilanciare la produzione di energia con la domanda di ciascun membro della comunità.

Lo studio include un'analisi dettagliata dei modelli di consumo energetico dei vari utenti della comunità, come una scuola, un supermercato, una stazione degli autobus, un hotel, famiglie residenziali e colonnine di ricarica elettrica per autoveicoli. I dati energetici di ciascun membro sono stati attentamente raccolti e analizzati, consentendo una comprensione approfondita delle esigenze energetiche individuali e collettive durante le diverse ore del giorno e i vari periodi dell'anno. Per evidenziare le opportunità di ottimizzazione dell'autoconsumo, i consumi sono categorizzati secondo fasce orarie principali: fascia di picco (F1), fascia intermedia (F2) e fascia fuori picco (F3).

Inoltre, è stata condotta un'analisi economica per valutare gli incentivi finanziari disponibili per la comunità e per proiettare il ritorno sugli investimenti della CER. Questa sezione considera incentivi governativi, come le sovvenzioni per la generazione di energia rinnovabile e l'uso condiviso dell'energia, che aumentano l'attrattiva economica della CER. L'analisi include anche una stima del periodo di recupero dell'investimento della comunità, a supporto della sostenibilità finanziaria del progetto.

Questa tesi illustra come CER come quella di Ischia contribuiscano agli obiettivi europei per le energie rinnovabili promuovendo sistemi energetici decentralizzati e orientati verso l'idea di comunità. I risultati enfatizzano il potenziale delle CER per ridurre la dipendenza dai grandi fornitori di energia e da sistemi di produzione centralizzata, abbassare i costi e promuovere la resilienza e la sostenibilità, offrendo un modello replicabile per altre comunità che mirano a adottare l'energia rinnovabile e raggiungere una maggiore autosufficienza.

List of Abbreviations

Throughout the thesis, several abbreviations are used to facilitate reading. The following is a list of abbreviations along with their meanings:

REC - Renewable Energy Community. It refers to a group of local producers and consumers sharing renewable energy produced and consumed within the community.

GSE - Energy Services Manager. Italian entity responsible to promote and support renewable energy sources in Italy.

PNRR - National Recovery and Resilience Plan. A European program that funds projects, including energy ones, to promote economic recovery post pandemic.

PV - Photovoltaic. Technology that converts sunlight directly into electricity using photovoltaic cells.

RES - Renewable Energy Source. It refers to all the renewable sources available to produce renewable energy.

CER - Comunità Energetica Rinnovabile (Italian abbreviation). Equivalent to REC, it refers to communities that manage and share renewable energy resources.

ARERA - Autorità di regolazione per energia reti e ambiente. Italian authority that regulates the energy, network, and environmental markets.

NPV - Net Present Value. A measure of investment profitability, calculated as the difference between the present value of cash inflows and outflows.

TIAD - Testo Integrato Autoconsumo Diffuso. It refers to regulations surrounding self-consumption in energy communities in Italy.

DSO - Distribution System Operator. The company responsible for operating the distribution network that delivers electricity from the transmission system to the consumer.

IEA - International Energy Agency. An organization which provides insights, data and solutions to ensure a sustainable energy.

POD - Point of Delivery. The identification code of each smart meter.

DHW - Domestic Hot Water. The water supplied for residential use.

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Introduction of Renewable Energy Communities (RECs) in Europe and Italy

In the past few decades, the growing awareness about climate change has highlighted the need to reduce greenhouse gas emissions and reliance on fossil fuels have driven the European Union to promote an energy transition based on renewable sources. In this context, Renewable Energy Communities (RECs) have emerged as a fundamental tool to "democratize" energy, involving citizens, businesses and local authorities in the production and consumption of renewable energy. Energy communities offer broad value propositions by contributing to the local energy supply and improving sustainability through prioritization of renewable energy sources. RECs promote energy self-consumption and foster decentralised energy technologies, as opposed to traditional and large-scale energy installations. Moreover, RECs reduce dependency on national energy policies and centralized energy providers, improving independence in energy management. RECs also encourage the active citizen participation, allowing communities to shape their energy futures and aligning energy practices with local needs. Through these contributions, energy communities are vital in building a sustainable, resilient and citizen focused energy landscape across Europe [1].

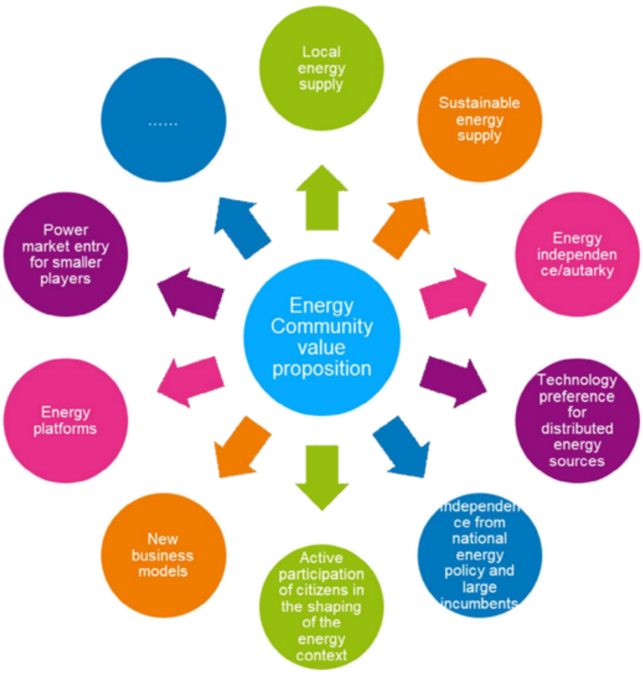

Figure 1: The value proposition of energy communities [2]

The European and Italian regulatory framework

At the European level, the first significant regulations on renewable energy and citizen participation date back to the early 2000s. The 2009/28/EC Directive, known as the Renewable Energy Directive (RED), laid the foundations for a common regulatory framework for renewable energy by establishing binding targets for member states. The legislative framework began to recognise the importance of distributed energy generation and active citizen involvement.

However, the real turning point came with the publication of the Clean Energy Package, a set of measures approved in 2018. These measures introduced significant innovations in the regulation of energy communities. In particular, the 2018/2001/EU Directive, known as RED II (Renewable Energy Directive II), introduced the concept of Renewable Energy Communities, defining key aspects and promoting their development to empower citizens as active participants in the energy system.

This directive set ambitious targets, requiring member states to raise the share of renewable energy to 32% by 2030. At the same time, it promoted the creation of a legal framework to facilitate the establishment of RECs, supporting local production and consumption of renewable energy from sources such as solar, wind and biomass. The aim of introducing RECs is to decentralise energy production and reduce dependence on large energy providers, while also promoting energy self-sufficiency among community members.

In Italy, the transposition of European legislation occurred in several phases. The Legislative Decree 102/2014, which transposed the 2012/27/EU Directive on energy efficiency, began outlining the initial guidelines for promoting renewable energy use. However, it was with the transposition of RED II through Legislative Decree 199/2021 that CERs, the Italian abbreviation for RECs which stands for "Comunità Energetica Rinnovabile", gained full regulatory legitimacy. This decree provided a clear regulatory framework for the establishment and development of RECs across the country.

One of the key measures promoting the expansion of RECs in Italy has been the introduction of targeted financial incentives for the self-consumed energy within the community. With the support of European and Italian legislation, GSE (Gestore dei Servizi Energetici) launched an incentive programme to promote the sharing of energy produced within local communities [3].

Another important instrument at the national level is the National Integrated Energy and Climate Plan (PNIEC), which is part of the Italy's strategy to meet the 2030 targets outlined in the "Agenda for Sustainable Development" [4]. The PNIEC actively promotes REC participation as a key element of the energy transition, focusing on energy efficiency and distributed renewable energy production.

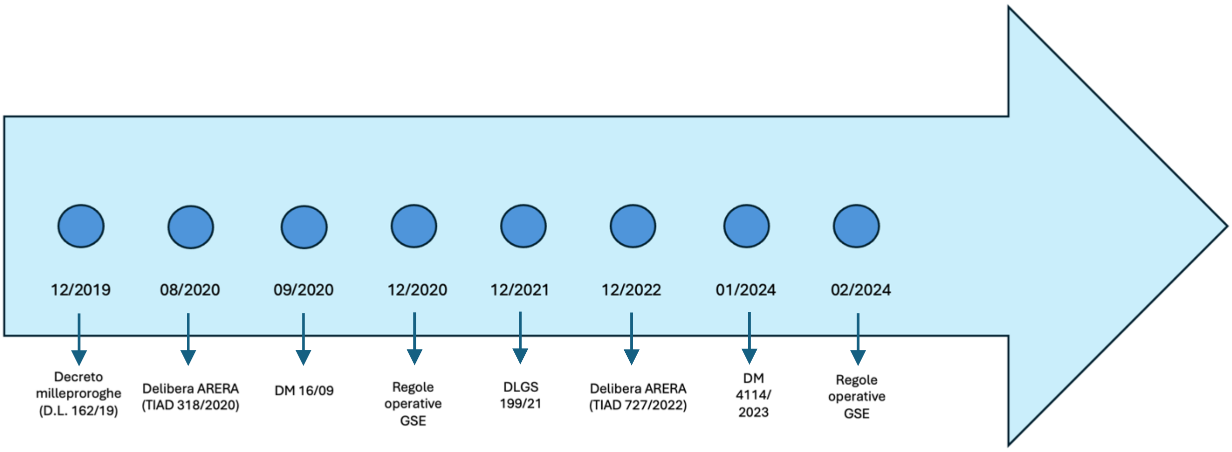

Figure 2: Timeline of the regulatory framework in Italy

The process of publishing regulations for the final framework with the aim to implement European legislation in Italy (Figure 2), is described in the following timeline:

1) 2019, D.L. 'Decreto Milleproroghe' (Article 42 bis). Italy introduced an early version of the European RED II Directive, which formally recognized energy communities and collective self consumption groups. This initial law laid the foundation for REC development, setting up the legal framework for community-based energy initiatives.

2) August 2020, Delibera ARERA 318/2020. The Italian Regulatory Authority for Energy, Networks and Environment (ARERA) established the guidelines for the economic management of shared energy. This decision gave a practical step toward implementing shared energy models with financial procedures for RECs.

3) September 2020, DM 16/09. This decree introduced specific incentive tariffs for renewable energy sources plants in self-consumption configurations. Incentives were designed to make REC participation more attractive by offering financial benefits directly to communities.

4) December 2020, GSE Technical Rules. The Gestore dei Servizi Energetici (GSE), published technical requirements for accessing the shared energy incentive service, offering clear guidelines for REC participants to benefit from shared energy schemes [5].

5) December 2021, Legislative Decree 199/21. This final transposition of Directive 2018/2001 brought full alignment with the European RED II, solidifying the regulatory structure supporting RECs and self-consumption initiatives in Italy.

6) December 2022, Delibera ARERA (TIAD 727/2022). This updated regulation replaced the previous one, 2020 Delibera ARERA and introduced the so called "Testo Integrato di Autoconsumo Diffuso" (TIAD). This regulation streamlined the self consumption evaluation processes in line with Decree 199/21 improving the efficiency and accessibility of REC operations [6].

7) January 2024, DM 414/2023. This decree set updated incentive tariffs for renewable energy systems involved in diffuse self-consumption and established criteria for accessing funding from Italy's National Recovery and Resilience Plan (PNRR), particularly benefiting smaller municipalities with populations under 5000 inhabitants.

8) February 2024, Decree CACER and TIAD. GSE introduced further operational rules for REC participation and PNRR funding. This regulation clarified access to diffuse self-consumption services, providing a well-defined pathway for new energy community configurations [7].

9) April 2024, GSE Online Portal Launch. GSE opened a window of opportunity allowing REC participants to register for diffuse self consumption configurations. This portal simplified the registration process and gave support for establishing energy communities, making RECs implementation more accessible for everybody [8].

The role of Renewable Energy Communities in the global energy transition

At the global level, renewable energy communities are increasingly recognised as essential drivers of the energy transition. According to the International Energy Agency (IEA), community-based renewable energy projects offer numerous benefits, such as reducing grid congestion, improving energy efficiency and promoting socio-economic growth. These communities enable citizens to participate in energy production and consumption, increasing local energy exchange and reducing costs.

For instance, projects in countries like Italy, supported by the National Recovery and Resilience Plan as well as others globally, demonstrate that local generation and consumption of renewable energy can reduce the strain on power grid distribution. Moreover, it can lower carbon emissions when the energy is produced from renewable energy sources (RES).

The regulatory framework governing RECs at both European and national levels is continuously expanding, highlighting the growing awareness of renewable energy's importance and the role of active citizen participation in the energy transition process. As previously discussed, RECs not only offer an opportunity to reduce environmental impact but also provide a model for more stable and decentralised energy governance.

The Projection of Solar Photovoltaic to 2028

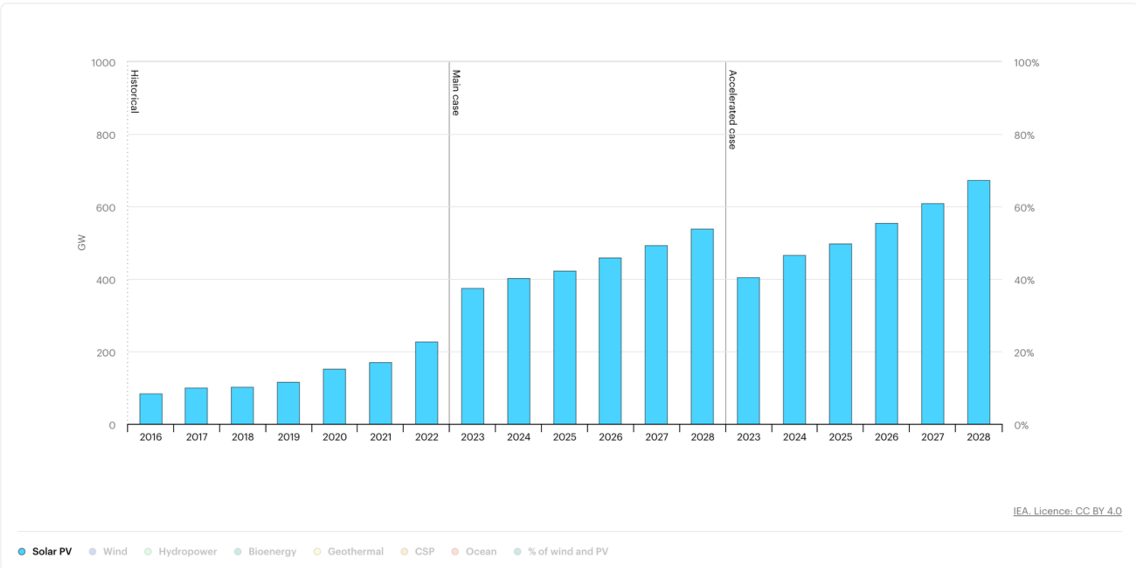

Figure 3: RES electricity capacity scenarios by technology and segment 2016-2028

The projection of the energy production to 2028 highlights the rapid growth in renewable energy capacity, driven primarily by solar PV, which has seen substantial expansion since 2020 due to its falling costs and scalable market. In a steady growth scenario, solar PV continues to dominate the renewable landscape. In an accelerated pathway, with stronger policies and technological advances, solar PV's role intensifies further, becoming as the cornerstone of the energy transition needed to meet ambitious climate targets by 2028 [9].

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The requirements to establish a Renewable Energy Community

Using precise terminology, a Renewable Energy Community is a legal entity empowered to produce, consume, store and share renewable energy among its members, based on open and voluntary participation. The community operates autonomously and is controlled by members who are in proximity to renewable energy plants. Members of the community include citizens, territorial authorities and local authorities, such as municipal governments, cooperatives, research institutions, religious organizations and third-sector entities.

There are specific requirements for renewable energy plants to qualify for incentives under the CACER decree:

1. They must belong to the ERC, a self consumption Group or a emote self consumption configuration.
2. They must be connected to the same primary substation [15].
3. They must have a maximum installed capacity of 1 MW.
4. Developers must realize the power plants through new construction or upgrades of existing facilities.
5. They must comply with the requirements of the DNSH (Do No Significant Harm) principle.
6. Photovoltaic plants must be built exclusively with newly constructed components, while for non-photovoltaic plants, the use of regenerated components is permitted.
7. Biogas or biomass plants must comply with criteria defined in the GSE Rules.
8. Production plants must be connected under the same primary substation as the configuration they belong to.
9. For plants with a capacity exceeding 1 MW, only contributions for the valorizations of self consumed electricity will be recognised.

The steps of establishing a Renewable energy community

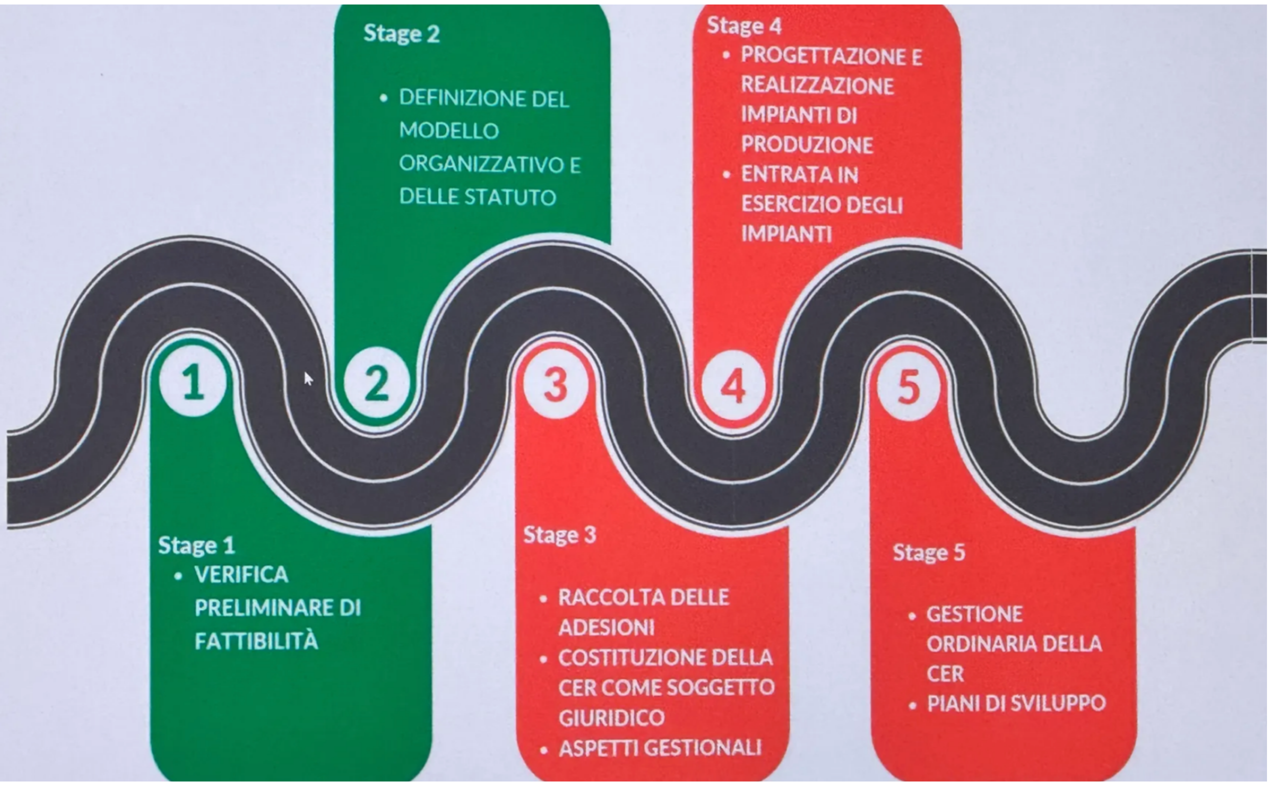


Figure 4: The five steps of establishing a REC, taken from Giacomo Loscalzo's presentation for a professional course provided by the "Albo degli Ingegneri di Torino" on the 15th of October 2024.

The process of establishing a REC follows a structured five stage approach. The first step involves a preliminary feasibility study, where technical, regulatory and economic conditions are assessed to determine the viability of the project. During this phase, it is essential to identify potential energy sources, financial support mechanisms and opportunities that could facilitate the implementation of the REC.

Once the feasibility study is completed, the next step focuses on selecting the organisational model and drafting the statute. At this stage, the legal and governance structure of the REC is defined, including the selection of the most suitable organisational identity, such as a cooperative, association or another legal entity.

Following this, attention shifts to the enrolment of members and the legal establishment of the REC. During this stage, interested citizens, businesses and institutions join the community. The REC is then registered as a legal entity and its operational structure is defined to ensure that all members clearly understand their roles and responsibilities.

With the legal framework in place, the next stage involves the design and implementation of the energy production system. This includes the development, installation and commissioning of renewable energy infrastructure, such as solar panels, wind turbines or other sustainable energy solutions. Moreover, the team must finalise grid connections and obtain regulatory approvals to comply with national energy policies.

Finally, once the energy systems are fully operational, the last step is the management and future development of the REC. This phase ensures the long-term sustainability of the community by planning for future expansions, such as increasing energy production capacity if required, optimising self consumption and enhancing energy sharing mechanisms.

Legal and regulatory insights for Renewable energy communities in Italy

Like other countries such as Germany, the UK and the US, Italy has introduced a regulatory framework based on European Union directives (RED II). This framework has been used to evaluate the community's economy, assess its applicability and outline the requirements for establishing a REC. However, the current regulatory framework presents several barriers that obstruct the establishment and expansion of RECs.
A significant challenge is the complex authorisation process, which makes it difficult to set up a REC. Establishing a community involves creating a legal entity, such as a cooperative or a non-recognized association and officially registering it with the Chamber of Commerce. This process requires drafting a memorandum of association and writing a full statute. Then, the REC must be registered on the GSE portal to initiate its initial configuration.

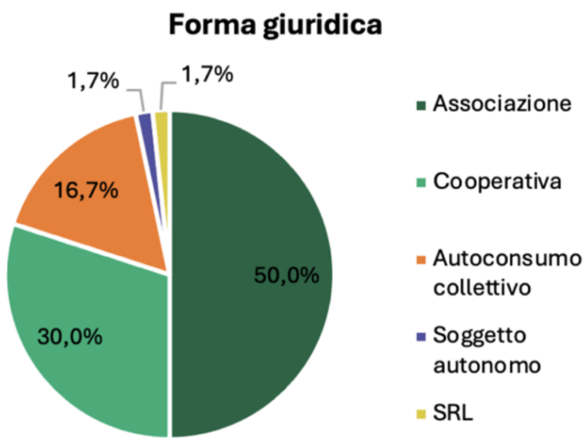


Figure 5: Distribution of the legal form of the community establishment [10]

In details, the renewable energy communities in Italy are structured under diverse legal frameworks, with associations and cooperatives as the most widely adopted models. These structures enable communities to collectively manage and optimise their energy consumption while benefiting from shared resources. Complex authorizations process still obstruct the implementation of RECs, requiring multiple levels of approval from national to local authorities.

There are 168 active configurations for energy communities and collective self-consumption, nearly double (+89%) compared to 2023 [10]. The most active regions are Piemonte, Lazio, Sicily and Lombardy, accounting for 48% of the total, counting for 80 initiatives.

Despite growing interest in Renewable Energy Communities, their overall impact remains limited. Most initiatives operate with simplified legal structures, with 50% registered as associations and rely on small-scale energy systems for their operation.

The need for standardization in grid connection procedures further complicates the expansion of these communities, as different regional policies and Distribution System Operators create inconsistencies in the regulatory landscape. Moreover, tax policies related to self consumed energy in RECs remain inconsistent, creating uncertainty for participants. Similarly, electricity billing models require further harmonization with national energy regulations to ensure a coherent and predictable framework for community energy projects.

To overcome legal barriers, RECs must focus on simplifying the regulatory process and improving cooperation with DSOs. Creating clear and standardized grid access rules is essential to facilitate energy sharing and distribution, ensuring a more efficient and streamlined integration of RECs into the national energy framework.

The role of Municipalities in RECs

Municipalities play a key role in the governance, development and long term sustainability of RECs. They facilitate implementation and provide regulatory support to accelerate the process.

Firstly, municipalities act as intermediaries between national policies and local implementation, incentivizing REC formation through tax reductions, fast-tracked approvals, grants and subsidies, which can significantly ease the process of establishing community energy projects [11]. By developing local energy regulations and assisting RECs in navigating bureaucratic hurdles, such as grid connection procedures and planning permissions, municipalities can help reduce time consuming and costly approval processes by local DSOs. Furthermore, zoning laws that designate suitable areas for RECs can further facilitate the creation of new communities [12].

Figure 6: The Burgerenergie community in Germany

Beyond regulatory support, municipalities can leverage financial and legal resources to improve REC projects by providing public funding for feasibility studies and infrastructure costs or applying for EU grants, such as Horizon Europe or EU Structural Funds, to finance RECs [13]. For instance, in Germany, the BürgerEnergie model enables municipalities to co-invest in RECs, supporting solar and wind projects. Similarly, in Spain, Barcelona Energia, a public municipal energy supplier, actively supports local RECs by providing financial and administrative assistance [14].

A major challenge for RECs is connecting power plants to the national grid. In this regard, municipalities should collaborate with local grid operators to prioritize grid access for community projects, promoting the integration and the development of local microgrids fostering energy independence. For instance, in the Netherlands, municipalities work closely with DSOs to develop energy-sharing mechanisms across microgrids, building a more decentralised and resilient energy system.
Beyond the topic of supporting RECs, municipalities can actively create and own renewable infrastructure, directly benefiting citizens. For example, by investing in solar photovoltaic systems on municipal buildings or developing district heating systems powered by renewable energy sources, local governments can lead by example.

The control volume of the Renewable energy community

For RECs, energy sharing boundaries are defined by the perimeter of the primary substation as indicated on the GSE portal. All energy communities must be located within Italian territory and each community must be confined within the area served by its respective primary substation.

Figure 7: Map of Italy primary substations [15]

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

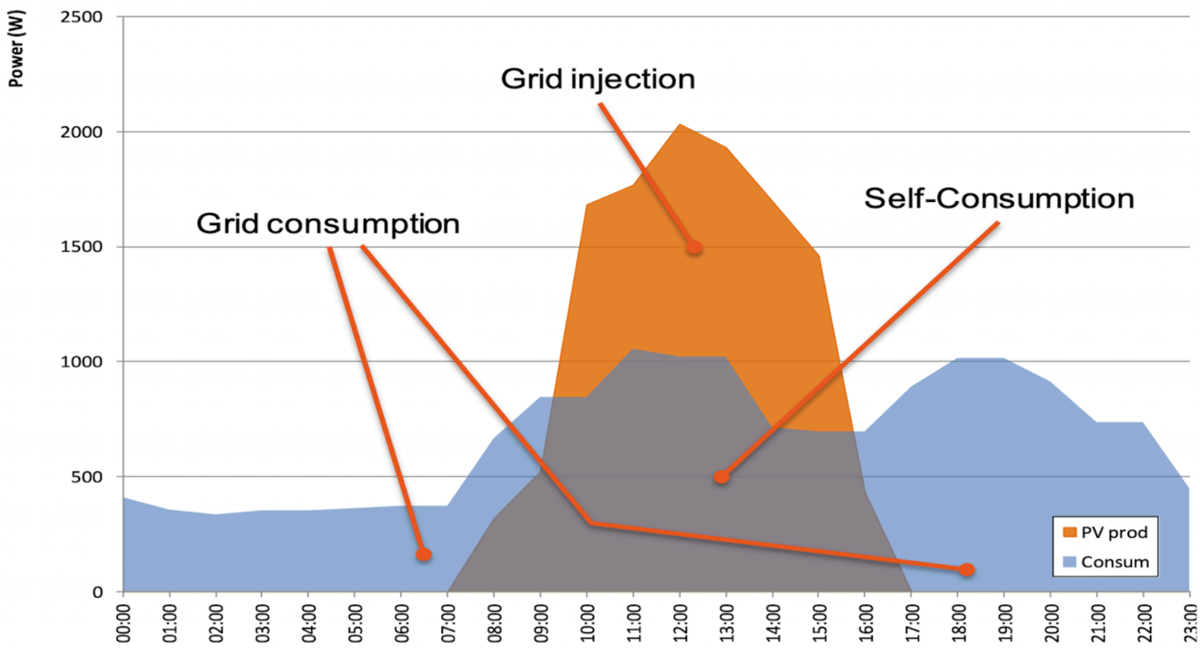


Figure 8: Comparison between production and consumption profiles

Figure 8 illustrates the combined load profile for the members of a standard Renewable Energy Community, displaying both electricity consumption from the grid by member users and the output from the community's photovoltaic plants [16]. The surplus of production and demand curves indicate periods of energy sharing within the REC, which represents a dynamic entity. The list of points of delivery (PODs) for withdrawals (consumers) and inputs (prosumers) can change, affecting the hourly energy flows and the volume of energy shared across the entire community.

Key performance indicators for monitoring a REC include the proportion of shared energy, which reflects the percentage of total energy produced by its renewable energy sources that is consumed within the community in a synchronised manner. Moreover, the total amount of energy injected into the grid compared to the total generated, as well as the proportion of energy withdrawn from the grid, should also be monitored.

To promote the growth of RECs, the GSE recognises an incentive tariff that includes:

1) Incentives for tariffs related to avoided energy transport and distribution costs, plus a bonus for energy shared.

2) A premium tariff based on the amount of energy shared.

3) Allocations for electricity that the REC injects into the grid.

Furthermore, the MASE Decree outlines economic benefits for those establishing a REC configuration. In particular, the tariff incentive applies to the amount of energy shared within REC settings, subject to a plant's maximum nominal power of 1 MW and its location under the same primary substation. This incentive includes both a fixed and a variable rate, adjusted for up to 20 years based on geographic location, with specific adjustments for Southern, Central and Northern Italy. This incentive can be combined with PNRR contributions; however, the rate is reduced by a maximum of 40% of the initial investment. This type of contribution consists of a non-repayable fund covering up to 40% of eligible costs for developing new renewable plants within RECs in municipalities with fewer than 5.000 inhabitants.

Incentives provided by "Gestore dei Servizi Energetici" (GSE)

The incentives of the GSE are different according to the capacity of the installed power, with different levels of subsidies based on the plant's size.

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

Additionally, the incentive tariff varies by region. For the regions of Tuscany, Marche, Lazio and Abruzzo, an additional bonus of 4 €/MWh is available, while all other regions receive a bonus of 10 €/MWh.

Incentives provided by PNRR

The "National Recovery and Resilience Plan" also known as "PNRR", offers significant financial support for developing renewable energy plants within RECs in municipalities with less than 5000 inhabitants. The PNRR provides funding covering up to 40% of the costs associated with renewable energy systems, with the actual amount determined based on the power capacity of the projects and subject to maximum allowable expenses and investment costs.

Power [kW]	PNRR maximum incentive [€/kW]
Power < 20 kW	1.500 €/kW
20 kW < Power < 200 kW	1.200 €/kW
200 kW < Power < 600 kW	1.100 €/kW
600 kW < Power < 1000 kW	1.050 €/kW

Analysis of energy consumptions of a Renewable Energy Community

The following paragraphs will explain the energy consumption patterns of various stakeholders within a Renewable Energy Community located in Ischia, an island located near Naples. The consumption data for this analysis is derived from actual measurements recorded monthly by each "POD" of the meters, ensuring a precise tracking of energy usage. All data have been meticulously sourced from the electricity bills provided by all the community members, who downloaded their real usage details directly from their respective electric utility providers' websites.

GIORNO \ ORE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Lunedì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Martedì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Mercoledì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Giovedì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Venerdì	F3	F3	F3	F3	F3	F3	F2	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F1	F2	F2	F2	F2	F3	F3
Sabato	F3	F3	F3	F3	F3	F3	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F2	F3	F3
Dom e Fest.	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3	F3

Figure 9: The three bands of energy consumption F1, F2, F3

To ensure accuracy and provide a comprehensive insight, all data were meticulously compiled and analysed using Excel spreadsheets. This process involved aggregating the data to accurately reflect the actual energy consumption of community members across three critical time of use categories: F1 for peak hours, F2 for intermediate hours and F3 for off-peak hours, as shown in Figure 9.

The following sections analyze energy consumption on a member-by-member basis, based on real data from the reference period of 2023. Each analysis aims to describe the energy usage patterns and explore their implications for the community's energy management.
In this case, all community members' meters are located under the same primary substation, fulfilling the requirement for establishing a community.
Furthermore, the island of Ischia has only one primary substation, meaning that all considered members fall within the same geographical area, enabling their inclusion in the community.

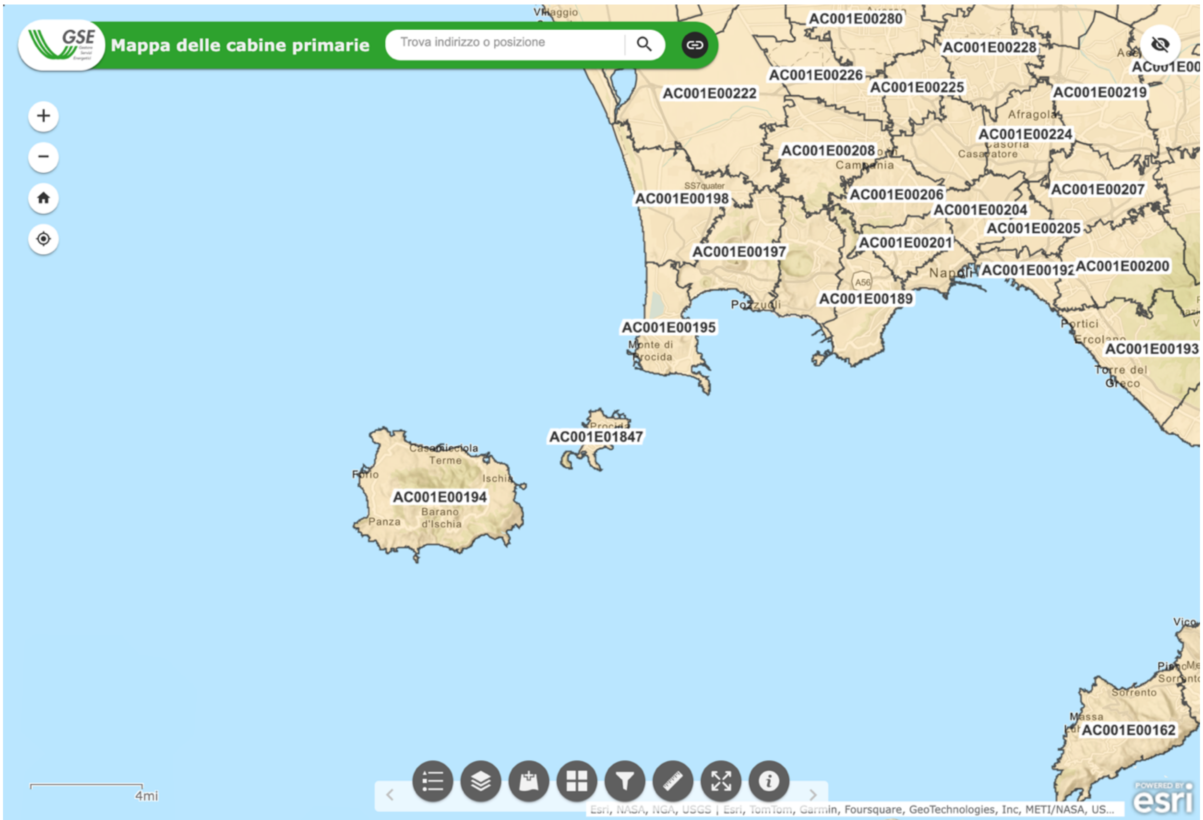


Figure 10: Map of the area covered by the primary cabin from the GSE website [15]

Description of the community members

The members of the REC have distinct energy consumption profiles. Their energy usage data has been collected through the energy bills provided by various members. These bills have been manually grouped and their recorded consumption history has been carefully analszed, as detailed in the following sections.

Furthermore, all individual member data has been evaluated within an integrated framework to calculate the community's total energy consumption. This comprehensive analysis forms the basis for designing a proper photovoltaic system tailored to the collective needs of the community.

The ultimate goal of this system design process is to reduce energy costs for members, enabling significant savings on their electricity bills.

The community members of this case study include:

1) The school called "Scuola Media Scotti", located in "Via Michele Mazzella, 117, 80077 Ischia (NA)". It has about 50 classrooms covering an area of around 700 m^2.

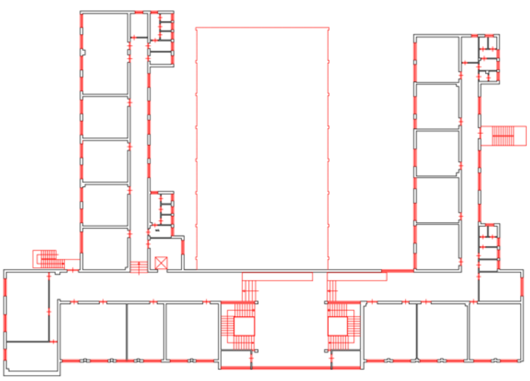


Figure 12: School planimetry of the first floor

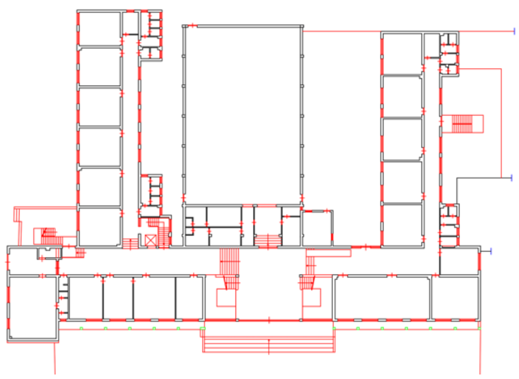
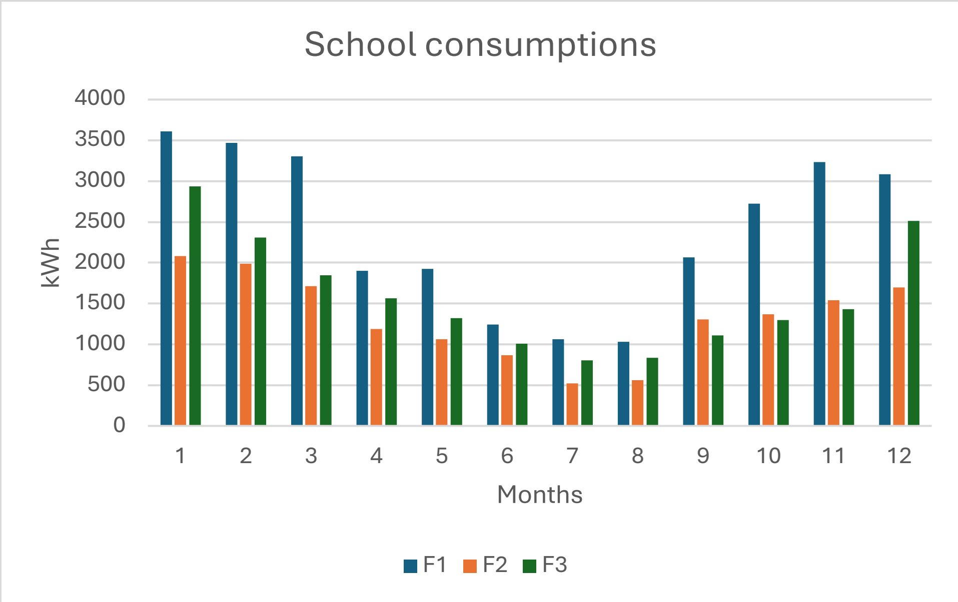


Figure 11: School planimetry of the ground floor

These planimetries display the layout of the entire school and illustrate the distribution of all classrooms. As the "Figure 11" and "Figure 12" show, the classrooms are organized across two levels, a ground floor and a first floor.

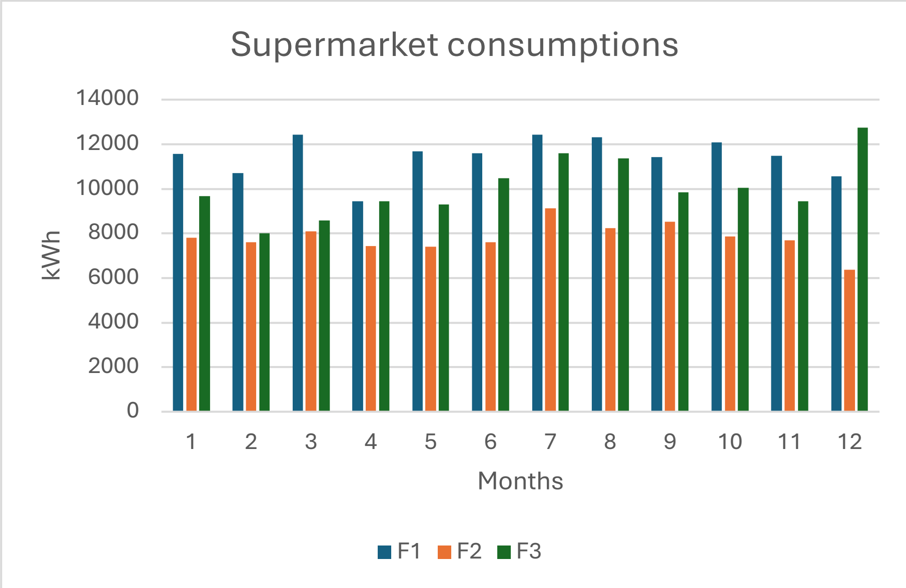
Regarding the school's energy consumption, the total electricity usage can be observed across three energy bands throughout 2023 which is displayed in "Graph 1".



Graph 1: School monthly consumptions divided in F1-F2-F3 bands

The graph illustrates the school's monthly energy consumption across different time of use categories (bands) [17]. The x-axis represents the months of the year (1-12), while the y-axis displays the kilowatt hours (kWh) consumed each month, corresponding to the different energy bands.
Throughout the year, the F1 time band consistently records the highest energy consumption, particularly during the winter months of January and February, as well as during November and December. This pattern is typical for schools, where peak energy usage occurs during daytime hours when heating and lighting systems are in full operation. The F2 and F3 bands show lower but stable consumption, with noticeable declines during the summer months, such as July and August, when the school is less active or closed for holidays. The consumption during these off-peak periods remains relatively low throughout the year, reflecting reduced activity outside regular school hours. The fluctuation in F1 consumption, with peaks in colder months and lower usage during summer, suggests the impact of seasonal factors, particularly heating and lighting, on overall energy demand. This trend underscores the school's closure during summer.

2) A supermarket, located opposite the school, at "Via Michele Mazzella 102, 80077, Ischia (NA)". It consists of a two-storey building, each floor covering approximately 600 square meters. The supermarket operates all the year, with concentrating its energy consumption primarily concentrated on weekdays, while it remains closed on Sundays.



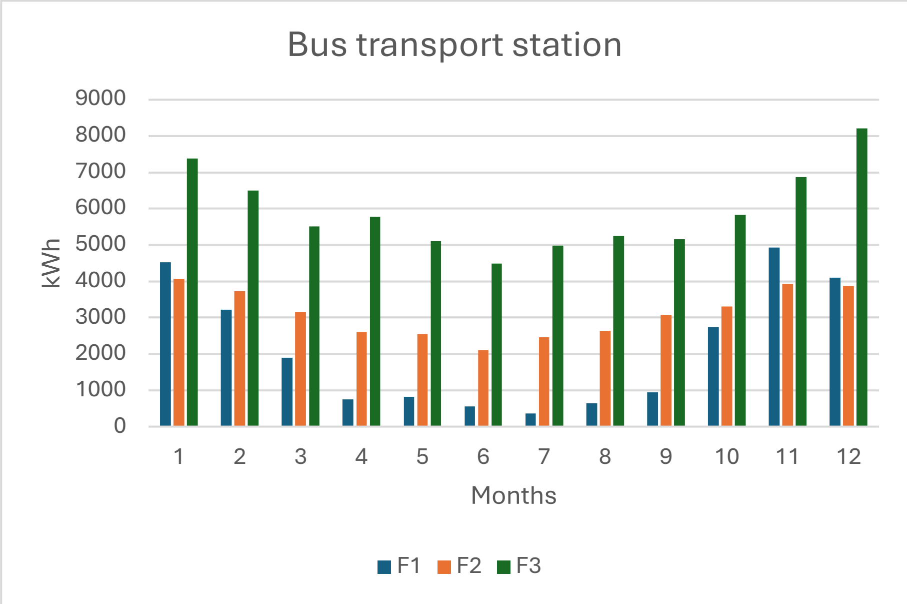
Graph 2: Supermarket monthly consumptions divided in F1-F2-F3 bands

Across all months, the F1 time band consistently records the highest energy consumption, reflecting the supermarket's intensive energy use during peak operational hours. The F3 band generally maintains slightly lower consumption than F1 and remains stable throughout the year, indicating the continuous operation of essential systems such as refrigeration, even during off peak hours. The F2 band shows lower but steady consumption levels. The overall consumption pattern remains consistent throughout the year, with slight declines in certain months (e.g. April and August), possibly due to reduced activity during these periods.

The primary contributors to this energy usage are refrigeration, lighting and air conditioning systems, which must operate continuously or at increased capacity during business hours.

Overall, the graph suggests that supermarket's energy use remains relatively stable across all time of use categories, underlining facility's constant operational needs.

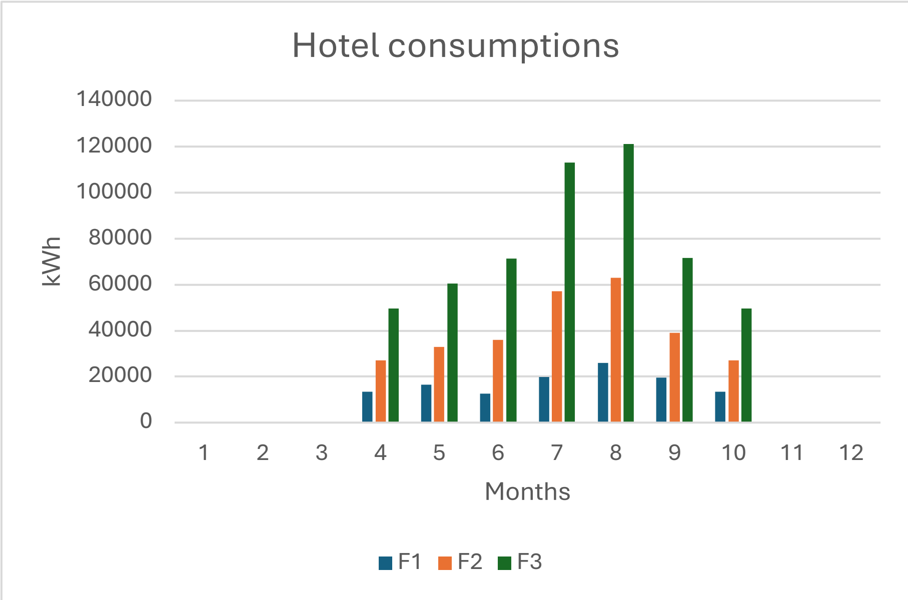
3) A Bus transport station, located next to the school at Via Michele Mazzella, 127, 80077 Ischia NA, exhibits a distinct energy consumption pattern. It is important to note that during the measurement period, no electric buses were in operation, meaning no electricity consumption was recorded for bus charging.



Graph 3: Bus transport station monthly consumptions divided in F1-F2-F3 bands

"Graph 3" presents the monthly energy consumption of the bus station, divided into three bands. A notable feature of the graph is the consistently high F3 consumption throughout the year, which is directly influenced by the presence of a photovoltaic system on the rooftop. The F1 band does not contribute to grid energy consumption, as most energy during these hours is self-consumed. The high F3 consumption suggests that while the PV system generates electricity during daylight hours, significant energy consumption still occurs when the produced energy is not self consumed, likely during non-sunlight hours or when production is insufficient to meet demand. The F1 and F2 bands show relatively lower and more stable consumption patterns. Sharp spikes in F3 consumption during certain months, such as February, April and December, suggest increased reliance on grid supplied energy during these periods, possibly due to reduced sunlight or higher energy demand. This pattern emphasizes the role of the PV system in covering part of the energy demand while highlighting periods when insufficient generation leads to increased grid consumption in F3.

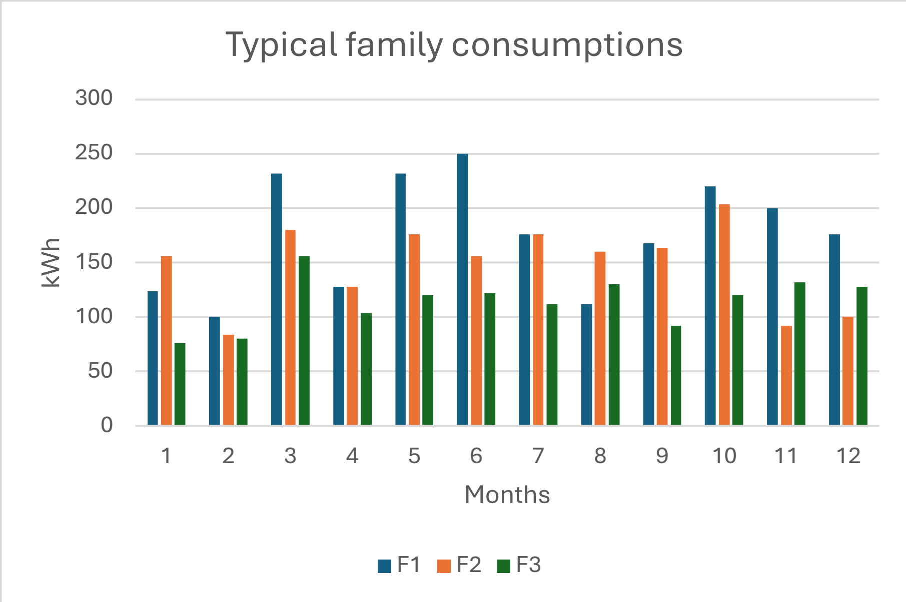
4) A four stars hotel, located near the supermarket in "Via Michele Mazzella 70, 80077, Ischia (NA)". The hotel features 244 rooms and several swimming pools, making its electricity consumption significantly higher than that of other buildings.



Graph 4: Hotel monthly consumptions divided in F1-F2-F3 bands

The hotel remains closed during the winter months, which explains why energy consumption is close to zero from November to March. However, from April to October, when the hotel is operational, energy usage rises significantly, peaking during summer months (July, August). Consumption in the F3 band is notably the highest, reflecting energy use during off peak hours, likely due to continuously operating systems such as air conditioning and lighting. Meanwhile, F1 band consumption has been partially mitigated by the presence of a photovoltaic system, which enables self consumption of solar energy during daylight hours, reducing reliance on grid electricity during peak times. The graph highlights how the hotel's energy demand is concentrated in the months when it is open, with a significant share of consumption offset by renewable energy during sunlight hours.

5) Residential Users – Families of 4/5 Members Each. Five families have been included in the community, all of whom are connected to the same primary substation. Additionally, a typical consumption pattern for an average family has been considered, assuming that these households, aware of their participation in the community, would strive to concentrate their energy usage during daylight hours to maximise self consumption.



Graph 5: Family of 4/5 members monthly consumptions divided in F1-F2-F3 bands

"Graph 5" illustrates noticeable variations in energy use throughout the year, with particularly high peaks during both the summer and winter months. This suggests increased energy demand during these periods, likely due to heating in winter and cooling in summer. It has been estimated that each household within the community typically consumes just over 5000 kWh of electricity annually.

6) A Wallbox of 22 kW and a Wallbox of 7 kW

Another consumer considered in the study includes two electric vehicle charging stations located approximately one kilometre from the school at "Via Michele Mazzella, 25, 80077 Ischia NA".

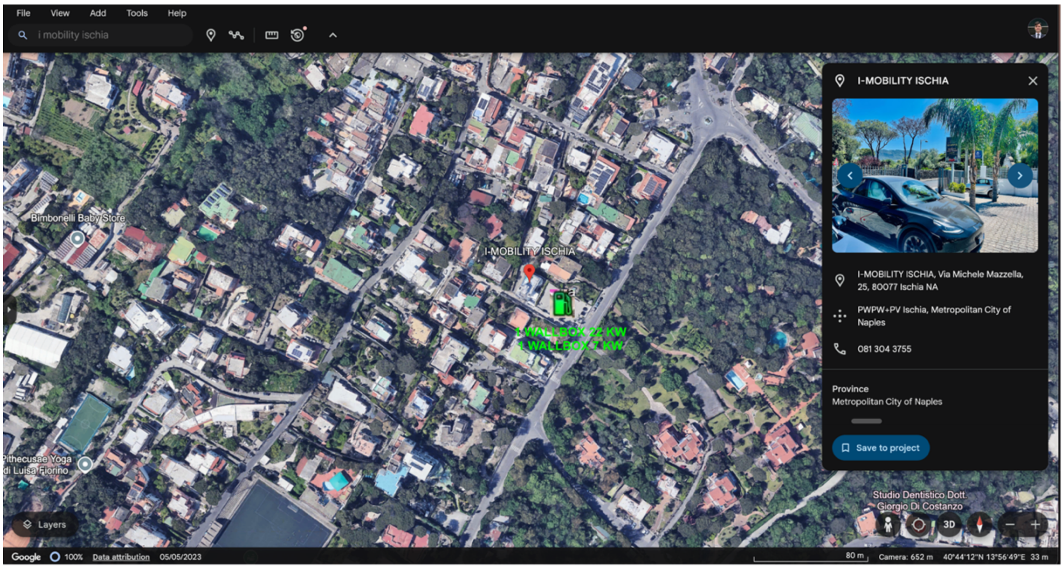
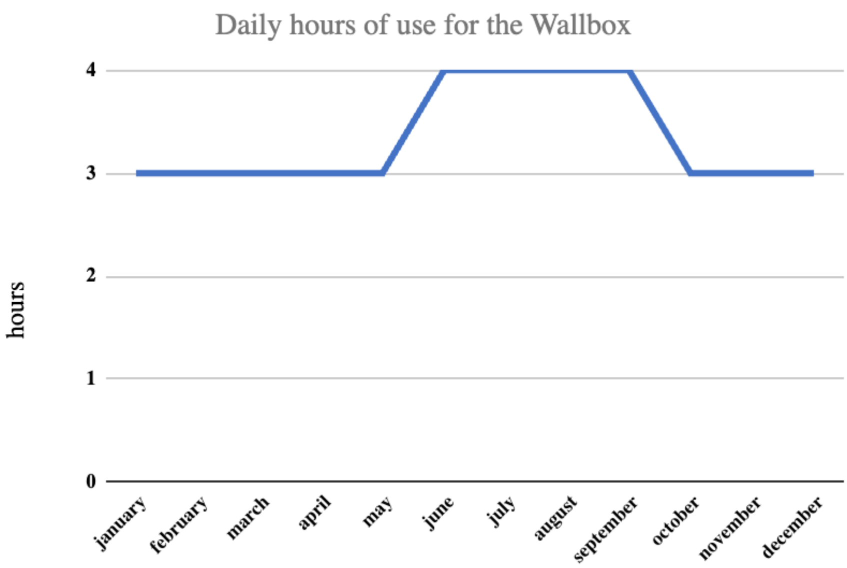


Figure 13: Wallbox recharging points

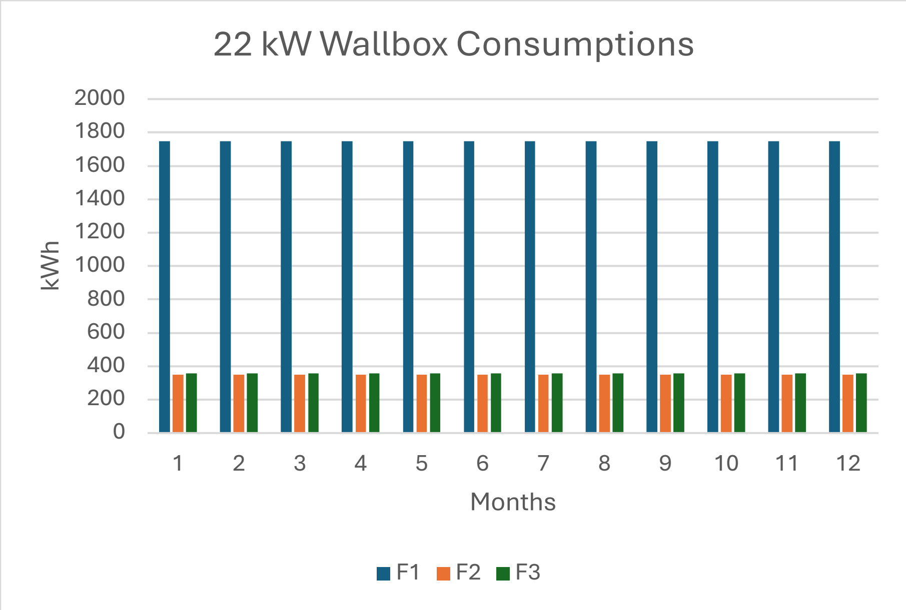
The two charging stations, indicated in green, have capacities of 22 kW and 7 kW respectively. As they were only recently installed as part of new electric vehicle supplier's facility, no historical consumption records are available. Based on information provided by the firm, it has been assumed that each station is used for three hours per day during low season and four hours per day during high season.

The total energy consumed by the two stations is estimated to be 29.458 kWh/year.



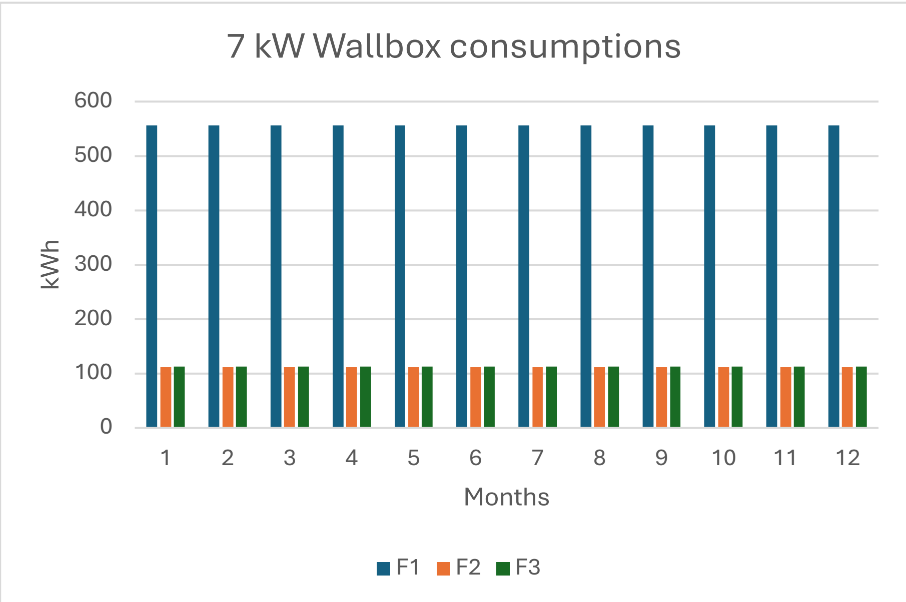
Graph 6: Consumption trend of the electric recharging points

It is further assumed that the two wallboxes are used in coordination with photovoltaic energy production, meaning they primarily charge electric vehicles during daylight hours when solar generation is at its peak. Consequently, they operate in the F1 time band on weekdays and switch to the F2 and F3 bands during weekends.



Graph 7: Electric consumption trend of the 22-kW recharging point in F1-F2-F3 bands

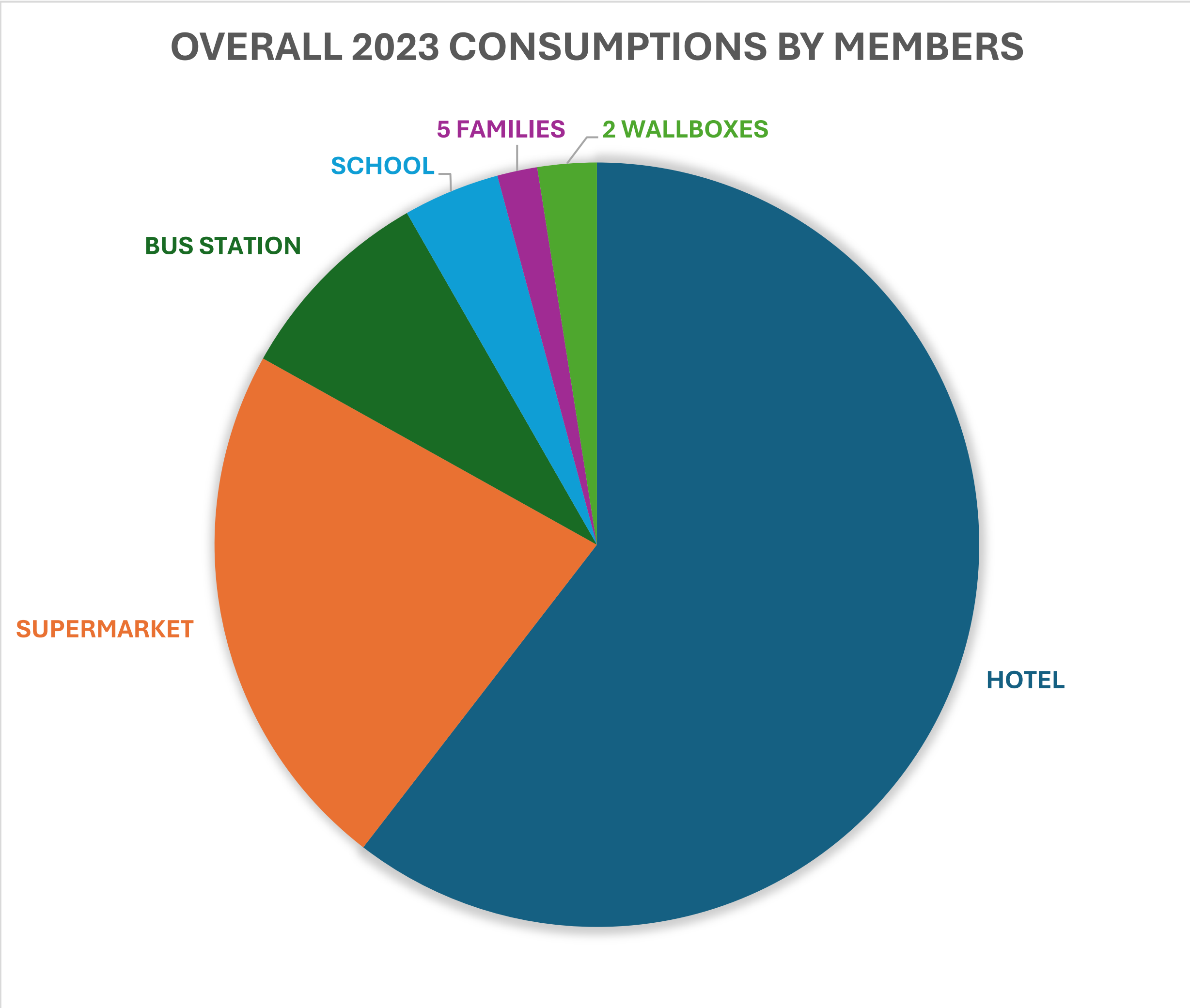
On the other hand, the 7 kW wallbox has the following consumption trend:



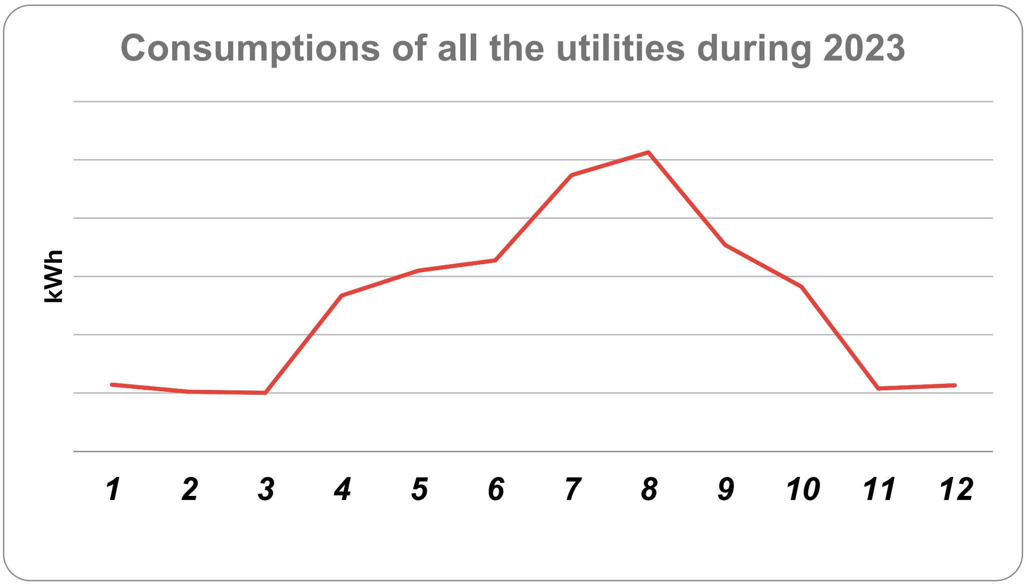
Graph 8: Electric consumption trend of the 7-kW recharging point in F1-F2-F3 bands

The 2023 Consumption by all the members

An analysis of energy consumption patterns across various entities within Ischia's REC highlights notable variations. The hotel is the largest energy consumer, driven by the extensive electrical demands of its numerous rooms during operational months. Following closely, the supermarket emerges as the second largest energy user due to its continuous operational needs. In contrast, the bus station and the school have lower energy demands, with the school recording the least consumption. These differences emphasise the need for tailored energy management strategies to meet the specific requirements of each entity.
The charging stations, while having a focused demand, still require a considerable amount of energy, particularly during peak hours. Meanwhile, the 20 family households exhibit moderate energy usage, reflecting typical residential patterns that fluctuate throughout the day but generally remain lower than those of commercial entities.

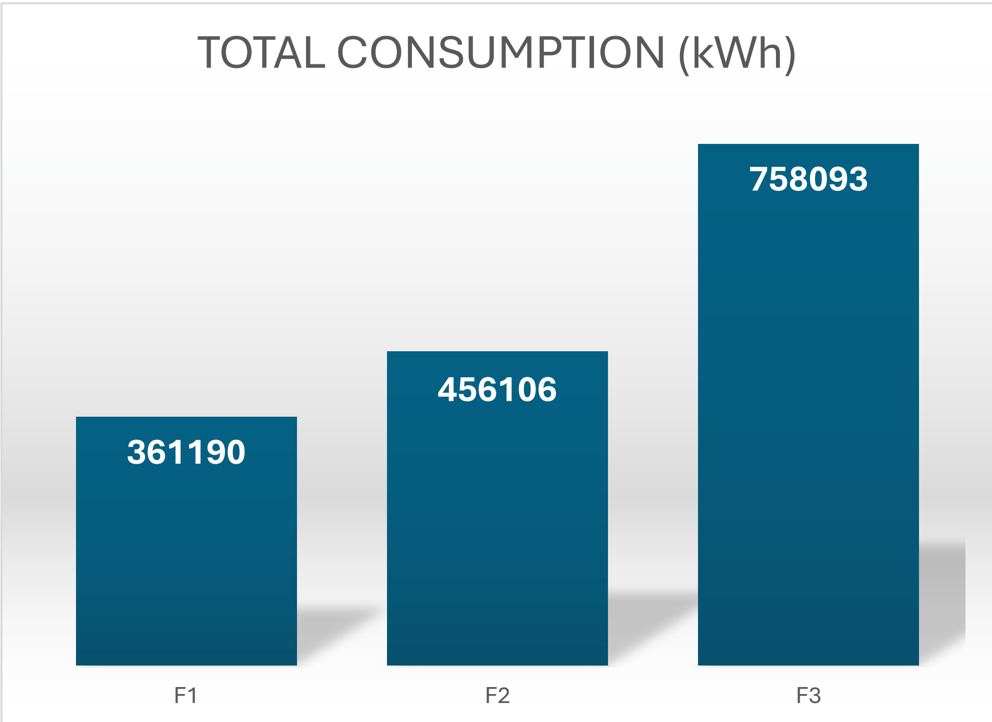


Graph 9: Overall consumption chart of all the members



Graph 10: Overall consumption of all the members throughout 2023

The data reveal relatively stable consumption in the early months, followed by a sharp increase from May, peaking in August. After this peak period, energy demand declines, reaching lower levels by December. This pattern likely reflects the increased energy demand during the summer months.



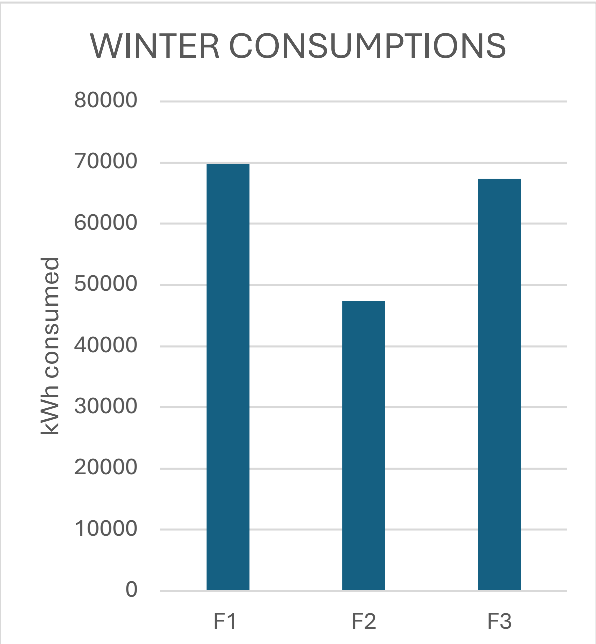
Graph 11: Total consumption trend in the three-time bands

In the overall annual consumption trend of the energy community, divided into time bands, the F1 band records a total consumption of 361.190 kWh. The F2 band, however, sees a higher consumption of 456.106 kWh while the highest consumption is observed in the F3 time band, with a total of 758.093 kWh. This distribution suggests that a significant portion of energy usage occurs during off peak hours.

Analysis of the Seasonal consumptions

The energy analysis is based on seasonal consumption data for 2023, beginning in winter and concluding with autumn. The approach mirrors that of the previous sections, with consumption divided and examined across the F1, F2 and F3 time bands.

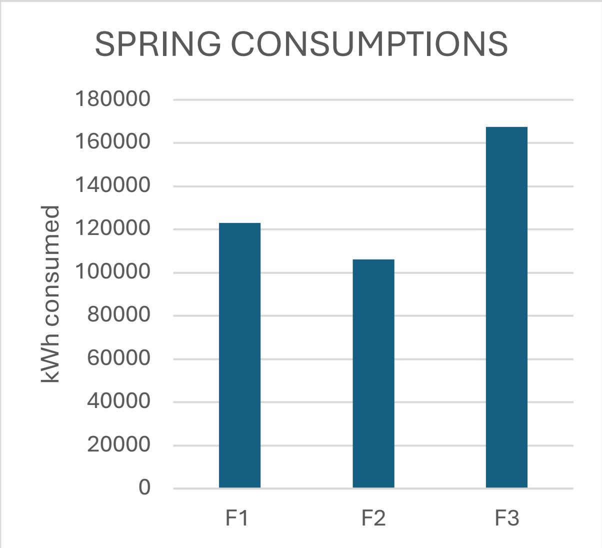
Winter Consumptions



Graph 6: Winter consumptions divided in time bands

Electricity consumption during winter is substantial due to increased indoor activities, although it remains lower than in spring and summer. This is likely due to shorter days and longer nights, which lead to higher demand for artificial lighting and electric heating. People also tend to engage in more indoor activities, such as cooking and entertainment. The F1 time band reflects increased usage related to lighting and essential appliances, while F2 consumption captures energy demand from devices like entertainment systems. The F3 band represent baseline energy usage, which remains consistent across all seasons. Overall, winter consumption patterns indicate a shift towards more energy intensive indoor activities as the season progresses.

Spring Consumptions



Graph 7: Spring consumptions divided in time bands

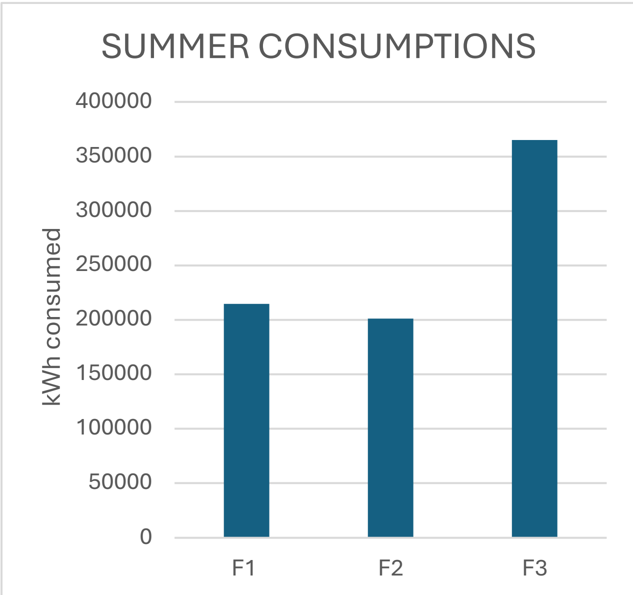
Electricity consumption in spring sees a notable increase, exceeding 100.000 kWh. This rise can be attributed to the increased use of electrical appliances and electronic devices, as well as the opening of the hotel for the season. Electricity is used extensively for lighting and other household needs.

In this context, F1 consumption likely reflects heightened activity in homes, while F2 consumption accounts for energy usage from specific devices such as entertainment systems. The F3 band records the highest consumption compared to the others.

Summer Consumptions

Summer sees a significant surge in electricity consumption, reaching nearly 400.000 kWh. This spike is primarily driven by the increased use of air conditioning and other cooling devices, which are essential for maintaining indoor comfort during the hotter months. Additionally, the use of outdoor appliances and extended nighttime lighting further contributes to high energy demand.

Moreover, the hotel, the largest energy consumer, is fully operational during this period. The F1 time band records substantial consumption due to cooling requirements, while F2 consumption reflects the energy demand of additional appliances, such as refrigerators and entertainment systems. The F3 band likely represents the continuous base load that remains steady throughout the summer months.

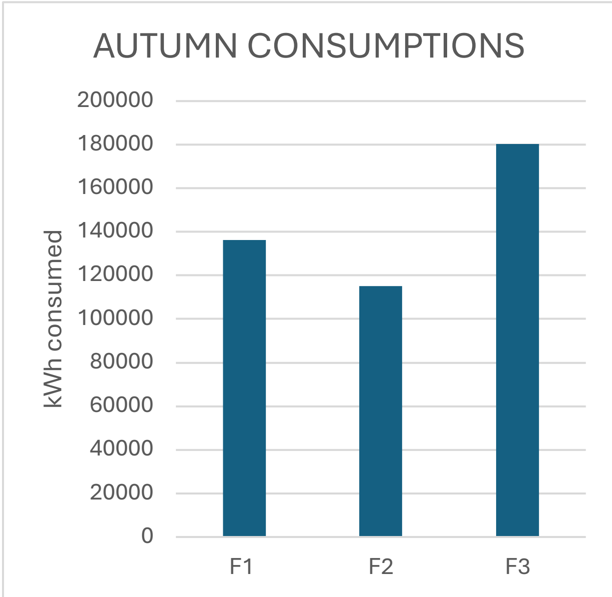


Graph 8: Summer consumptions divided in time bands

Autumn Consumptions

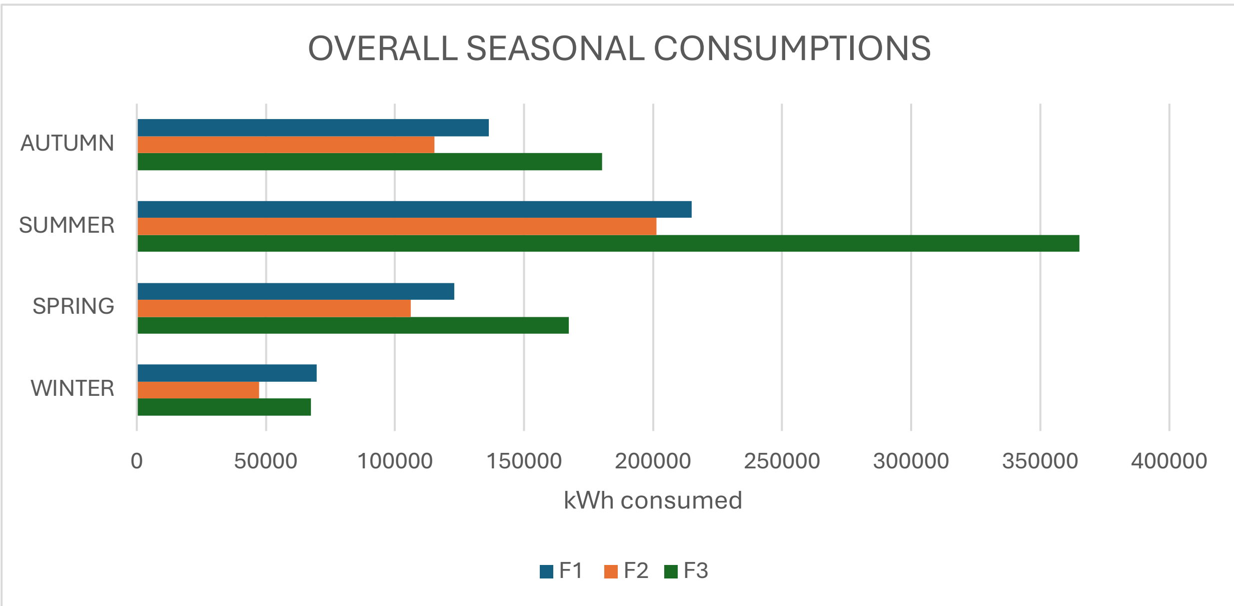
Electricity consumption in autumn decreases compared to summer but remains higher than in winter. This trend is likely due to a combination of heating use and electrical appliances as temperatures begin to drop.

During this season, the F1 time band may indicate a return to more typical usage patterns as cooling needs decline, while F2 consumption likely represents energy use from household appliances as people adjust their routines. The F3 band remains relatively stable, reflecting the baseline electricity consumption throughout the year.



Graph 9: Autumn consumptions divided in time bands

By analysing the overall energy consumption of the community, the findings indicate a significant increase in demand during the summer months. This is likely driven by the energy intensive operation of the hotel, which plays a major role in shaping the overall electricity consumption trend.



Graph 10: Overall consumption of all the members throughout seasons

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The photovoltaic existing installations among REC's area

Among the community members mentioned above, most already have a photovoltaic system installed on their rooftops:

- The hotel, as a major energy consumer and producer, has a substantial PV system with a peak capacity of 215 kW. This system enables the hotel to offset part of its energy demand, particularly during operational months, while also contributing excess power to the community during periods of lower consumption.
- The bus station, is equipped with a 95,5 kW photovoltaic system, actively participating in the community's renewable energy generation.

The hotel solar photovoltaic system - 215 kW

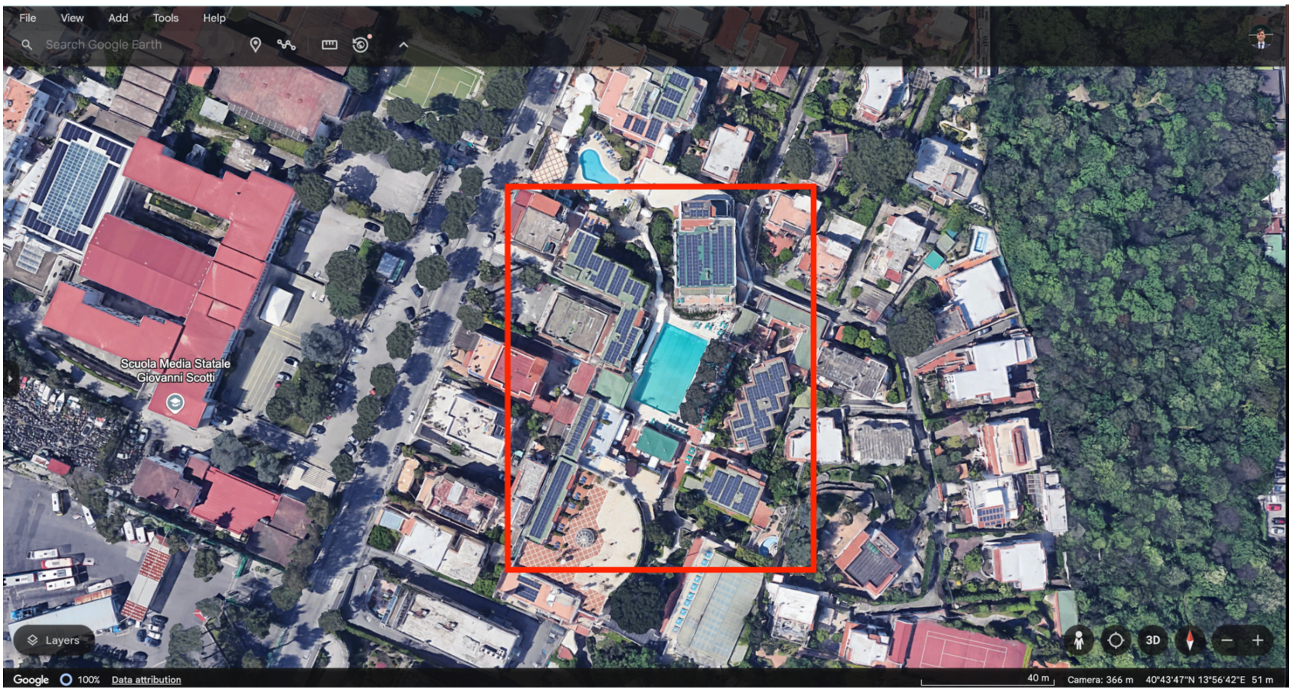


Figure 14: Aereal view of the hotel

The hotel has installed a large-scale solar power system, consisting of 613 photovoltaic modules. Together, these panels provide a peak power capacity of 215 kW.

The bus station deposit solar photovoltaic system – 95,5 kW

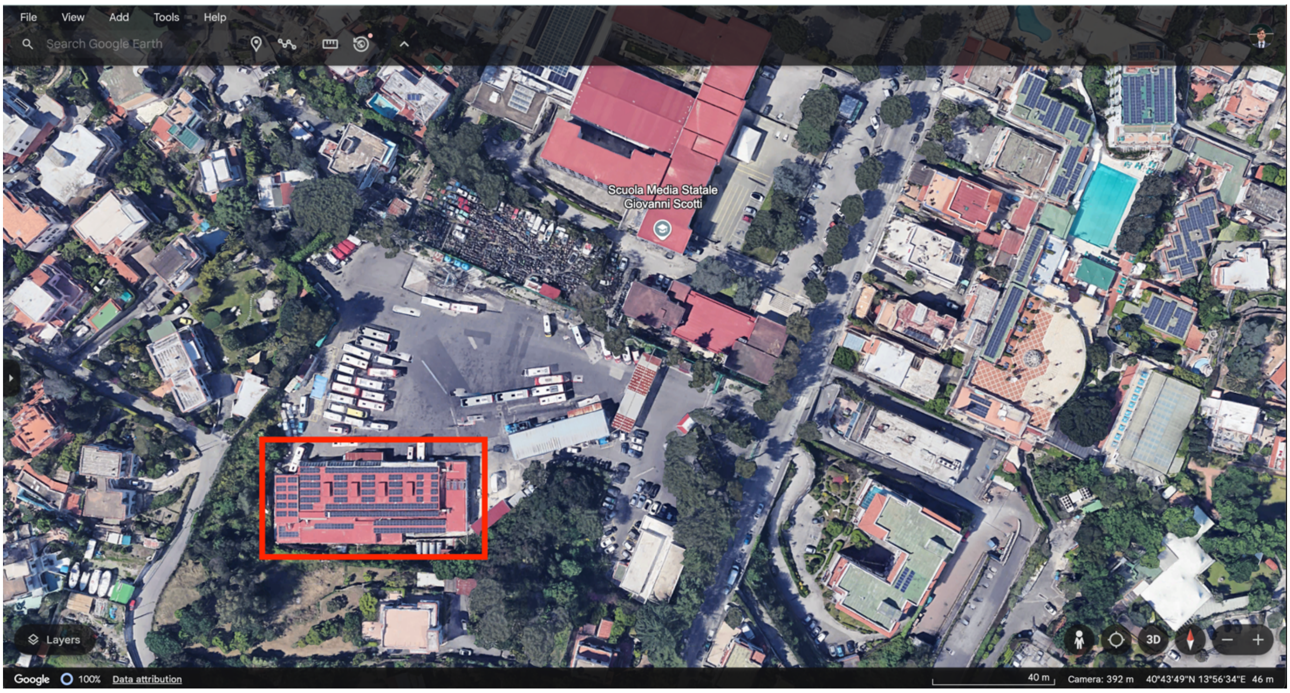
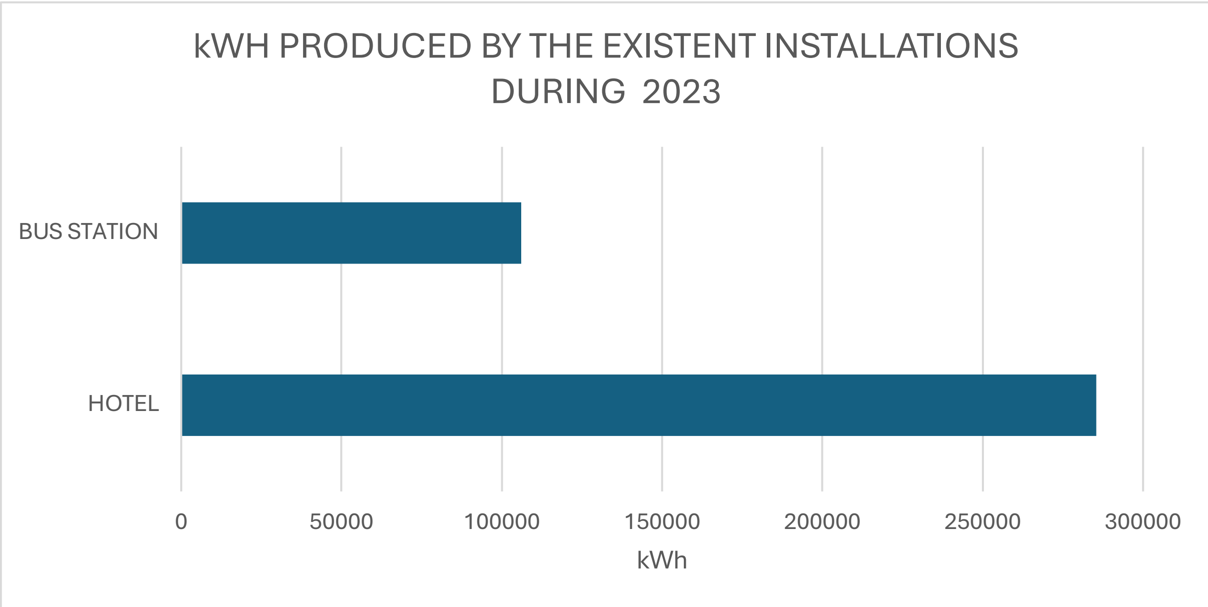


Figure 15: Aereal view of the bus transport station

The bus transport station has an installed capacity of 95,5 kW. All data have been sourced from the inverter production records for 2023, as provided by the company.

According to the latest GSE guidelines (Section 1.2.2.2, Part II), these members cannot include their existing photovoltaic installations within the energy community, as the energy community can only consist of newly installed photovoltaic systems.

However, these existing rooftop installations can still contribute to the overall energy balance of the community by indirectly supporting the self consumption of individual members. As a result, each user requires less electricity from the grid and the community's shared energy resources.

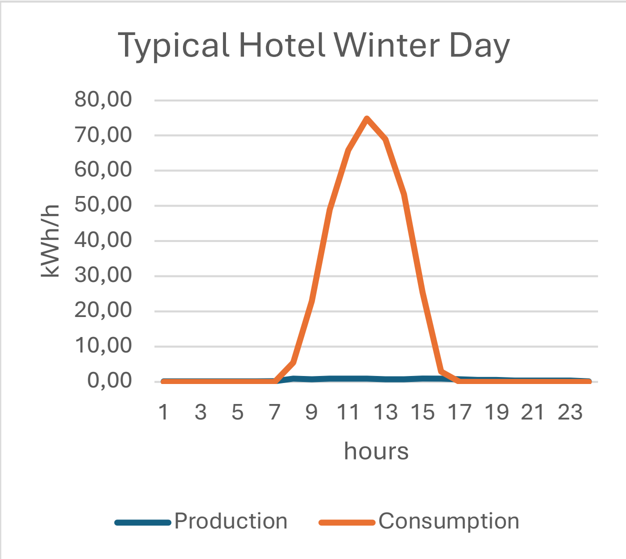


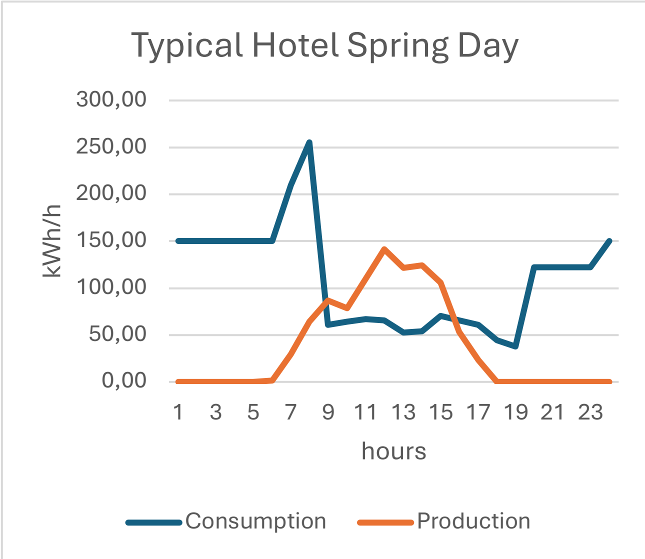
Graph 11: Energy produced by the existing solar photovoltaic installations during 2023

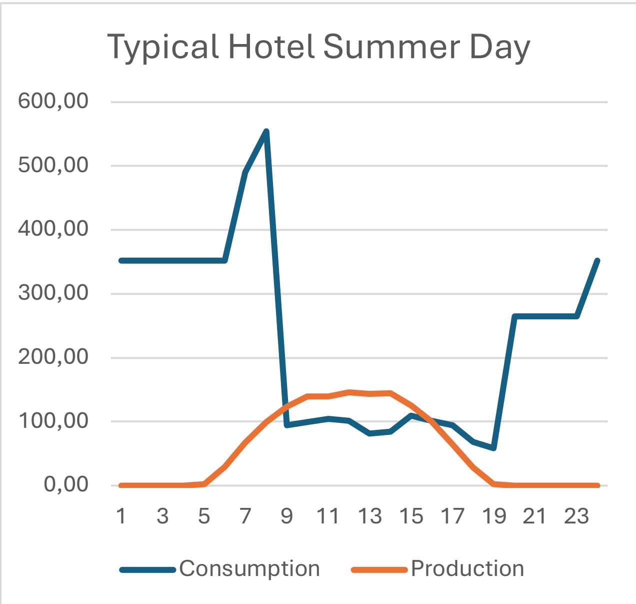
The production and consumption patterns of members with existing photovoltaic installations

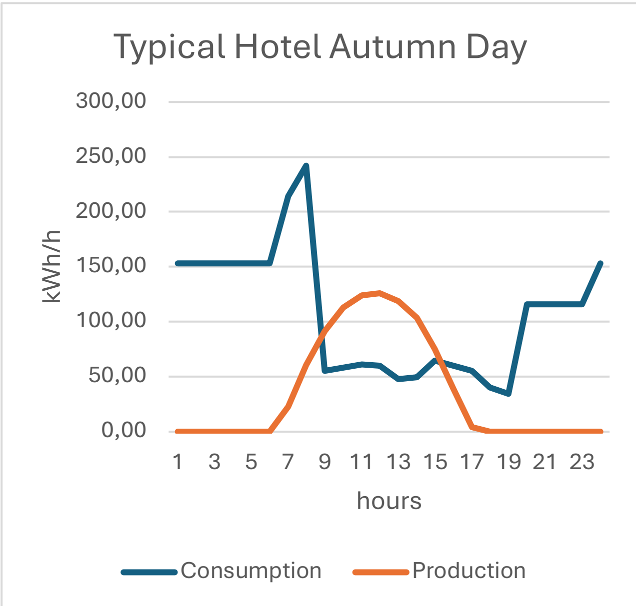
In addition, these two members demonstrate different energy production and consumption patterns depending on the season. By analysing a typical day in each of the four seasons, the following graphs illustrate the results:

Hotel production - consumption curve - existing installation (215 kW)

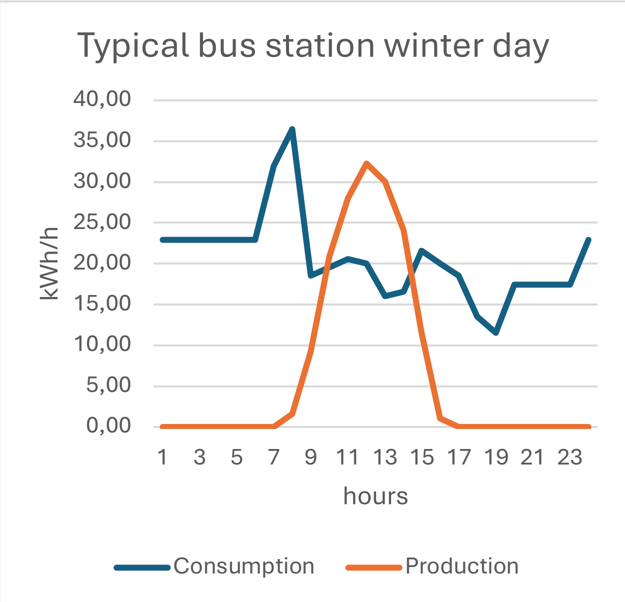


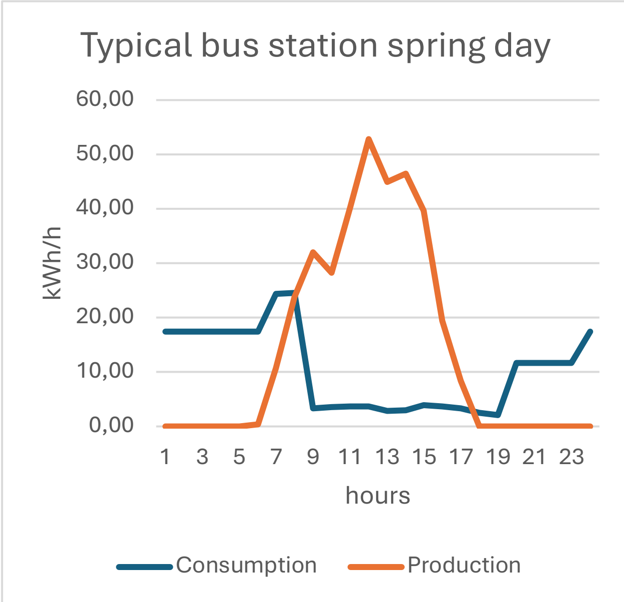


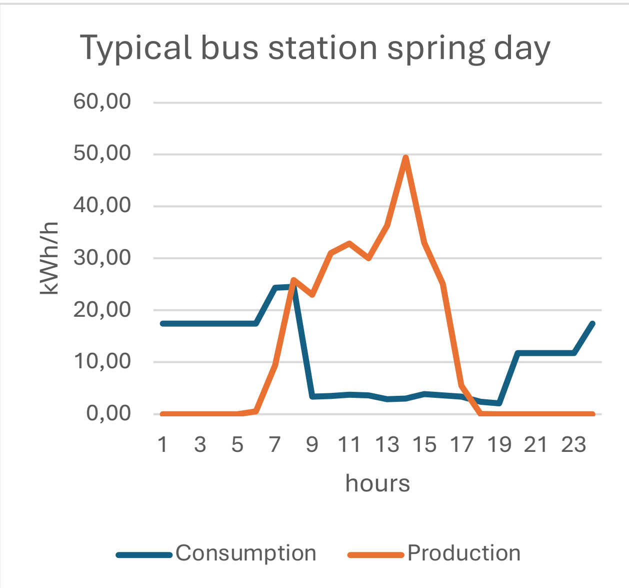


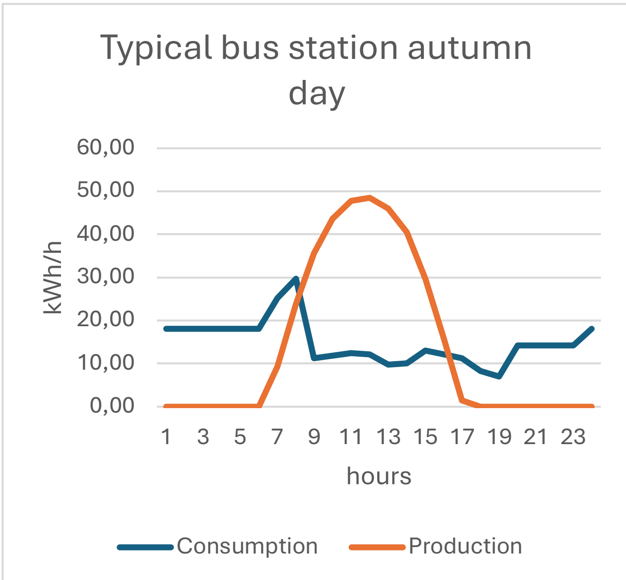


Bus station deposit production-consumption curve – existing installation (95,5 kW)









As shown in the graphs, the existing photovoltaic installations help to meet the energy demands of the buildings. However, they are not always able to fully cover the energy demand throughout the day due to the absence of a dedicated storage system.

Beyond these two installations, no other existing photovoltaic systems are currently in place, meaning all other members must purchase their electricity entirely from the grid. In the following sections, a plan for additional photovoltaic installations will be outlined to facilitate energy sharing within the energy community. This will include the design and installation of three new photovoltaic systems dedicated to serving the community.

The role of Prosumer members and PV project planning

Within the Renewable Energy Community, there are three key prosumers that both produce and consume electricity. For each of these, a dedicated section will be provided to outline the design of a photovoltaic system on its respective rooftop.
The prosumers include:

1) The school with a 264,5 kW photovoltaic system on its rooftop;
2) The hotel, as a major energy consumer and producer, with a peak capacity of 72 kW installed on the rooftop of the swimming pool. This system helps offset part of the hotel's energy demand that is not covered by the existing PV installation, particularly during operational months, while also contributing surplus power to the community during periods of lower energy demand.
3) The bus station depot, equipped with a 42,5 kW of photovoltaic system installed on the rooftop of a nearby building.

Prosumer 1: The school

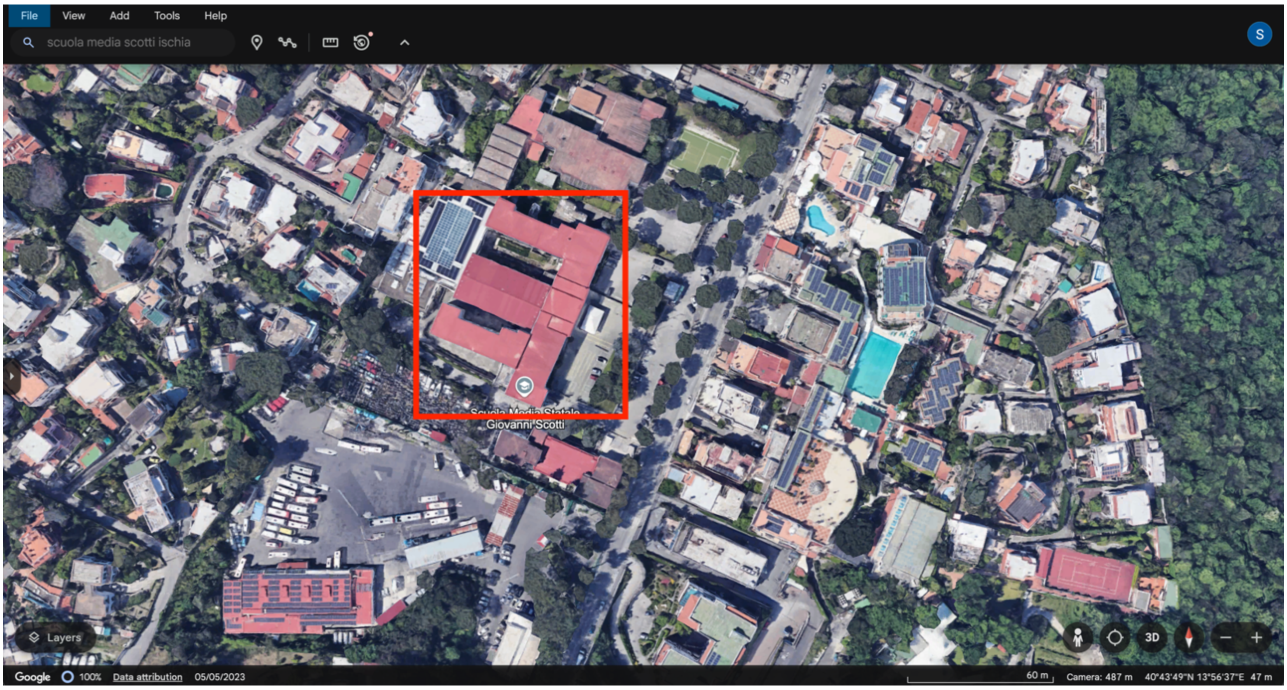


Figure 16: Aereal view of the site of school

The school building, located at "Via Michele Mazzella, 125, 80077 Ischia NA", has been selected for the installation of 264,5 kW photovoltaic system on its rooftop. The installation was carefully planned to ensure compliance with building regulations, particularly allowing that the panels' tilt did not exceed the maximum height of the existing parapet. To adhere to these requirements, a 7 degrees tilt was chosen for the modules. While this is not optimal for solar gain, it meets the guidelines established by regional planning and historical preservation authorities on the island [18].

For this installation, 529 panels each rated at 500 W, specifically the DMEGC model (DMxxxM10RT-60HBW-V) [19] was considered. The layout of these panels is being designed using AutoCAD software, ensuring precision and minimizing shading between rows.

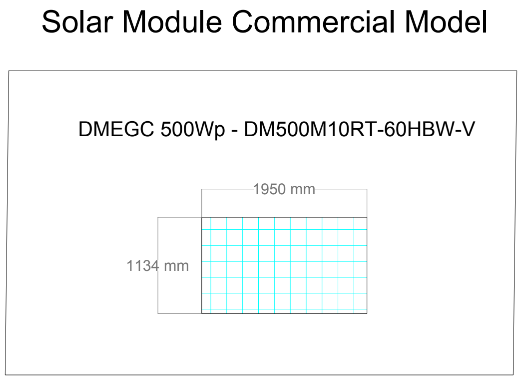


Figure 17: Solar photovoltaic commercial module

The panels are oriented with an azimuth of -67 degrees, aligning them with the roof's orientation.

The coordinates are latitude 40.730615400747325 and longitude 13.943406048565615.

To evaluate the solar declination, the worst scenario has been chosen.

$$\sigma_s = 23{,}45° \times \sin\left(\frac{360 \times (284 + n)}{365}\right) = -23{,}45°$$

The n parameter represents the day of the year, starting from 1st January. The value n =355 (21st December) was chosen, as this is the day with the lowest solar elevation of the year.

Moreover, the maximum solar hour angle was set to $h_s = 0$, corresponding to the solar noon.

The solar angles were then calculated using the following equation:

$$\sin(\alpha) = \sin(L) \times \sin(\delta_s) + \cos(L) \times \cos(\delta_s) \times \cos(h_s)$$

$$\sin(\alpha) = \sin(40{,}73) \times \sin(-23{,}45) + \cos(40{,}73) \times \cos(-23{,}45) \times \cos(0) = 0{,}44$$

$$\alpha = \sin^{-1}(0{,}44) = 26{,}10\,°$$

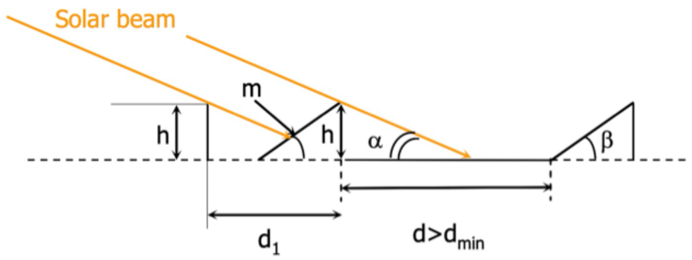


Figure 18: Solar beam angles and irradiation on photovoltaic modules

The vertical length of each solar panel is equal to $m = 1134\ mm$

Based on the previous discussion, the chosen tilt angle is equal to $\beta = 7\,°$

To prevent shading between rows of panels, the minimum distance between them is evaluated as follows:

$$dmin = \frac{m \times \sin(\beta)}{\tan(\alpha)} = \frac{1134 \times \sin(7)}{\tan(26{,}10)} = 283\ mm$$

The same evaluation is applied to other photovoltaics projects to determine optimal spacing between panel rows.

In this case, despite the availability of ample space roof, a deliberate choice was made to space the rows one meter apart, significantly exceeding the minimum of 283 mm required to prevent self-shading.

The productivity of the photovoltaic system was calculated using the Photovoltaic Geographical Information System (PVGIS) tool, which provides comprehensive data on solar energy producibility across the Earth's surface [20].

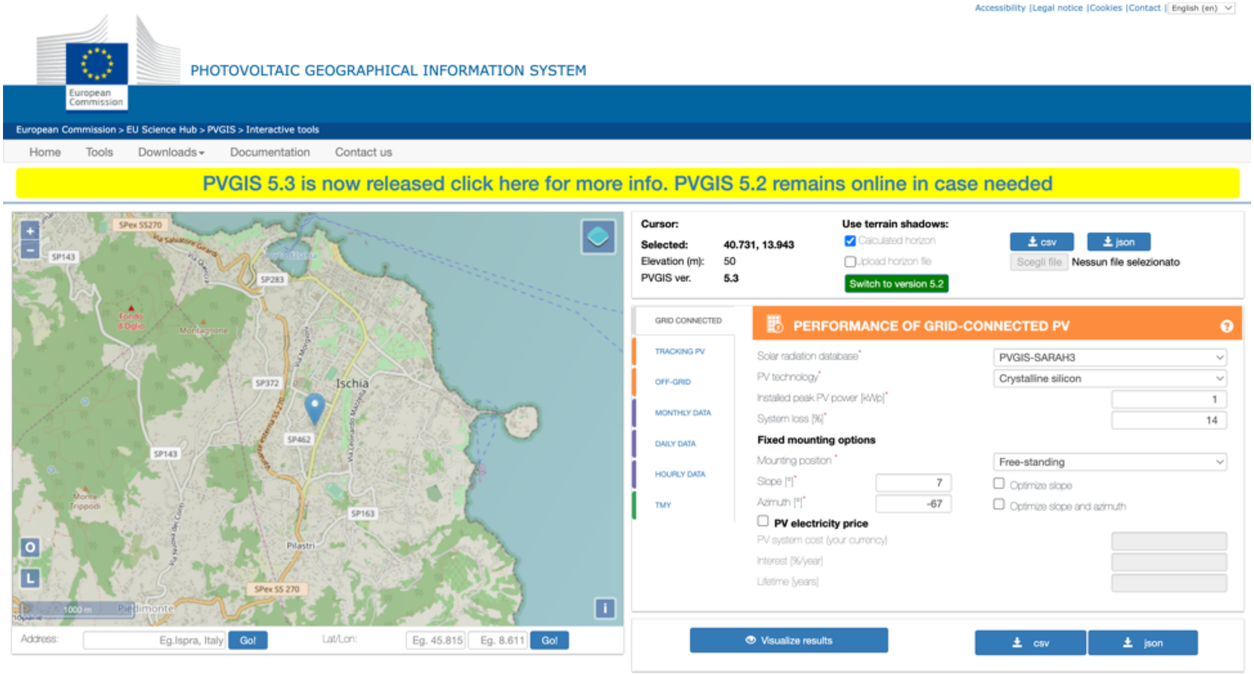


Figure 19: PVGIS tool configuration system

The key input parameters for the tool are:

- Latitude and longitude are calculated automatically by the PVGIS Tool when the building is located on the provided map.

- The Photovoltaic technology considered was monocrystalline silicon photovoltaic modules, with thin-film technology selected for curved roofs to facilitate better integration.

- System Losses include losses due to cables, inverters, and dirt on the modules, are accounted for as 14% in the energy produced.

- The power chosen is equal to 264,5 kW, which means 529 solar modules.

- Mounting System, which is for buildings with pitched roofs, a system integrating the modules into the roof covering is used, whereas buildings with flat roofs utilize a support structure.

- Inclination and azimuth where the chosen tilt inclination is equal to 7°. The azimuth of the photovoltaic modules is set based on the orientation of the roof pitches where applicable, with in this case is equal to – 67°.

The results obtained are the annual production of the power plant and the distribution of the productivity throughout the year.

European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

Provided inputs:

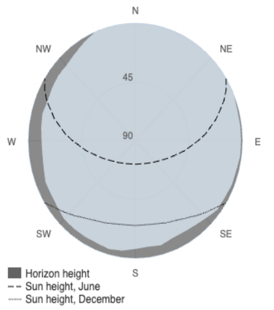
Latitude/Longitude: 40.731,13.943
Horizon: Calculated
Database used: PVGIS-SARAH3
PV technology: Crystalline silicon
PV installed: 264.5 kWp
System loss: 14 %

Simulation outputs

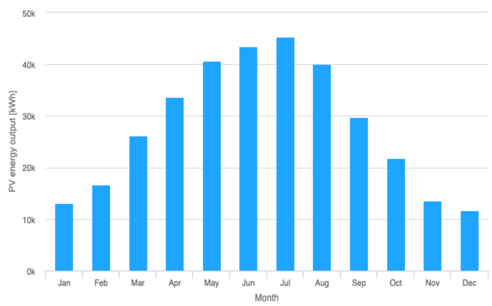
Slope angle: 7 °
Azimuth angle: -67 °
Yearly PV energy production: 335808.28 kWh
Yearly in-plane irradiation: 1694.42 kWh/m²
Year-to-year variability: 8419.57 kWh
Changes in output due to:
- Angle of incidence: -3.4 %
- Spectral effects: 0.18 %
- Temperature and low irradiance: -9.97 %

Total loss: -25.07 %

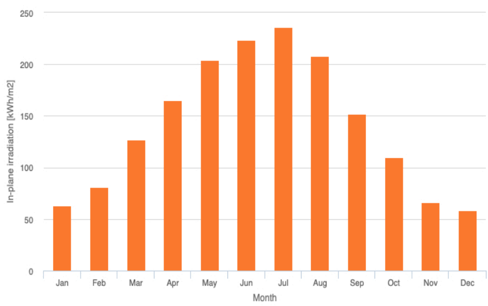
Outline of horizon at chosen location:



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	13011.9	62.9	1555.9
February	16727.7	80.9	2111.1
March	26196.0	126.6	2975.2
April	33626.6	165.3	1768.9
May	40641.6	204.2	2919.6
June	43476.0	223.9	1300.2
July	45313.8	236.2	1107.4
August	40066.1	208.1	1601.0
September	29695.9	151.7	1217.5
October	21860.4	110.0	2109.9
November	13568.8	66.5	1700.4
December	11623.6	58.1	1287.3

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].

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Figure 21: PVGIS simulation tool results School

As previously mentioned, various modules layout configurations can be applied. In this case, a layout with one meter spacing between rows has been selected.

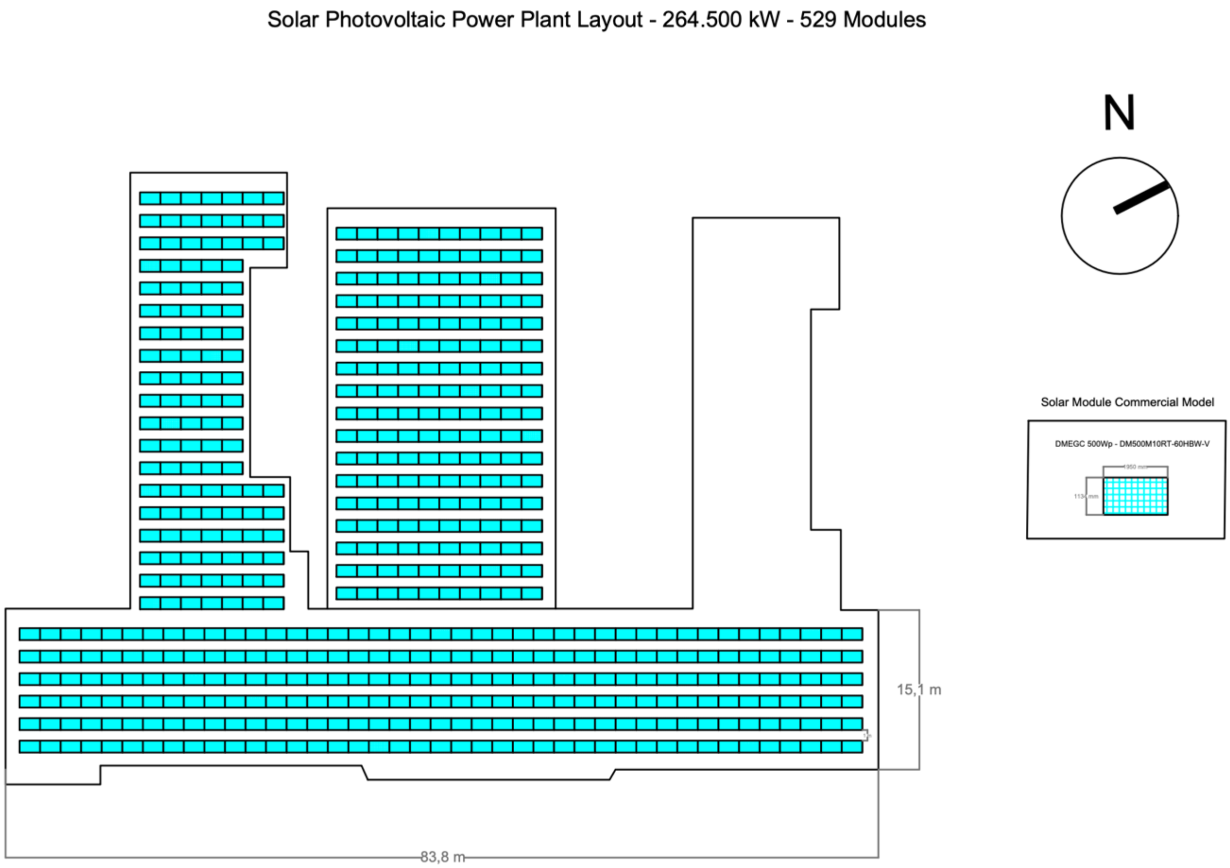

Figure 22: Solar photovoltaic layout on the school rooftop

Prosumer 2: Hotel continental

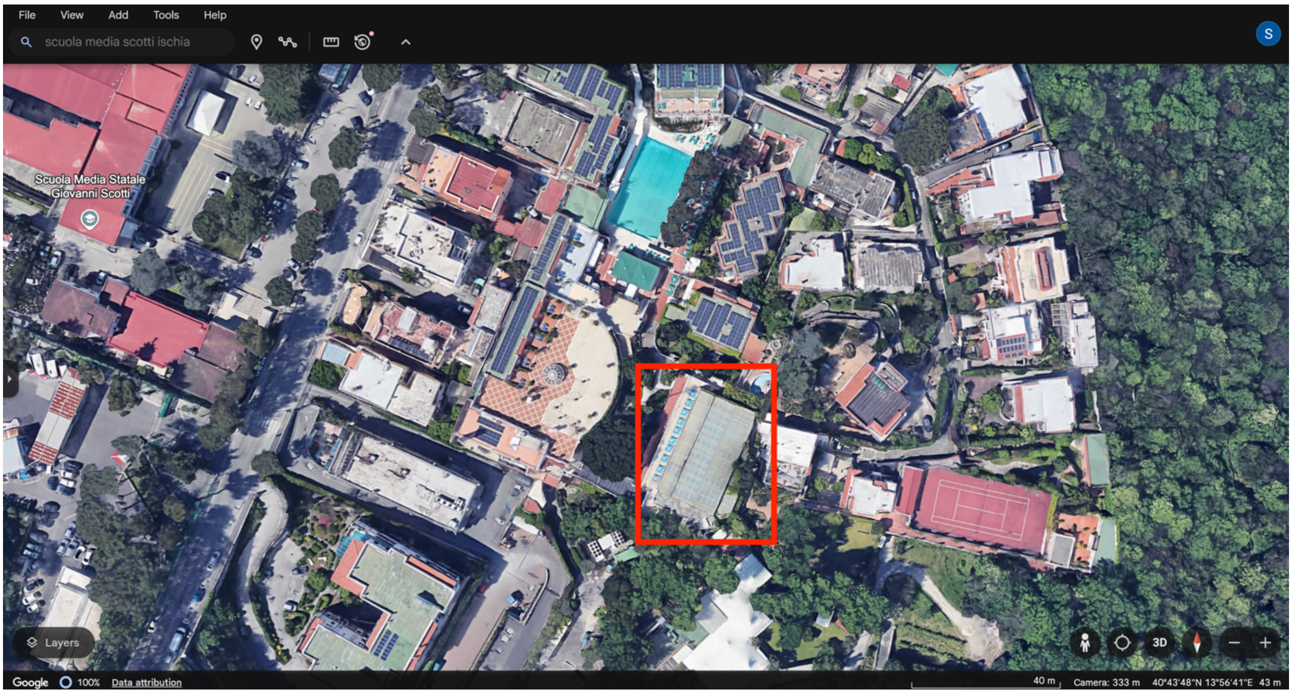

Figure 23: Aereal view of the area used for the photovoltaic installations in the hotel propriety

Within the energy community, Hotel Continental stands out as another major electricity producer. The swimming pool roof has been identified as a potential location for a new photovoltaic system.

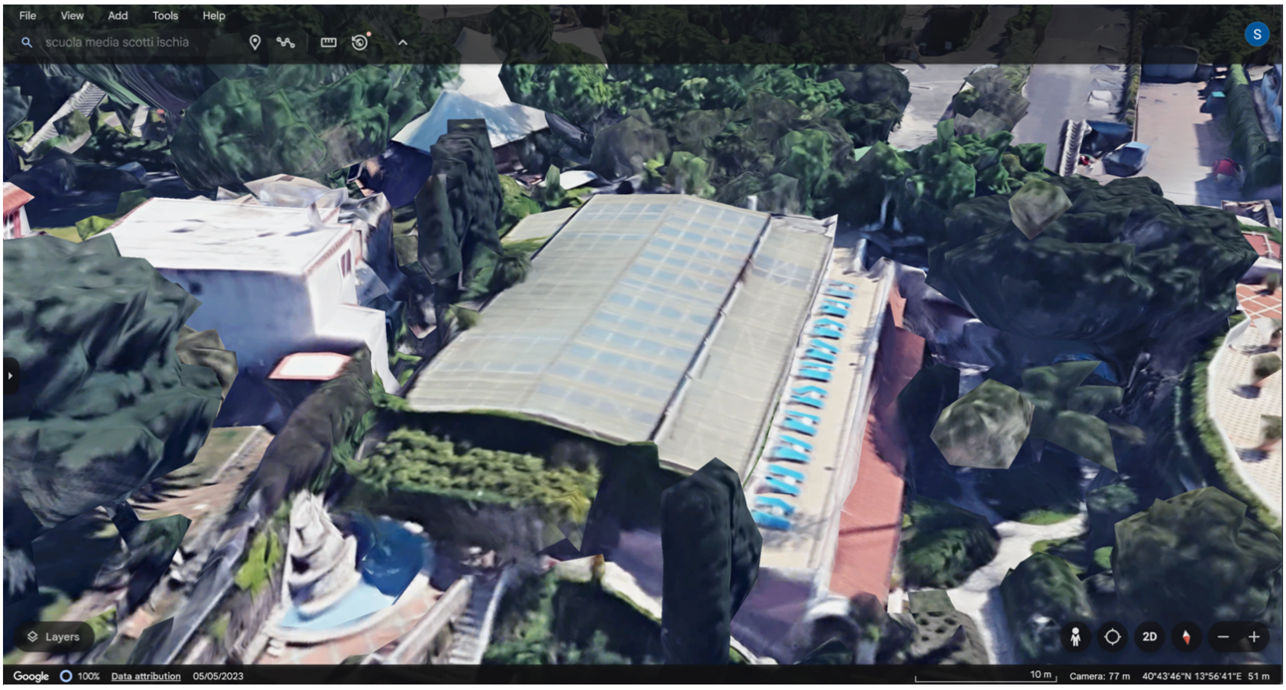

Figure 24: Side view of the swimming pool

The roof inclination of the swimming pool is approximately 20 degrees, meaning the photovoltaic modules will naturally be installed at this tilt angle. The azimuth of the modules is set at 110 degrees with respect to the south direction.

A potential panel layout, using only the unshaded portion of the roof, could be as follows:

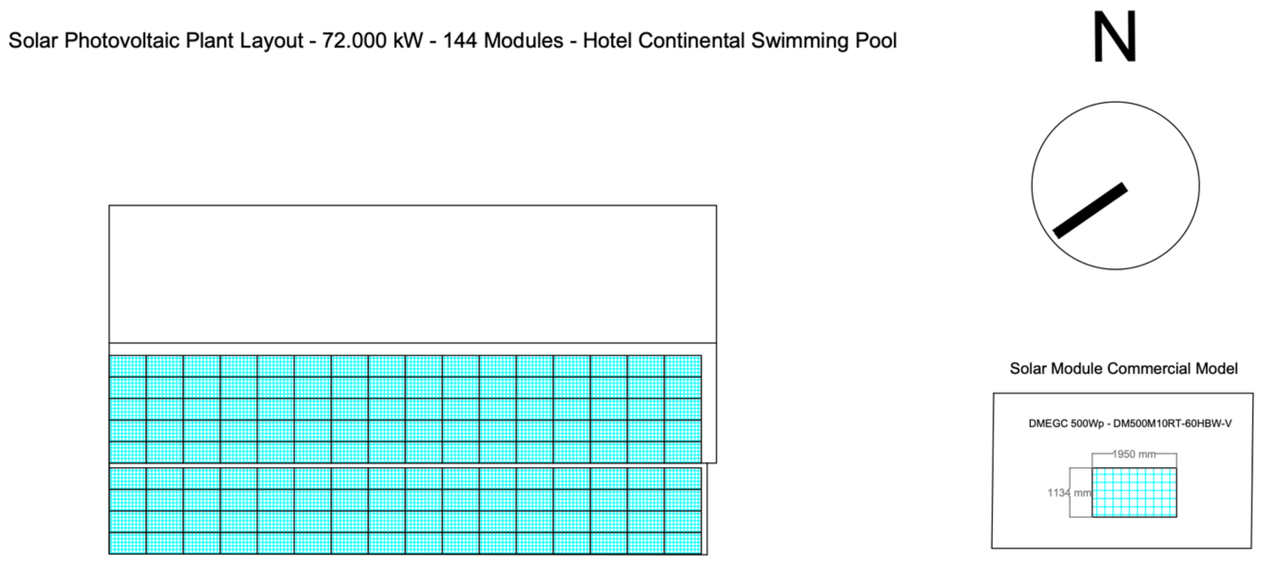

Figure 25: Solar photovoltaic layout on hotel swimming pool

The energy production of the system was estimated using the PVGIS tool, following the same methodology as applied to the school's photovoltaic system. Hourly data were extracted for analysis, with a summarized overview shown as follows:

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European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

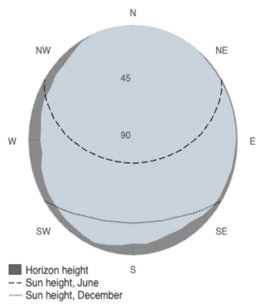
Provided inputs:

Latitude/Longitude:	40.730,13.945
Horizon:	Calculated
Database used:	PVGIS-SARAH3
PV technology:	Crystalline silicon
PV installed:	72 kWp
System loss:	14 %

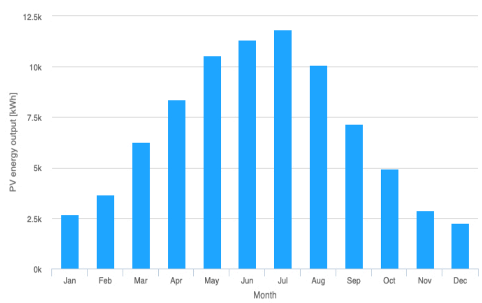
Simulation outputs

Slope angle:	20 °
Azimuth angle:	110 °
Yearly PV energy production:	81978.97 kWh
Yearly in-plane irradiation:	1523.96 kWh/m²
Year-to-year variability:	1730.97 kWh
Changes in output due to:	
Angle of incidence:	-3.9 %
Spectral effects:	0.15 %
Temperature and low irradiance:	-9.74 %
Total loss:	-25.29 %

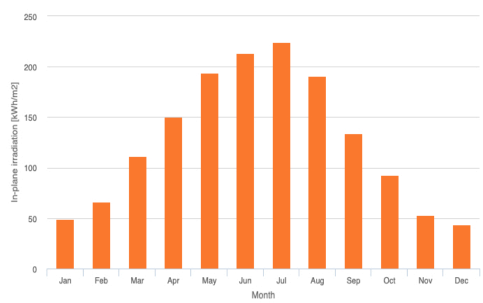
Outline of horizon at chosen location:



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	2672.8	49.3	259.3
February	3670.6	66.4	417.4
March	6263.0	111.7	684.3
April	8354.8	150.6	392.8
May	10545.1	193.6	742.7
June	11343.8	213.1	330.8
July	11831.3	224.6	336.3
August	10072.0	191.0	345.3
September	7148.0	134.3	256.2
October	4963.2	92.7	406.4
November	2865.0	53.2	296.0
December	2249.5	43.4	193.6

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].

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Figure 26: PVGIS simulation results - hotel swimming pool

Prosumer 3: The bus station deposit PV area

Another key prosumer within the community is the bus transport station, where a 42,5 kW photovoltaic system is planned for installation on the rooftop of a nearby building. However, before proceeding with the installation, a preliminary assessment is required to ensure the building complies with regulatory standards.

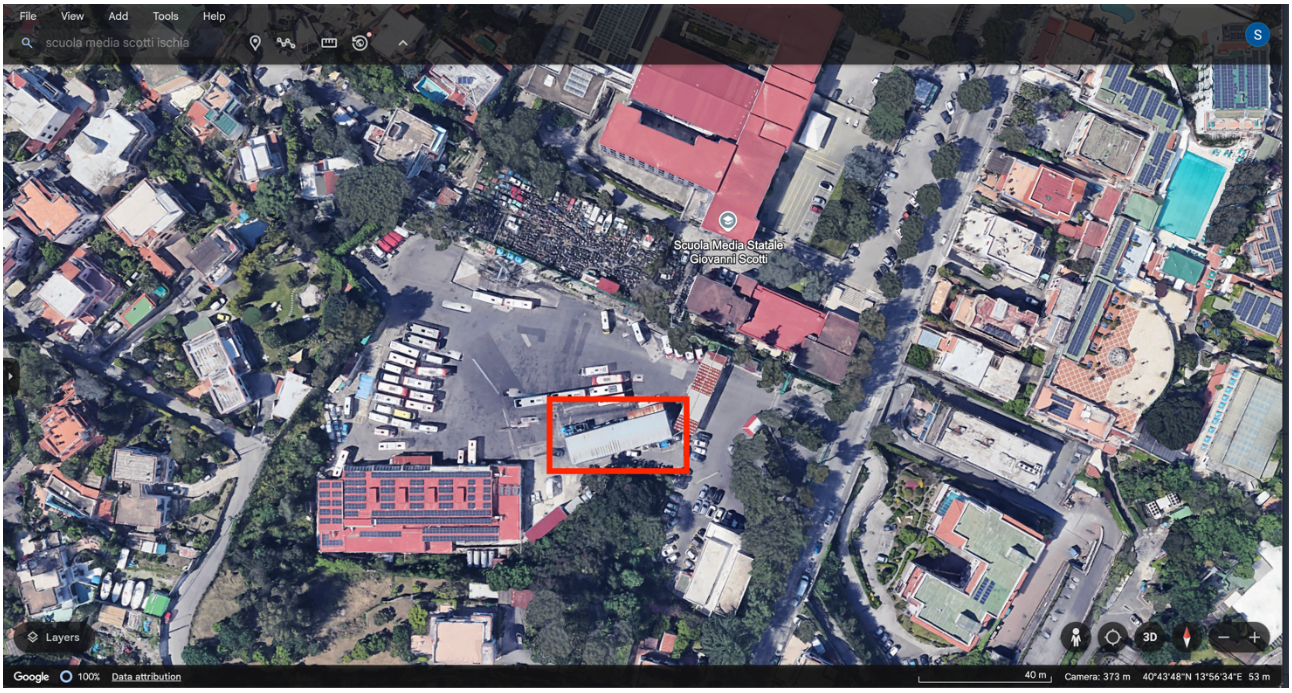


Figure 29: Aereal view of the site of interest Eavbus

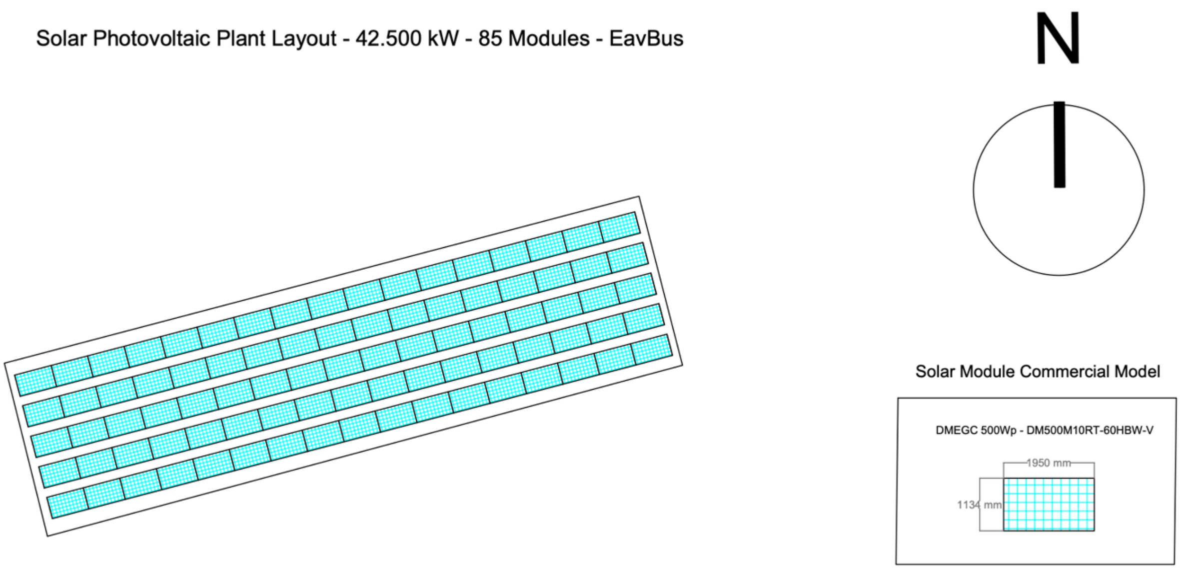
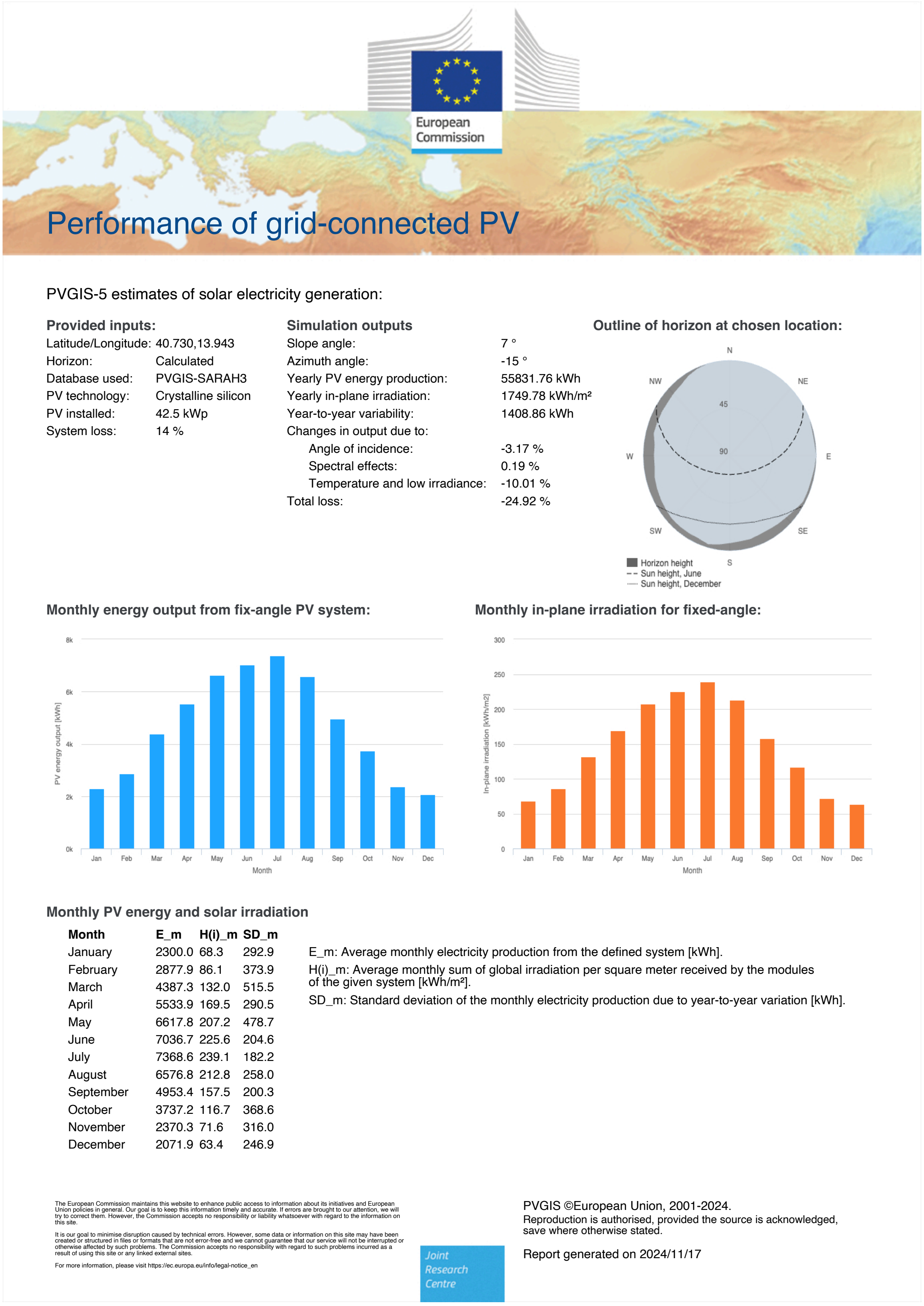


Figure 28: Solar photovoltaic layout of the eavbus chosen area

In this case, the azimuth is set to -15 degrees, and the chosen tilt angle is 7 degrees.



European Commission

Performance of grid-connected PV

PVGIS-5 estimates of solar electricity generation:

Provided inputs:

Latitude/Longitude:	40.730,13.943
Horizon:	Calculated
Database used:	PVGIS-SARAH3
PV technology:	Crystalline silicon
PV installed:	42.5 kWp
System loss:	14 %

Simulation outputs

Slope angle:	7 °
Azimuth angle:	-15 °
Yearly PV energy production:	55831.76 kWh
Yearly in-plane irradiation:	1749.78 kWh/m²
Year-to-year variability:	1408.86 kWh
Changes in output due to:	
Angle of incidence:	-3.17 %
Spectral effects:	0.19 %
Temperature and low irradiance:	-10.01 %
Total loss:	-24.92 %

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	2300.0	68.3	292.9
February	2877.9	86.1	373.9
March	4387.3	132.0	515.5
April	5533.9	169.5	290.5
May	6617.8	207.2	478.7
June	7036.7	225.6	204.6
July	7368.6	239.1	182.2
August	6576.8	212.8	258.0
September	4953.4	157.5	200.3
October	3737.2	116.7	368.6
November	2370.3	71.6	316.0
December	2071.9	63.4	246.9

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].

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Figure 30: PVGIS simulation test eavbus chosen area

Overall productivity of the PV plants

It is possible to compare the theoretical production of the three photovoltaic plants, respectively of the school, the hotel and the Eavbus station.

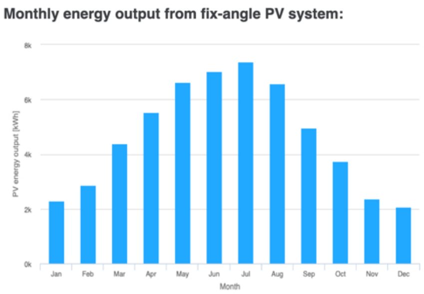


Figure 33: Producibility of the School PV plant

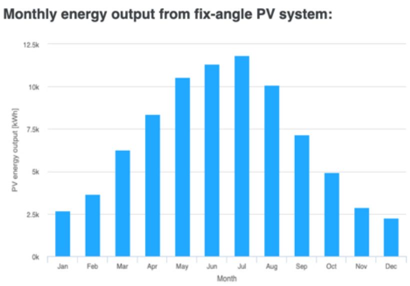


Figure 32: Producibility of the Hotel PV plant

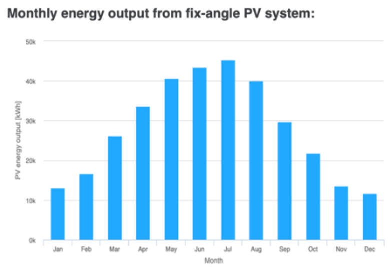


Figure 31: Producibility of the EAVBUS PV plant

As expected, the school's photovoltaic system achieves the highest energy production, as it has the largest installed capacity. This is followed by the hotel's system, with the bus station ranking third in terms of energy output.

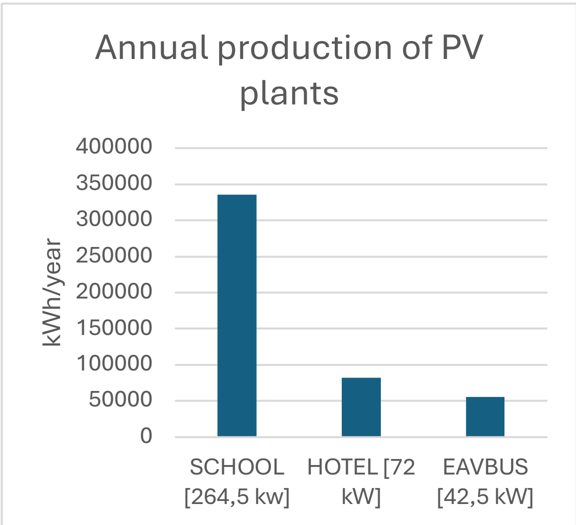


Figure 34: Annual theorical production of the 3 prosumers

As illustrated in Figure 34, the school's system reaches an annual output of nearly 350.000 kWh, for exceeding the production of the hotel and bus station, which each generate approximately 100.000 kWh annually.

This difference is primarily due to the school's significantly higher installed capacity. Additionally, less favourable conditions, such as suboptimal panel orientation and azimuth angles, affect the efficiency and overall output of the hotel and bus depot systems.

Energy Performance Evaluation

All the energy producing members of the community have been organized into a table that includes a summary displaying the installed power on various rooftops, the energy consumed throughout the year, the potential energy production, the instant energy consumption and the energy that each member has injected into the community.

More specifically, the indices used are as follows:

Annual consumption:

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

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

Annual production:

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

Where:

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

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

Energy direct self-consumed:

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

Where:

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

Energy injected grid:

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

Where:

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

Furthermore, two index are being provided to evaluate the

Self-sufficiency index:

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

Where:

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

Self-consumption index:

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

Where:

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

Self consumption and self sufficiency values are being calculated for individual members of the community considering both preexisting and newly installation plants for the energy community.

MEMBER	PEAK POWER EXSISTING INSTALLATION [kW]	PEAK POWER INSTALLED [kW]	TOTAL POWER INSTALLED [kW]	ANNUAL PRODUCTION [kWh]	ANNUAL CONSUMPTION [kWh]	ENERGY SELF CONSUMED [kWh]	SELF CONSUMPTION %	SELF SUFFICIENCY %
SCHOOL	0	264,5	264,5	326364	63684	34788	11%	55%
BUS STATION	95,5	42,5	138	162215	134475	44582	27%	33%
HOTEL	215	72	287	368021	952850	190061	52%	20%

Prosumer list existing plants and new installations

The values of self consumption and self sufficiency for the energy community have been calculated, and the results are displayed in the table.

PROSUMER LIST REC							
MEMBER	**PEAK POWER INSTALLED [kW]**	**ANNUAL PRODUCTION [kWh]**	**ANNUAL CONSUMPTION [kWh]**	**ENERGY SELF CONSUMED [kWh]**	**ENERGY SURPLUS INJECTED TO CER [kWh]**	**SELF CONSUMPTION %**	**SELF SUFFICIENCY %**
SCHOOL	264,5	326364	63684	34788	291576	-	-
BUS STATION	42,5	56191	134475	44582	26288	-	-
HOTEL	72	82691	952850	190061	17508	-	-
	PEAK POWER INSTALLED [kW]	**ANNUAL PRODUCTION [kWh]**	**ANNUAL CONSUMPTION [kWh]**	**ENERGY SELF CONSUMED [kWh]**	**ENERGY SURPLUS INJECTED TO THE CER [kWh]**		
REC	**379**	**465246**	**1151009**	**223409**	**335371**	**67%**	**19%**

$$SELF\ CONSUMPTION\ \% = \frac{ENERGY\ SELF\ CONSUMED}{ENERGY\ SURPLUS\ INJECTED\ TO\ THE\ GRID} = 67\ \%$$

Unfortunately, the result obtained is relatively low because the self-consumed energy, which is the basis for calculating the applicable incentives, should be around 80%.

Optimised Case and possible configurations

In this simulation, an attempt has been made to achieve a higher percentage of self consumed energy, thereby enhancing the community's performance.

To increase self consumption, a decision was made to reduce the installed power capacity of the school's photovoltaic system, which was previously oversized for its energy demand using most of the roof surface. The new installed capacity has been reduced to 150 kW.

From a design perspective, an optimal approach involves creating three separate strings, each using five 30 kW inverters.

A possible configuration example could be as follows:

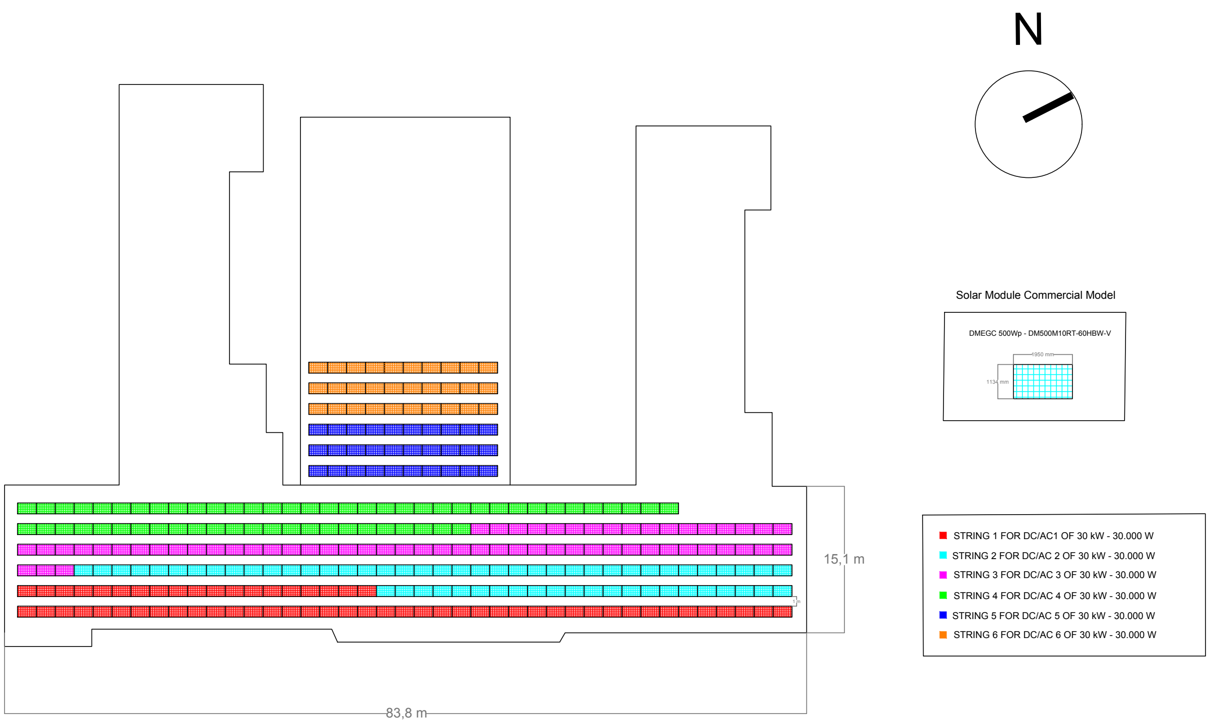


Figure 35: School photovoltaic layout in the optimized case

To maximise solar resource efficiency through MMPT (Maximum Power Point Tracking), a suitable inverter setup has been designed using the online configurator on the Zucchetti ZCS website [21].

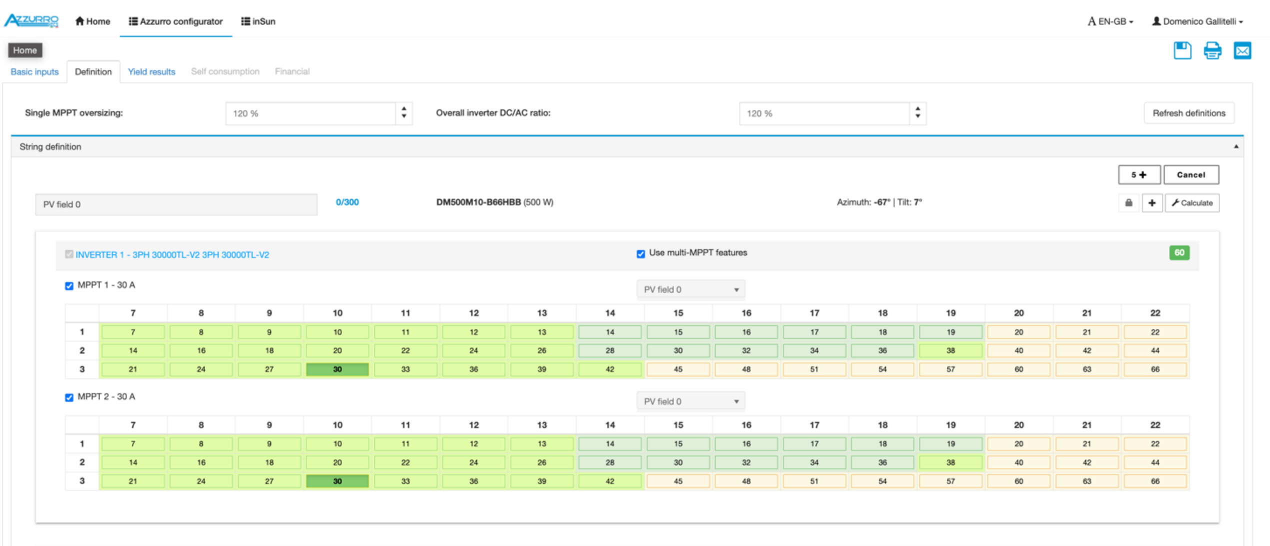


Figure 36: First inverter configuration

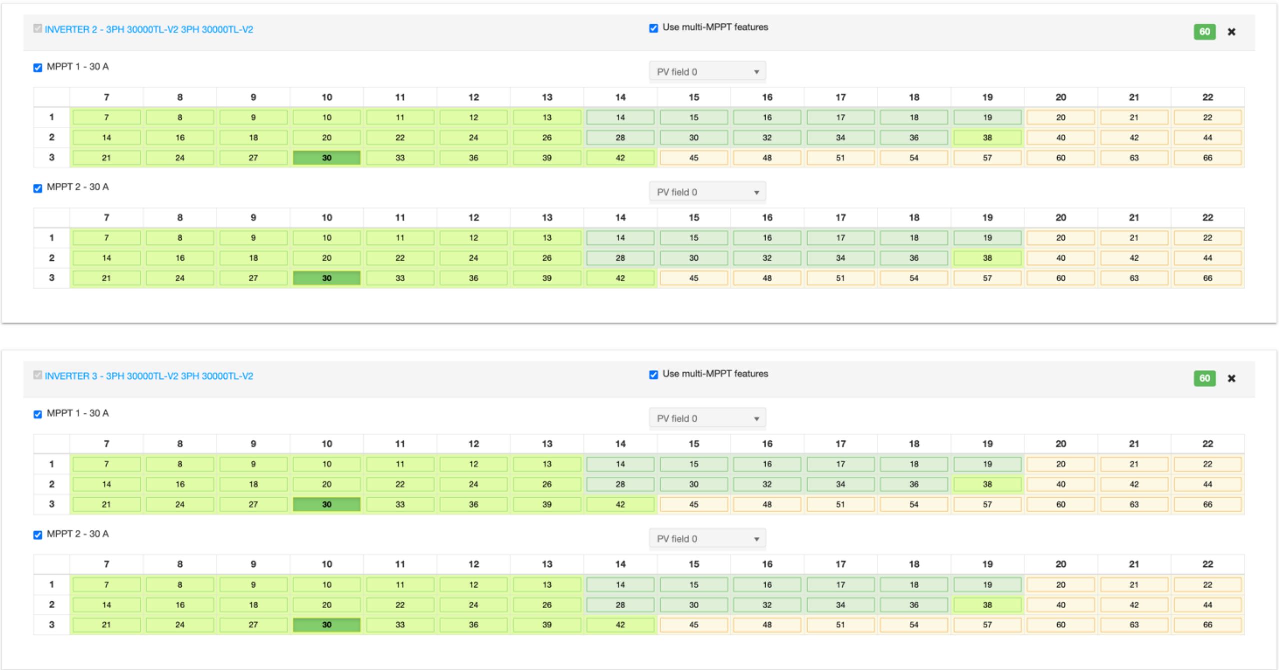


Figure 37: Second and third inverter configuration

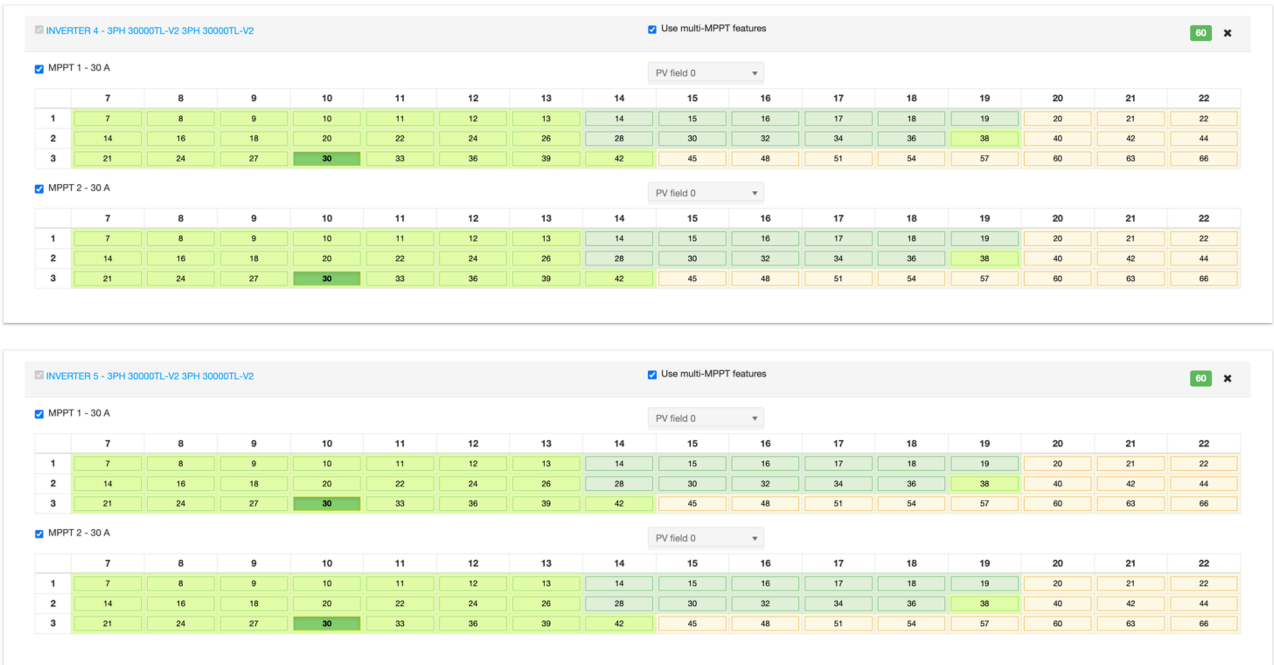


Figure 38: 5th and 6th inverter configuration

As a result, the new photovoltaic graphs for the system generated using the ZCS tool [21], are presented in the following section.

AZZURRO ZCS SIR in Via alfonso bonafous 8

Project Scuola media scotti Ischia **Date** 03/11/2024
Reference
Description
Address Via Michele Mazzella, 125, 80077 Ischia NA, Italy
Latitude 40.7306811 **Longitude** 13.9431920 **Altitude** 48.28

	PV field 0
Installation type	Roof mounted
Tilt	7.00°
Azimuth	-67.00°
Producer	DMEGC Solar
Model	DM500M10-B66HBB
N. modules	300
Total power	150 kWp
Min Temperature	-0.6 °C
Max Temperature	60.78 °C

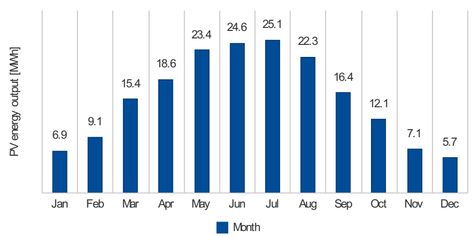
PV field 0

Nominal power	**500.00 W**	Open Circuit Voltage Voc	**45.74 V**
Short-circuit current Isc	**13.75 A**	Nominal voltage Vmp	**37.47 V**
Nominal current Imp	**13.35 A**	Temperature Coefficient of Voc	**-0.25 %/°C**
Temperature Coefficient of Isc	**0.04 %/°C**	Temperature Coefficient of Pmax	**-0.33 %/°C**

Summary

Yearly energy production	**186.87 MWh**	Specific Production	**1,245.81 kWh/kWp**
DC nominal power	**150.00 kWp**	AC nominal power	**150.00 kW**
Horizontal Irradiation	**1,455.99 kWh/m²**	Tilted irradiation	**1,546.97 kWh/m²**
Meteo data provider	**Meteonorm**	Performance Ratio PR	**83.23%**

Annual energy production



Performance Ratio PR

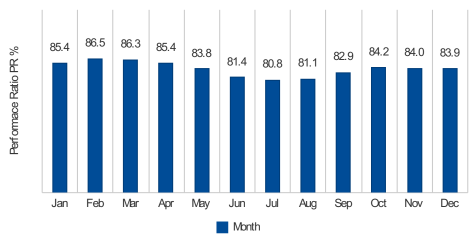


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Figure 39: Results of the tool simulation

SIR in Via alfonso bonafous 8

Inverter 1, 2, 3, 4, 5

Model	**3PH 30000TL-V2-3PH 30000TL-V2**
AC nominal power	**30 kW**
Rated voltage	**620 V**
Number of MPPT channel	**2**
Total modules number	**60**
Installed DC power STC	**30 kW**

The selected working conditions may involve power limitations

	MPPT 1	MPPT 2
PV field	PV field 1	PV field 1
Modules per string	10	10
Number of strings in parallel	3	3
Total modules number	30	30
Installed STC power MPPT [kW]	15	15
Power limit MPPT [kW]	18	18
PPV(inst),MPPTi/PMMPTMAX	0.83	0.83
PPV(inst)/PACR	100.00%	
PPV(inst)/PACMAX	90.91%	
Maximum inverter input voltage	1100	1100
Activation voltage	250	250
Operating range MPPT at maximum power	520 - 850	520 - 850
Voc_Max String open circuit @Min.Temp	486.21	486.21
Voc_Min String open circuit @Max.Temp	417.14	417.14
Vmp_Max Voltage mp string @Min.Temp	398.30	398.30
Vmp_Min Voltage mp string @Max.Temp	341.72	341.72
DC Max Isc current	37.5	37.5
DC Isc current @Max.Temp	41.91	41.91
Max Imp current	30	30
Max Imp current @Max.Temp	40.69	40.69
Battery model		
Storage system		
Enabled for Storage	False	

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Figure 40: The chosen inverter model 3PH 30000TL-V2-3PH 30000TL-V2 [22]

For the EAV Bus station, the decision was made to use two 20 kW inverters to connect to the photovoltaic panels.

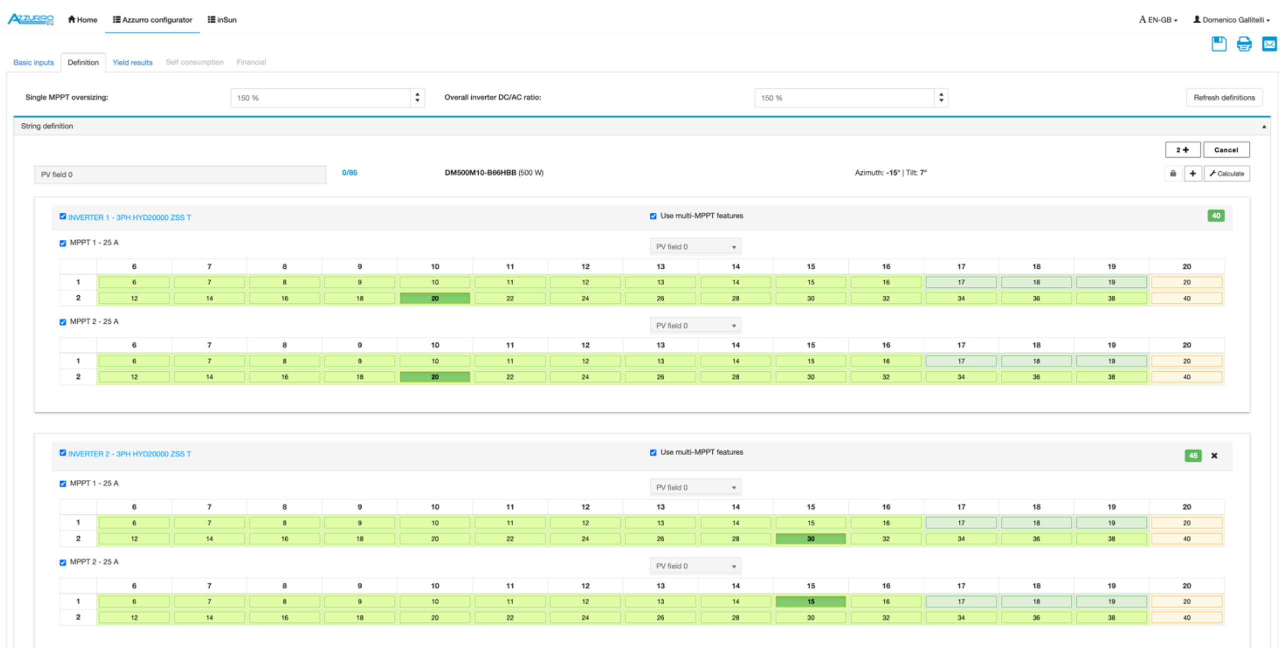
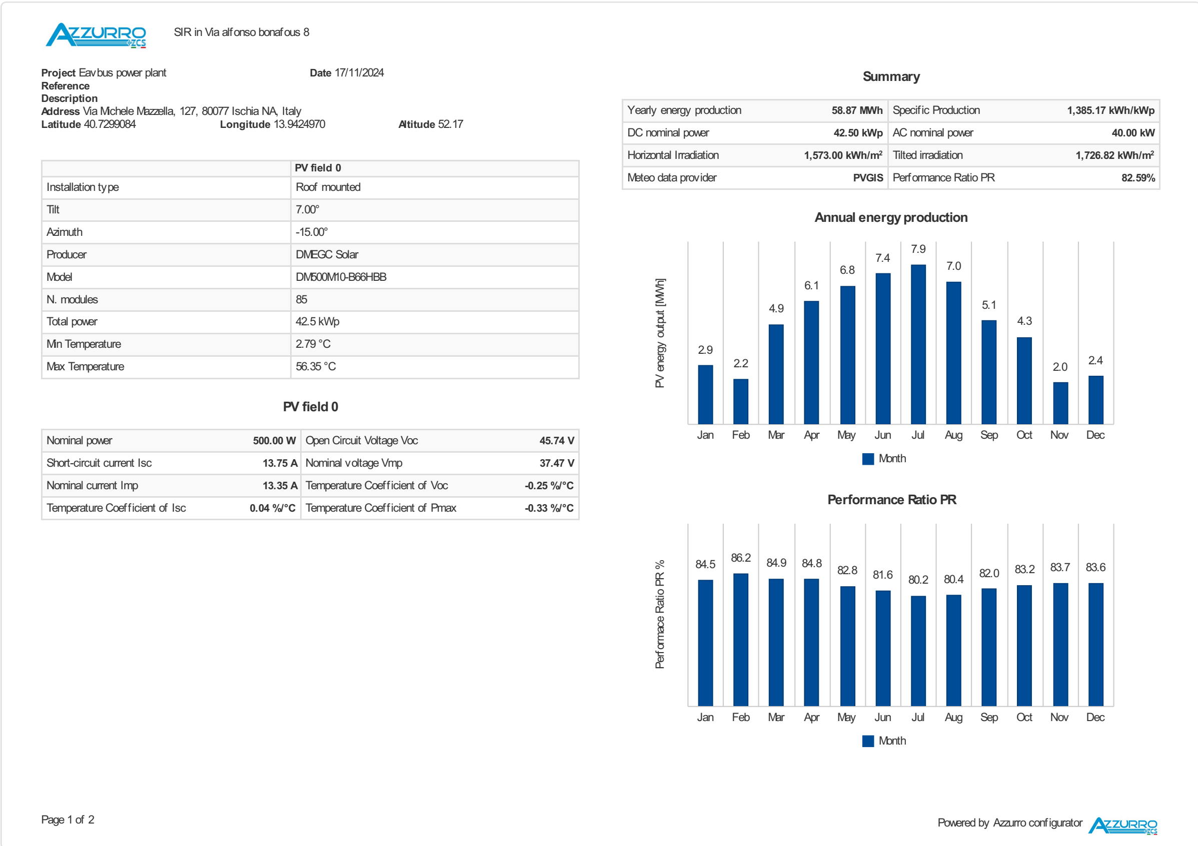


Figure 42: First and second inverter possible configuration



SIR in Via alfonso bonafous 8

Project Eavbus power plant **Date** 17/11/2024
Reference
Description
Address Via Michele Mazzella, 127, 80077 Ischia NA, Italy
Latitude 40.7299084 **Longitude** 13.9424970 **Altitude** 52.17

	PV field 0
Installation type	Roof mounted
Tilt	7.00°
Azimuth	-15.00°
Producer	DMEGC Solar
Model	DM500M10-B66HBB
N. modules	85
Total power	42.5 kWp
Min Temperature	2.79 °C
Max Temperature	56.35 °C

PV field 0

Nominal power	500.00 W	Open Circuit Voltage Voc	45.74 V
Short-circuit current Isc	13.75 A	Nominal voltage Vmp	37.47 V
Nominal current Imp	13.35 A	Temperature Coefficient of Voc	-0.25 %/°C
Temperature Coefficient of Isc	0.04 %/°C	Temperature Coefficient of Pmax	-0.33 %/°C

Summary

Yearly energy production	58.87 MWh	Specific Production	1,385.17 kWh/kWp
DC nominal power	42.50 kWp	AC nominal power	40.00 kW
Horizontal Irradiation	1,573.00 kWh/m²	Tilted irradiation	1,726.82 kWh/m²
Meteo data provider	PVGIS	Performance Ratio PR	82.59%

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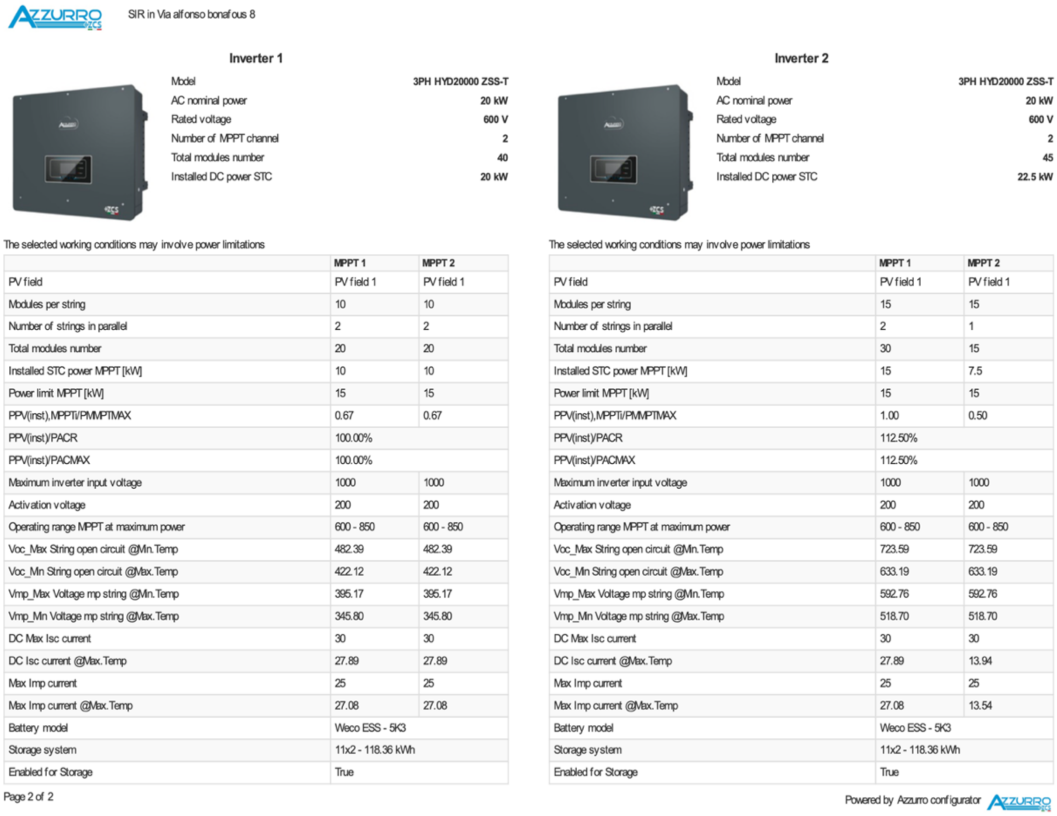
Figure 43: Result of the tool simulation (Eavbus)



SIR in Via alfonso bonafous 8

Inverter 1

Model	3PH HYD20000 ZSS-T
AC nominal power	20 kW
Rated voltage	600 V
Number of MPPT channel	2
Total modules number	40
Installed DC power STC	20 kW

The selected working conditions may involve power limitations

	MPPT 1	MPPT 2
PV field	PV field 1	PV field 1
Modules per string	10	10
Number of strings in parallel	2	2
Total modules number	20	20
Installed STC power MPPT [kW]	10	10
Power limit MPPT [kW]	15	15
PPV(inst),MPPTi/PMMPTMAX	0.67	0.67
PPV(inst)/PACR	100.00%	
PPV(inst)/PACMAX	100.00%	
Maximum inverter input voltage	1000	1000
Activation voltage	200	200
Operating range MPPT at maximum power	600 - 850	600 - 850
Voc_Max String open circuit @Min.Temp	482.39	482.39
Voc_Min String open circuit @Max.Temp	422.12	422.12
Vmp_Max Voltage mp string @Min.Temp	395.17	395.17
Vmp_Min Voltage mp string @Max.Temp	345.80	345.80
DC Max Isc current	30	30
DC Isc current @Max.Temp	27.89	27.89
Max Imp current	25	25
Max Imp current @Max.Temp	27.08	27.08
Battery model	Weco ESS - 5K3	
Storage system	11x2 - 118.36 kWh	
Enabled for Storage	True	

Inverter 2

Model	3PH HYD20000 ZSS-T
AC nominal power	20 kW
Rated voltage	600 V
Number of MPPT channel	2
Total modules number	45
Installed DC power STC	22.5 kW

The selected working conditions may involve power limitations

	MPPT 1	MPPT 2
PV field	PV field 1	PV field 1
Modules per string	15	15
Number of strings in parallel	2	1
Total modules number	30	15
Installed STC power MPPT [kW]	15	7.5
Power limit MPPT [kW]	15	15
PPV(inst),MPPTi/PMMPTMAX	1.00	0.50
PPV(inst)/PACR	112.50%	
PPV(inst)/PACMAX	112.50%	
Maximum inverter input voltage	1000	1000
Activation voltage	200	200
Operating range MPPT at maximum power	600 - 850	600 - 850
Voc_Max String open circuit @Min.Temp	723.59	723.59
Voc_Min String open circuit @Max.Temp	633.19	633.19
Vmp_Max Voltage mp string @Min.Temp	592.76	592.76
Vmp_Min Voltage mp string @Max.Temp	518.70	518.70
DC Max Isc current	30	30
DC Isc current @Max.Temp	27.89	13.94
Max Imp current	25	25
Max Imp current @Max.Temp	27.08	13.54
Battery model	Weco ESS - 5K3	
Storage system	11x2 - 118.36 kWh	
Enabled for Storage	True	

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Figure 44: The chosen inverters for Eavbus PV plant

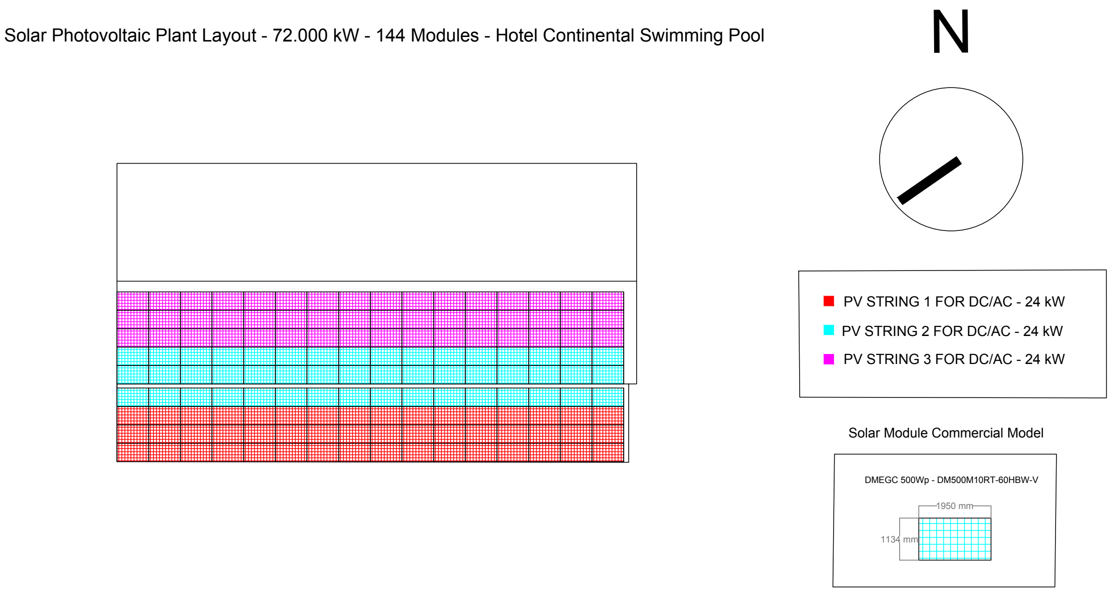


Figure 45: Hotel continental swimming pool photovoltaic possible configuration

A possible configuration for the Hotel swimming pool PV plant can be the following:

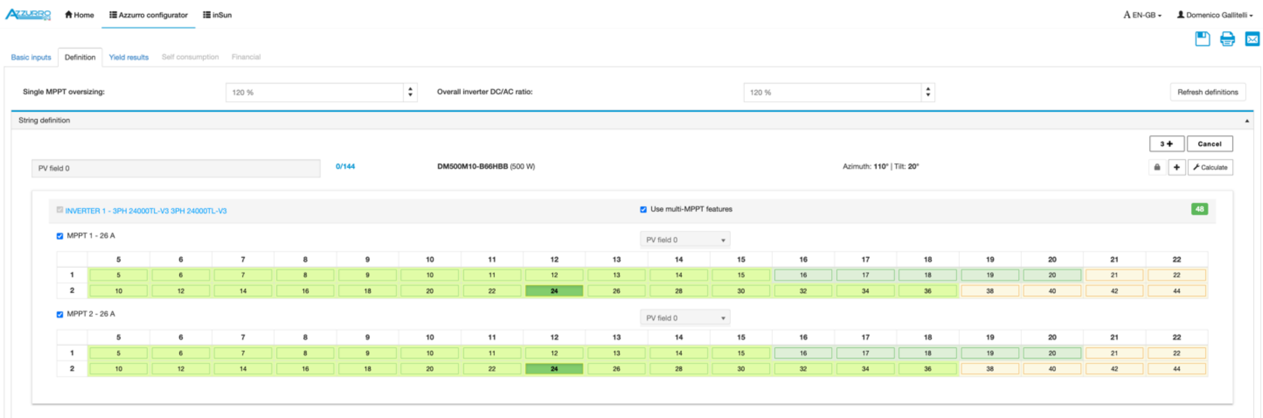


Figure 46: First inverter possible configuration

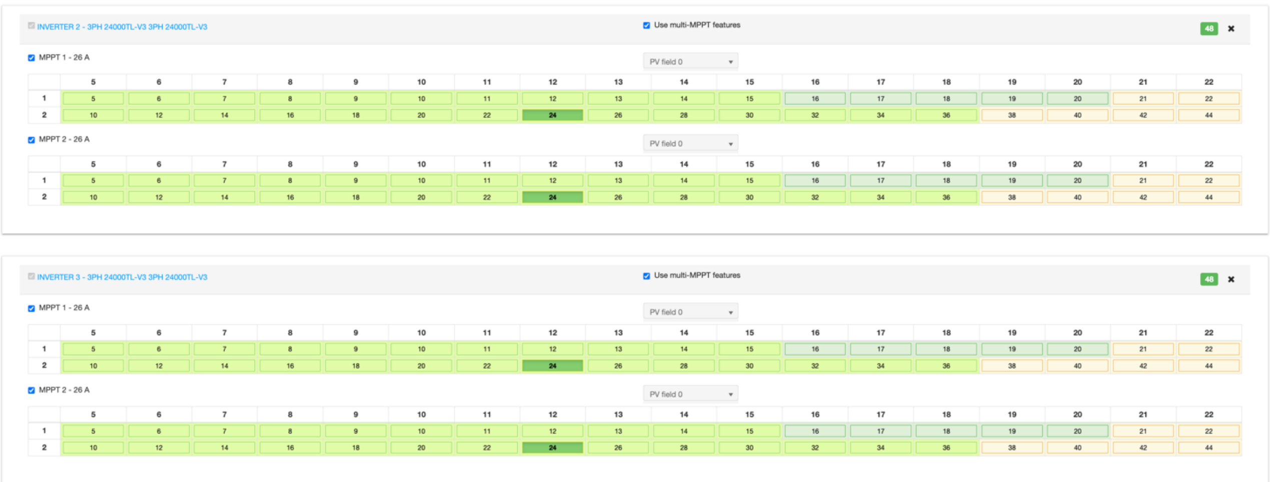
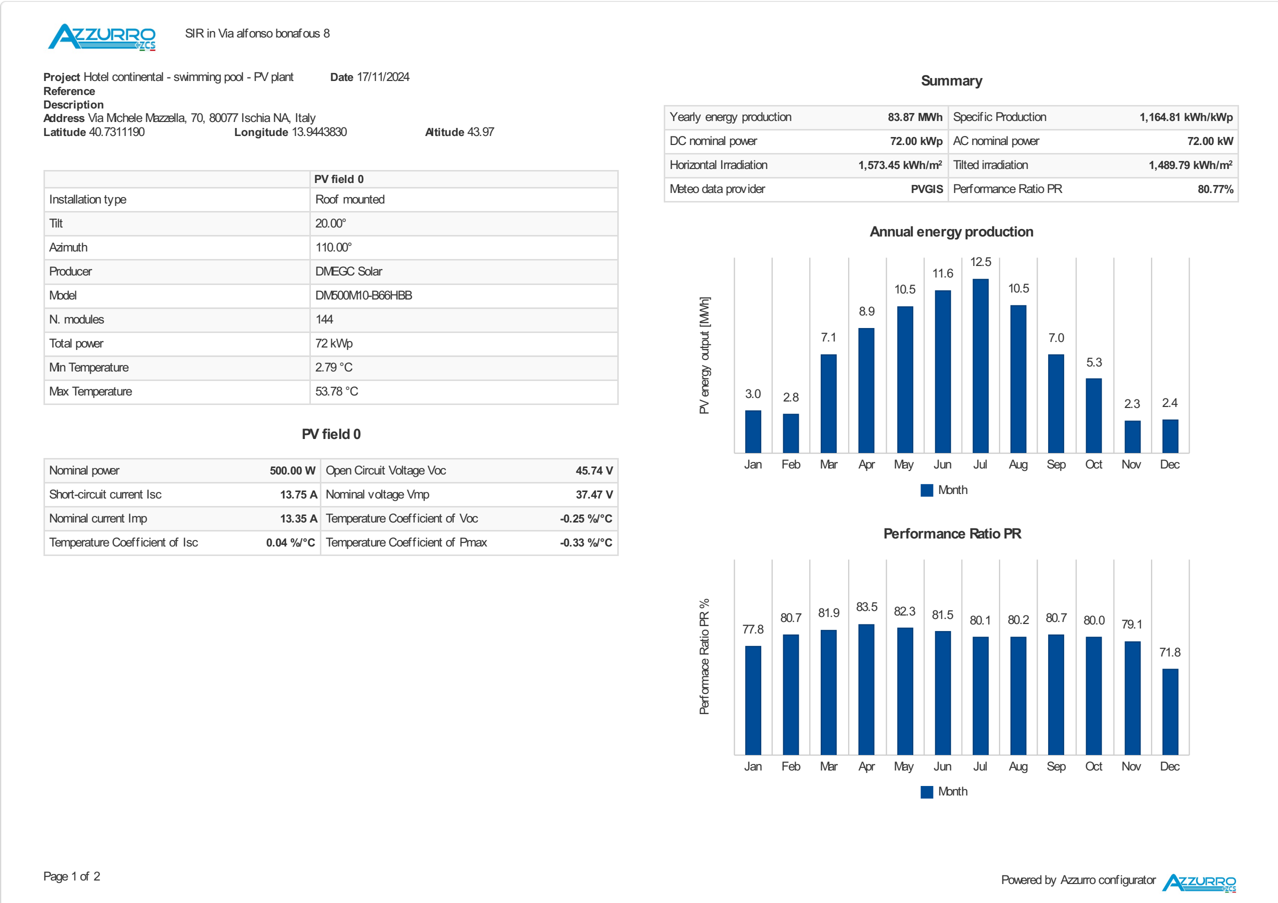


Figure 47: Second and third inverter possible configuration



SIR in Via alfonso bonafous 8

Project Hotel continental - swimming pool - PV plant **Date** 17/11/2024
Reference
Description
Address Via Michele Mazzella, 70, 80077 Ischia NA, Italy
Latitude 40.7311190 **Longitude** 13.9443830 **Altitude** 43.97

	PV field 0
Installation type	Roof mounted
Tilt	20.00°
Azimuth	110.00°
Producer	DMEGC Solar
Model	DM500M10-B66HBB
N. modules	144
Total power	72 kWp
Min Temperature	2.79 °C
Max Temperature	53.78 °C

PV field 0

Nominal power	500.00 W	Open Circuit Voltage Voc	45.74 V
Short-circuit current Isc	13.75 A	Nominal voltage Vmp	37.47 V
Nominal current Imp	13.35 A	Temperature Coefficient of Voc	-0.25 %/°C
Temperature Coefficient of Isc	0.04 %/°C	Temperature Coefficient of Pmax	-0.33 %/°C

Summary

Yearly energy production	83.87 MWh	Specific Production	1,164.81 kWh/kWp
DC nominal power	72.00 kWp	AC nominal power	72.00 kW
Horizontal Irradiation	1,573.45 kWh/m²	Tilted irradiation	1,489.79 kWh/m²
Meteo data provider	PVGIS	Performance Ratio PR	80.77%

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Figure 48: Simulation results of hotel swimming pool PV plant

SIR in Via alfonso bonafous 8

Inverter 1, 2, 3

Model	**3PH 24000TL-V3-3PH 24000TL-V3**
AC nominal power	**24 kW**
Rated voltage	**650 V**
Number of MPPT channel	**2**
Total modules number	**48**
Installed DC power STC	**24 kW**

The selected working conditions may involve power limitations

	MPPT 1	**MPPT 2**
PV field	PV field 1	PV field 1
Modules per string	12	12
Number of strings in parallel	2	2
Total modules number	24	24
Installed STC power MPPT [kW]	12	12
Power limit MPPT [kW]	15	15
PPV(inst),MPPTi/PMMPTMAX	0.80	0.80
PPV(inst)/PACR	100.00%	
PPV(inst)/PACMAX	90.91%	
Maximum inverter input voltage	1100	1100
Activation voltage	160	160
Operating range MPPT at maximum power	580 - 850	580 - 850
Voc_Max String open circuit @Min.Temp	578.87	578.87
Voc_Min String open circuit @Max.Temp	510.02	510.02
Vmp_Max Voltage mp string @Min.Temp	474.21	474.21
Vmp_Min Voltage mp string @Max.Temp	417.81	417.81
DC Max Isc current	36	36
DC Isc current @Max.Temp	27.85	27.85
Max Imp current	26	26
Max Imp current @Max.Temp	27.04	27.04
Battery model		
Storage system		
Enabled for Storage	False	

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Figure 49: The chosen inverter module for hotel swimming pool

With this new configuration:

MEMBER	PEAK POWER EXSISTING INSTALLATION [kW]	PEAK POWER INSTALLED [kW]	TOTAL POWER INSTALLED [kW]	ANNUAL PRODUCTION [kWh]	ANNUAL CONSUMPTION [kWh]	ENERGY SELF CONSUMED [kWh]	SELF CONSUMPTION %	SELF SUFFICIENCY %
SCHOOL	0	150	150	185083	63684	32987	18%	52%
BUS STATION	95,5	42,5	138	162215	134475	44582	27%	33%
HOTEL	215	72	287	368021	952850	190061	52%	20%

And, regarding the REC energy balance:

PROSUMER LIST REC							
MEMBER	**PEAK POWER INSTALLED [kW]**	**ANNUAL PRODUCTION [kWh]**	**ANNUAL CONSUMPTION [kWh]**	**ENERGY SELF CONSUMED [kWh]**	**ENERGY SURPLUS INJECTED TO CER [kWh]**	**SELF CONSUMPTION %**	**SELF SUFFICIENCY %**
SCHOOL	150	185083	63684	32987	152096	-	-
BUS STATION	42,5	56191	134475	44582	26288	-	-
HOTEL	72	82691	952850	190061	17508	-	-
	PEAK POWER INSTALLED	**ANNUAL PRODUCTION**	**ANNUAL CONSUMPTION**	**ENERGY SELF CONSUMED**	**ENERGY SURPLUS INJECTED TO THE CER**		
REC	**264,5**	**323965**	**1151009**	**163763**	**195892**	**84%**	**14%**

As a result, the reduction in kWh has enabled better self-consumption rates for the community.

$$SELF\ CONSUMPTION\ \% = \frac{ENERGY\ SELF\ CONSUMED}{ENERGY\ SURPLUS\ INJECTED\ TO\ THE\ GRID} = 84\ \%$$

This value is considered sufficiently reliable for assessing the amount of energy self consumed, as it exceeds 80% of the entire community. This high level of self consumption suggests a strong potential for economic subsidies that the community could receive.

Politecnico di Torino

Economic evaluation

The economic analysis of the Renewable Energy Community aims to assess the financial viability and benefits of adopting this model as an energy solution for municipalities or local authorities. Specifically, the analysis examines economic feasibility, costs and benefits for the local area. Various economic indices, such as CAPEX and OPEX, are used in the evaluation, alongside insights into the community's broader economic objectives.

CAPEX (Capital Expenditures)

This metric is useful for assessing the investment costs associated with installing photovoltaic systems (e.g. solar panels, inverters and batteries) for each prosumer within the community. The evaluation considers both the optimised scenario (designed for the best possible installable power) and the non-optimised scenario (focused on the maximum possible power installation).

The following costs can be considered for the procurement and installation of the photovoltaic systems depending on the size of the plant:

Plant size (Power) [kW]	Unit prices [€/kW]
P < 20 kW	1500 €/kW
20 kW < P < 200 kW	1200 €/kW
200 kW < P < 600 kW	1100 €/kW
600 kW < P < 1000 kW	1050 €/kW

In this scenario:

	Base Case		Optimised Case	
MEMBER	**POWER [kW]**	**CAPEX [€]**	**POWER [kW]**	**CAPEX [€]**
SCHOOL	264,5	290.950	150	180.000
BUS STATION	42,5	51.000	42,5	51.000
HOTEL	72	86.400	72	86.400
REC	**379**	**428.350**	**264,5**	**317.400**

OPEX (Operating Expenses or Expenditure)

Annual management costs are estimated to maintain the plant's operation at peak performance.

OPEX includes maintenance and operational expenses, estimated at approximately €20/kWp per year, alongside insurance costs, which amount to roughly 1% of the total CAPEX.

OPEX	Unit prices	Costs Base Case	Costs Optimised Case
Maintenance costs	[€/kWp/year]	7.580	5.290
Insurance costs	1 % of capex [€/year]	4.284	3.174

Revenues

An economic analysis is necessary to estimate the future revenue generated by photovoltaic systems installed on building rooftops. These revenues can either be paid directly to the prosumer or allocated to the energy community to which the installations belong. In the latter scenario, a portion of the revenues is subsequently redistributed to the prosumer who initially invested, in accordance with the regulations governing RECs.

Generally, the three energy vectors in the photovoltaic energy balance are: consumed energy (taken from the grid), injected energy (sent to the grid) and self consumed energy.

Produced energy refers to the total amount of energy generated by the photovoltaic systems. Injected energy is the portion of this production that is not consumed locally and is instead fed into the electrical grid for external use outside the community. Consumed energy represents the part of the produced energy that is utilized directly by the producer or within the REC, without being sent to the grid.

For example, as previously discussed in Figure 8, the scenario for a member of the REC could be as follows: grid-injected electricity occurs primarily during the middle hours of the day when there is a lot of electricity production. Meanwhile, electricity is drawn from the grid during off-peak periods (such as at night) when there is no photovoltaic production. Then, self-consumed energy is typical when the electricity produced by the photovoltaic system matches the user's consumption.

Incentives allocation and distribution

Revenue generated by energy shared within each renewable energy plant is distributed across several categories, each serving a distinct purpose:

- Management fund is allocated to cover the costs of managing and operating the REC.
- Producer allocation is designated for distribution among the producer members of the community those who generate electricity.
- Corporate consumer share is part of revenues allocated to consumer members that are companies, as part of the REC.
- Non-corporate consumer share represents the share allocated to consumer members who are not companies (e.g. individuals or other non business entities).
- Social fund is reserved for the REC to support social initiatives or community-based activities.

If the shared renewable energy is generated from installations that were not subsidised by non-repayable incentives, revenue distribution follows specific priorities and percentage allocations outlined in the guidelines.

Cash Flow analysis and Net Present Value (NPV)

In the following paragraphs, a cash flow analysis has been performed for each prosumer to evaluate the economic performance and the return of investment (ROI) of the PV plants.

Self-consumption contribution

Self consumption refers to the ability of energy producers to use the electricity they generated within the same building. This practice reduces electricity bills by minimising reliance on the national grid. The financial savings resulting from reduced grid dependence, covering both energy costs and network costs, are estimated at approximately 240 €/MWh.

As a result, direct self consumption is the most cost-effective option for prosumers, as it enables them to directly offset their electricity expenses. In November 2024, the average electricity price stood at 0,28 €/kWh, meaning a prosumer saves € 0,28 for every kilowatt hour self-consumed. Additionally, self consumption avoids energy transport and distribution costs, making it a more financially beneficial alternative to selling surplus energy back to the grid.

Dedicated Withdrawal contribution

Starting from January 2025, the on-site exchange (known as "Scambio sul Posto") is no longer available, making dedicated withdrawal the preferred contractual arrangement for producers to sell surplus energy to the grid. Under this arrangement, producers can sell electricity fed into the grid, with revenues calculated by the zonal electricity price which, as of November 2024, averages around 105 €/MWh.

Prezzi 2024 (Euro/MWh)												
Fascia	**F1**											
Zona	**gen.**	**feb.**	**mar.**	**apr.**	**mag.**	**giu.**	**lug.**	**ago.**	**set.**	**ott.**	**nov.**	**dic.**
Centro Nord	103,60	90,82	90,02	76,12	90,75	99,92	106,41	116,88	115,57	112,93		
Centro Sud	101,75	86,00	89,59	75,54	88,94	99,83	106,35	116,63	113,11	109,12		
Nord	103,42	90,34	89,79	76,60	90,50	99,56	105,87	116,77	115,73	114,48		
Sardegna	93,82	84,99	63,45	47,17	73,37	96,66	86,11	117,70	92,67	99,24		
Sicilia	98,95	87,45	83,24	73,78	86,45	99,14	107,30	117,73	113,88	122,28		
Sud	100,85	85,04	83,69	73,86	82,33	99,82	106,52	116,72	112,23	111,11		
Calabria	100,51	84,39	83,70	73,65	82,78	99,56	106,25	117,51	113,39	110,92		
Fascia	**F2**											
Zona	**gen.**	**feb.**	**mar.**	**apr.**	**mag.**	**giu.**	**lug.**	**ago.**	**set.**	**ott.**	**nov.**	**dic.**
Centro Nord	96,96	83,30	79,34	74,81	83,59	87,03	110,08	120,40	102,53	102,77		
Centro Sud	95,27	81,03	70,97	74,36	80,51	86,41	107,43	116,38	97,80	97,34		
Nord	97,39	84,17	78,74	77,19	86,34	91,26	103,30	116,36	104,55	108,15		
Sardegna	98,87	79,88	69,68	64,69	84,24	95,23	122,60	131,05	89,91	86,29		
Sicilia	94,51	84,46	68,31	71,30	81,52	91,07	106,81	119,46	102,98	114,43		
Sud	98,88	85,36	73,00	75,39	82,16	88,65	107,37	116,32	100,82	102,81		
Calabria	98,74	85,73	73,17	74,40	84,59	89,96	107,53	118,75	104,42	102,18		
Fascia	**F3**											
Zona	**gen.**	**feb.**	**mar.**	**apr.**	**mag.**	**giu.**	**lug.**	**ago.**	**set.**	**ott.**	**nov.**	**dic.**
Centro Nord	85,75	72,02	65,74	58,12	60,60	71,34	100,45	117,11	85,38	99,27		
Centro Sud	82,22	71,65	58,71	56,32	57,70	73,58	99,80	116,07	81,52	96,29		
Nord	87,48	72,48	66,03	63,32	65,88	76,47	96,94	116,14	90,79	100,07		
Sardegna	84,60	65,28	54,86	54,47	58,08	81,38	105,96	120,17	82,11	91,42		
Sicilia	84,59	70,30	48,14	54,87	56,77	73,11	99,35	117,17	80,06	102,27		
Sud	83,34	71,73	56,39	59,03	62,71	74,38	100,19	116,25	85,11	96,25		
Calabria	84,89	73,00	57,23	56,37	62,34	78,37	100,02	117,03	86,32	99,30		

Figure 50: GSE Zonal prices

Dedicated withdrawal allows producers to sell the energy fed into the grid at the average zonal price, which was € 0,103/kWh in October 2024. While this kind of revenue depends on market conditions and local energy demand which can introduce variability, it provides a consistent income stream for surplus energy that is not consumed on-site. Although the earnings from dedicated withdrawal are lower than those from self-consumption, it helps prosumers to optimise their total revenue by monetizing excess energy.

Avoided Network Costs (ARERA Contribution)

In addition, the "Testo Integrato Autoconsumo Diffuso" (TIAD), published by ARERA, stipulates that electricity shared among connection points within the same distribution network area, served by a single primary substation, is valued through the reimbursement of the variable component of the transmission tariff. For example, for the reference year 2024, this reimbursement is set at 10,57 €/MWh.

Premium Tariff (REC incentive)

Renewable Energy Communities receive an incentive known as the premium tariff, which is applied to the energy shared among the community members. This tariff, established by the "Ministero dell'Ambiente e della Sicurezza Energetica" (MASE), corresponds to an average zonal price of approximately 140 €/MWh.

The combination of the premium tariff and ARERA contribution rewards prosumers who contribute to the sustainability of RECs. If more than 35% of the energy fed into the grid is consumed within the REC, the prosumer receives 25% of the premium tariff plus the ARERA contribution. In this way prosumers are incentivized to contribute to the energy efficiency and sustainability of RECs while offering an additional financial benefit.

Installed capacity [kW]	Incentive [€/MWh]	ARERA tariff [€/MWh]	Overall maximum contributions [€/MWh]
P < 200 kW	80 + max(0;180-Pz)	10	140
200 kW < P < 600 kW	70 + max(0;180-Pz)	10	130
P > 600 kW	60 + max(0;180-Pz)	10	120

Cash flow analysis

The cash flow analysis is helpful to evaluate the return of investment (ROI) and it is calculated as:

$$CASH\ FLOW = (Revenues_t - OPEX_t) \cdot \frac{1}{(1+i)^t} \quad with\ t = 1,2,3, \dots 20\ and\ i = 4\%$$

Where the parameter "t" represents the life of the plant, the revenues are the sum of the annual income generated by the photovoltaic plat, the cash flow during the 0^{th}-year (t=0) is equal to -CAPEX and the parameter $i = 4\%$.

Type of Incentive	Incentive [€/kWh]	Indices	Percentage distribution [%]	Revenues [€/kWh]
Self consumption	0,28	E_{sc}	100%	0,28
Dedicated Withdrawal	0,105	E_{inj}	100%	0,105
Premium Tariff [P < 200 kW]	0,157	E_{inj}	15 % - 25 %	0,0393
Premium Tariff [200 kW < P < 600 kW]	0,147	E_{inj}	15 % - 25 %	0,0368
Premium Tariff [P > 600 kW]	0,137	E_{inj}	15 % - 25 %	0,0343
Avoided network costs	0,0106	E_{inj}	25 %	0,0027

Net Present Value (NPV)

The Net Present Value (NPV) is a key financial indicator used to evaluate the profitability of an investment over time. It calculates the present value of all future cash flows generated by the whole project, adjusted to their current value and subtracts the initial capital investment which is the CAPEX. This calculation provides a year by year representation of the net investment value.

For a renewable energy plant, NPV considers the costs and benefits of operating renewable energy infrastructure. This includes components such as solar panels, inverters, cables, switchers, electric materials and associated facilities. The analysis incorporates factors such as CAPEX, OPEX, energy production, revenue streams and discount rates. A positive NPV indicates that the project is expected to generate a return on investment, confirming its financial viability.

In the specific case of a renewable energy plant, the NPV calculation also includes all revenues derived from energy production. As previously discussed, these revenues for a prosumer include:

$$Revenues_{P<200kW} = E_{sc}[kWh] * 0{,}28\ [€/kWh] + E_{inj}[kWh] * (0{,}0027 + 0{,}0393)[€/kWh] + E_{inj}[kWh] * 0{,}105[€/kWh]$$

$$Revenues_{200kW<P<600kW} = E_{sc}[kWh] * 0{,}28\ [€/kWh] + E_{inj}[kWh] * (0{,}0027 + 0{,}0368)[€/kWh] +$$

$$+E_{inj}[kWh] * 0{,}105[€/kWh]$$

$$Revenues_{P>600kW} = E_{sc}[kWh] * 0{,}28\ [€/kWh] + E_{inj}[kWh] * (0{,}0027 + 0{,}0343)[€/kWh] + E_{inj}[kWh] * 0{,}105[€/kWh]$$

Cash flow analysis in the Standard Case

Prosumer 1: The school - Standard Case - 264,5 kW

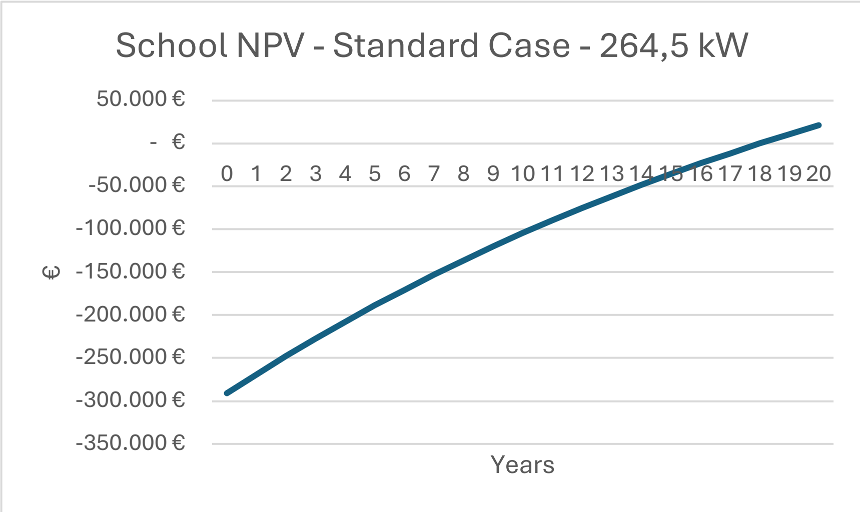
CAPEX			
PV PLANT			290.950 €
REVENUES FOR PROSUMER			
	Energy [KWh]	Unit price [€/kWh]	Total [€/year]
Self consumption	34788	0,28	9740,64
Dedicated Withdrawal	94516	0,105	9924,17
Premium Tariff (200kW<P<600kW)	291576	0,0368	10.730
Avoided network costs	291576	0,0027	787
TOTAL REVENUES			31.182

OPEX			
Plant Maintenance	Unit tariff [€/kWp]	Installed Power	Total [€/year]
	20	264,5	5.290 €
Plant insurance	Unit tariff [%]	CAPEX	Total [€/year]
	1%	290.950 €	2.910 €

In the case of the school, the total cost of the photovoltaic system amounts to € 290.950, covering the full installation expense. In terms of revenue, the annual income is approximately € 31.000, derived from multiple sources. A significant portion comes from self consumption, which translates into direct savings on electricity bills by using the energy produced and consumed on-site instead of purchasing it from the grid. Additional revenue is generated through dedicated withdrawal, representing the energy sold to the external grid outside the community.

Furthermore, the school benefits from a share of the premium tariff, along with government subsidies allocated to the community. Lastly, there are financial gains associated with the avoided costs of network tariffs.

Regarding operational expenditures, the main costs include approximately € 5.290 per year for system maintenance and an annual insurance fee of nearly € 3.000.



Graph 12: School net present value in the standard case

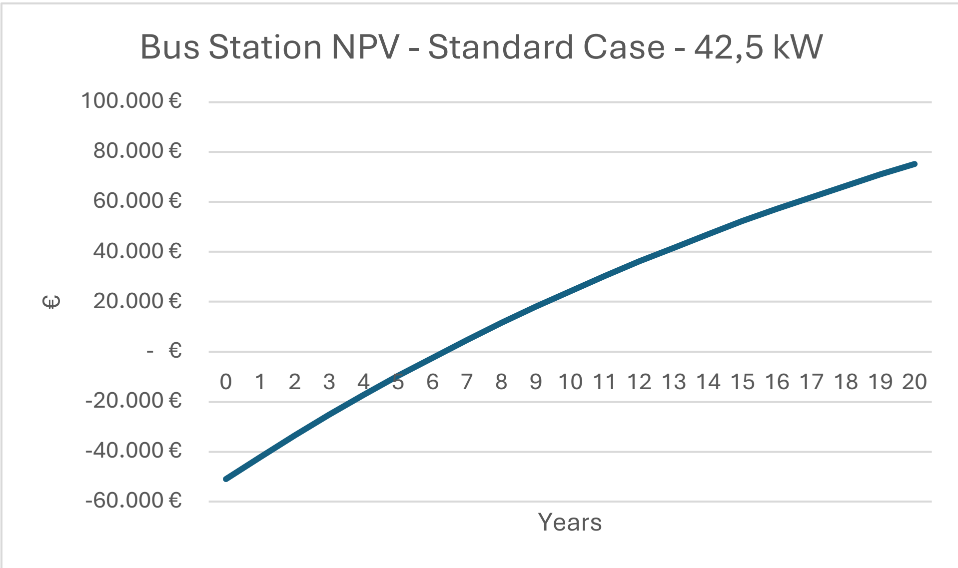
Based on the CAPEX, OPEX and total revenue data, the payback time has been calculated showing that the investment reaches its break-even point in the 16th year.

Prosumer 2: The Bus station – Standard Case – 42,5 kW

CAPEX			
PV PLANT			51.000 €
REVENUES FOR PROSUMER			
	Energy [KWh]	Unit price [€/kWh]	Total [€/year]
Self consumption	29903	0,28	8372,84
Dedicated Withdrawal	11166	0,105	1172,38
Premium Tariff (P<200 kW)	26288	0,0393	1033
Avoided network costs	26288	0,0027	71
TOTAL REVENUES			10.649
OPEX			
Plant Maintenance	Unit tariff [€/kWp]	Installed Power	Total [€/year]
	20	42,5	850 €
Plant insurance	Unit tariff [%]	CAPEX	Total [€/year]
	1%	51.000 €	510 €

In the case of the EAVBUS station, the initial investment cost amounts to € 51.000. Revenues is primarily generated from self consumption, which accounts for € 8.373, along with the sale of surplus energy to the grid, amounting to € 1.172,38. Moreover, the REC incentive contributes approximately € 1.000, while savings from avoided network costs total €71.

By combining these factors, the total annual revenue amounts to approximately € 10.650. As in the previous case, maintenance and insurance costs have also been incorporated into the financial assessment.



Graph 13: Bus Station net present value in the standard case

For the bus station, the payback period is significantly shorter, with the investment reaching its break-even point as early as the sixth year. This means that by the 20th year of the system's lifespan, the total accumulated revenue could reach approximately € 80.000.

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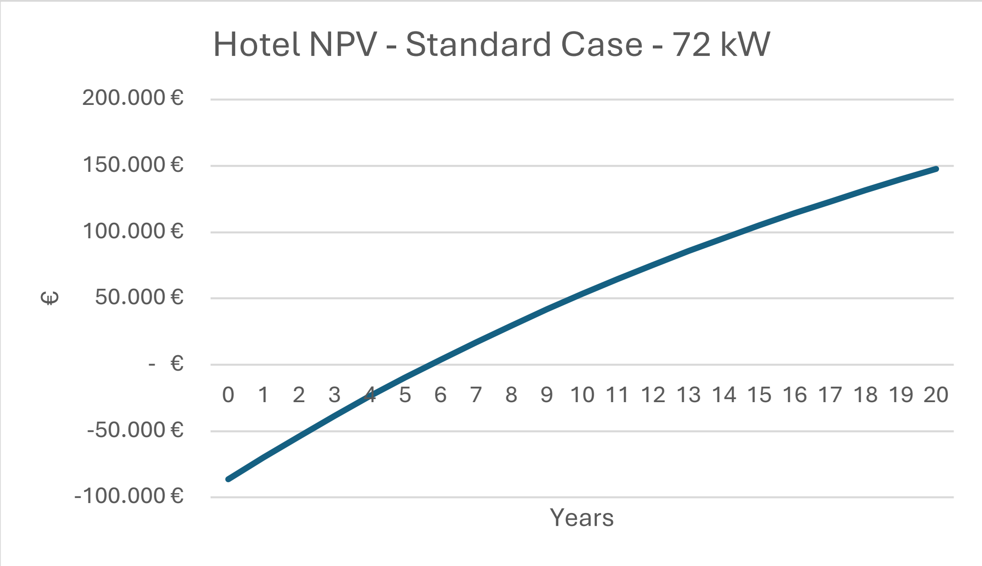
Prosumer 3: The Hotel - Standard Case - 72 kW

CAPEX			
PV PLANT			86.400 €
REVENUES FOR PROSUMER			
	Energy [KWh]	Unit price [€/kWh]	Total [€/year]
Self consumption	65184	0,28	18251,52
Dedicated Withdrawal	5167	0,105	542,56
Premium Tariff (P<200 kW)	17508	0,0393	688
Avoided network costs	17508	0,0027	47
TOTAL REVENUES			19.529

OPEX			
Plant Maintenance	Unit tariff [€/kWp]	Installed Power	Total [€/year]
	20	72	1.440 €
Plant insurance	Unit tariff [%]	CAPEX	Total [€/year]
	1%	86.400 €	864 €

In the case of the hotel, the initial investment cost amounts to € 86.400. The total annual revenue is approximately € 20.000, while the combined maintenance and insurance costs amount to just over € 2.000 per year.



Graph 14: Hotel net present value in the standard case

In this scenario, the payback time is reached during the fifth year following the system's activation. Over its operational lifespan, the investment has the potential to yield positive returns, with profit margins exceeding 80%.

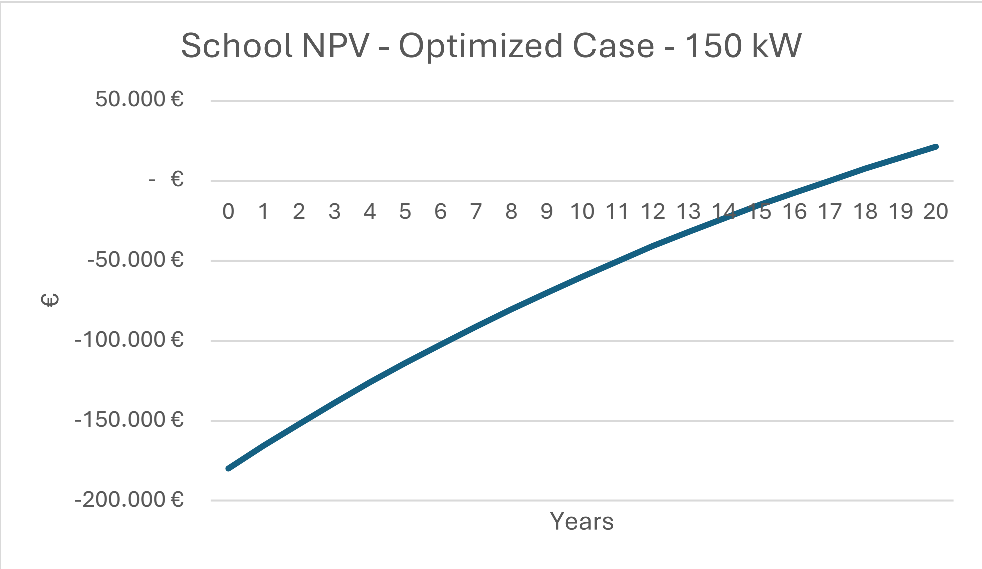
Cash flow analysis in the Optimized Case

Prosumer 1: The school - Optimized Case - 150 kW

CAPEX			
PV PLANT			180.000 €
REVENUES FOR PROSUMER			
	Energy [KWh]	Unit price [€/kWh]	Total [€/year]
Self consumption	32987	0,28	9236,36
Dedicated Withdrawal	27717	0,105	2910,29
Premium Tariff (P<200kW)	188996	0,0368	6955
Avoided network costs	188996	0,0027	510
TOTAL REVENUES			19.612

OPEX			
Plant Maintenance	Unit tariff [€/kWp]	Installed Power	Total [€/year]
	20	150	3.000 €
Plant insurance	Unit tariff [%]	CAPEX	Total [€/year]
	1%	180.000 €	1.800 €

In the optimised scenario, the school has a lower installed capacity of just 150 kW, leading to a reduced initial investment of € 180.000. The annual revenue is projected to be nearly € 20.000, while maintenance and insurance costs remain at approximately € 5.000 per year.

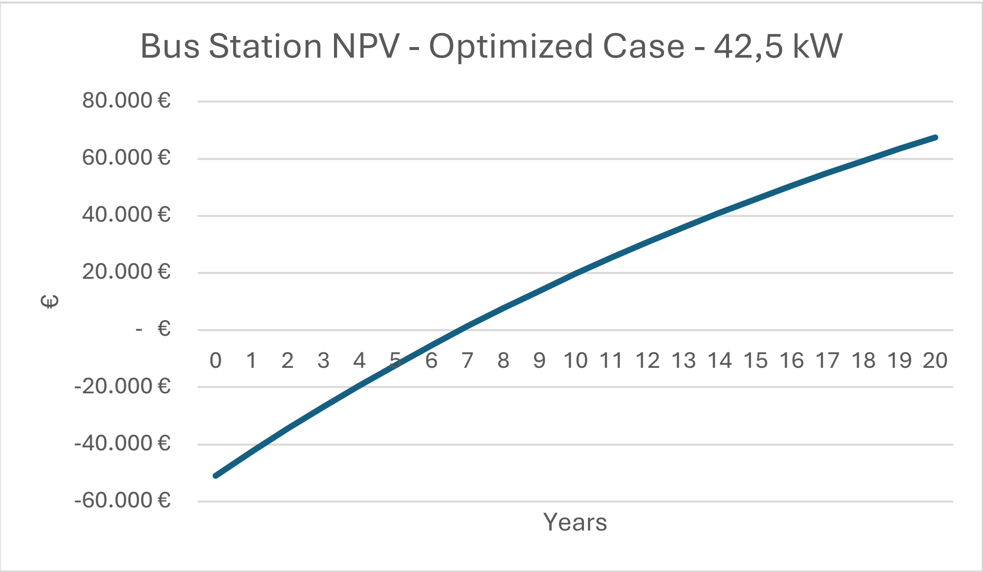


Graph 15: School net present value in the optimized case

In the optimised scenario, the lower initial investment enables a quicker payback period, reducing the time needed to recoup the investment by roughly two years compared to the previous case.

Prosumer 2: The Bus Station – Optimized Case – 42,5 kW

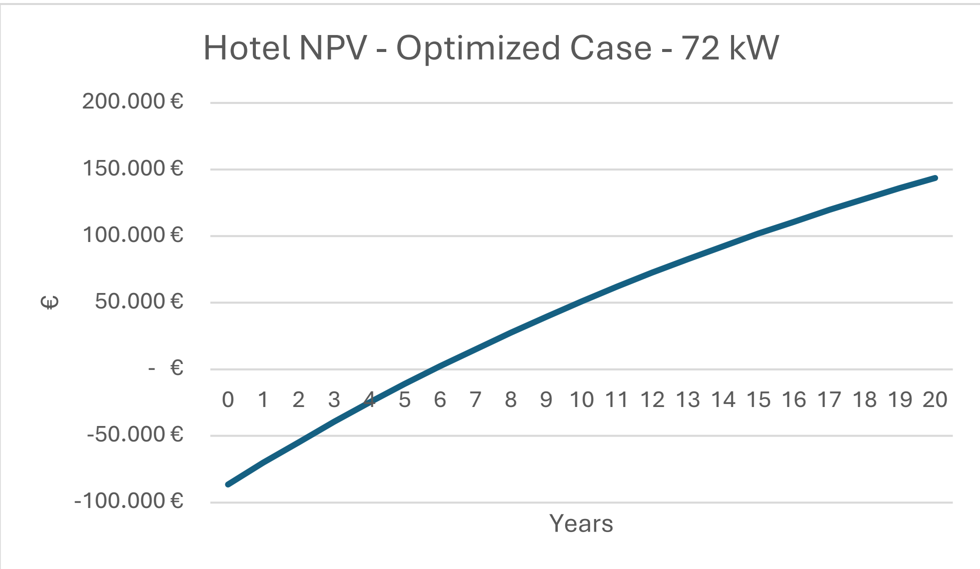
CAPEX			
PV PLANT			51.000 €
REVENUES FOR PROSUMER			
	Energy [KWh]	Unit price [€/kWh]	Total [€/year]
Self consumption	29903	0,28	8372,84
Dedicated Withdrawal	5688	0,105	597,28
Premium Tariff (P<200 kW)	26288	0,0393	1033
Avoided network costs	26288	0,0027	71
TOTAL REVENUES			10.074
OPEX			
Plant Maintenance	Unit tariff [€/kWp]	Installed Power	Total [€/year]
	20	42,5	850 €
Plant insurance	Unit tariff [%]	CAPEX	Total [€/year]
	1%	51.000 €	510 €



Graph 16: Bus station net present value in the optimized case

Prosumer 3: The Hotel – Optimized Case – 72 kW

CAPEX			
PV PLANT			86.400 €
REVENUES FOR PROSUMER			
	Energy [KWh]	Unit price [€/kWh]	Total [€/year]
Self consumption	65184	0,28	18251,52
Dedicated Withdrawal	2342	0,105	245,93
Premium Tariff (P<200 kW)	17508	0,0393	688
Avoided network costs	17508	0,0027	47
TOTAL REVENUES			19.233
OPEX			
Plant Maintenance	Unit tariff [€/kWp]	Installed Power	Total [€/year]
	20	72	1.440 €
Plant insurance	Unit tariff [%]	CAPEX	Total [€/year]
	1%	86.400 €	864 €



Graph 17: Hotel net present value in the optimized case

In the optimised scenario, there are no changes for either the bus station or the hotel, resulting in identical outcomes to those observed in the standard case.

Financing and crowdfunding models for RECs

Financing plays a key role in the success of RECs, determining whether a project can be developed, maintained and effectively scaled. Traditional financing methods, such as government subsidies, bank loans and private investments, remain essential but can be complemented by innovative approaches like crowdfunding and cooperative financing models. These alternative methods empower RECs to take direct control of their energy investments while reducing reliance on external investors and fostering greater community participation [23].

Traditional financial instruments include government grants, subsidies and bank loans, with some RECs securing funding from sustainability focused institutions that offer very low-interest loans for renewable energy projects. However, crowdfunding is emerging as a powerful tool for financing RECs, as individuals increasingly show interest in collectively investing in renewable energy initiatives. This approach democratises energy financing, enabling citizens to support projects with small contributions while benefiting from potential financial returns [24].

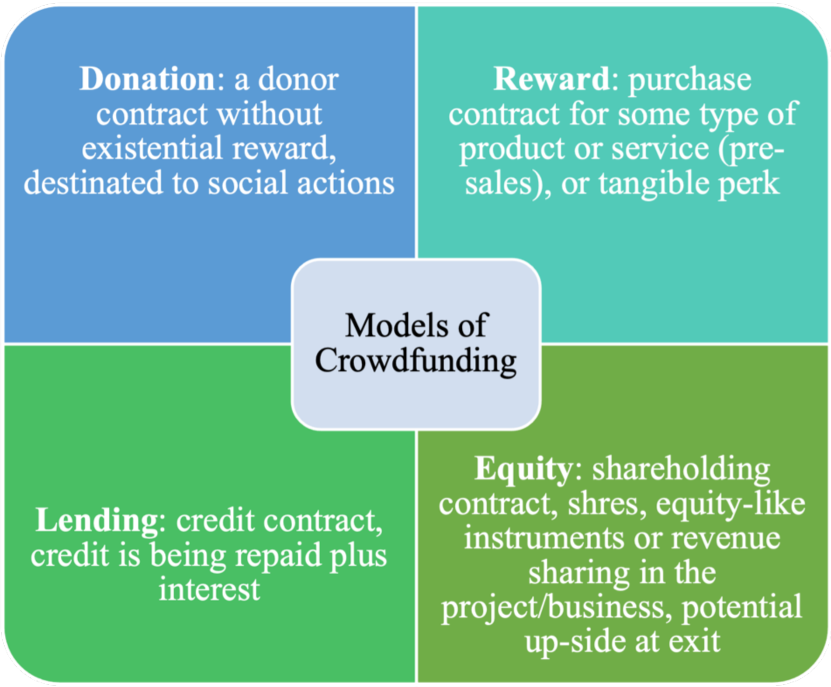


Figure 51: The different models of crowdfunding

Several crowdfunding models can be adopted by RECs. Donation based crowdfunding allows contributors to support a project without expecting financial returns, with many motivated by environmental or social impact. Reward based crowdfunding offers non-financial incentives, such as discounts on future electricity bills. Equity based crowdfunding grants investors shares in the REC, giving them ownership rights and access to dividends based on project revenue. Loan based crowdfunding enables individuals to lend money to RECs at a fixed interest rate, with repayments made over time through energy sales revenue [25], [26].

An example of successful crowdfunding model is “Lumo”, developed in France, which is a platform for citizen to invest small amounts of money to support solar and wind infrastructure projects [27].
Beyond crowdfunding, many RECs operate as cooperatives, as shown in the “Figure 5”, allowing citizens to invest directly in local energy infrastructure and share the profits, reinforcing community ownership and engagement.
Despite the growing success of alternative funding models, several challenges remain. Long payback periods, often ranging from 5 to 15 years, can deter investors, while the risk of external influence poses a threat, as large investors may seek greater control, potentially undermining the community driven nature of RECs. Looking ahead, innovative solutions could address these challenges. Blockchain technology could enable transparent financial models, allowing community members to own digital shares in renewable projects and ensuring secure and decentralised ownership. Additionally, as the European Union expands its government directives and economic models, an increase in grants and subsidies is expected to further support local communities in the coming years.

Smart grid integration and Demand side management

There are a range of strategies and technologies designed to optimise electricity consumption, collectively known as demand-side management (DSM), which are particularly beneficial for RECs. This approach enables consumers and prosumers to align their energy demand with available renewable generation, ultimately reducing costs across the entire renewable energy community [28].
One of the most important tools to encourage demand side management is the use of smart metering and data analytics to provide real time insights into energy consumption patterns of various community members. By using data analytics and predictive models, users can reduce peak demand and maximise the self consumption of PV energy. Load shifting, for example, allows users to concentrate electricity usage during sunlight hours, leading to greater savings and improved self consumption across the community.

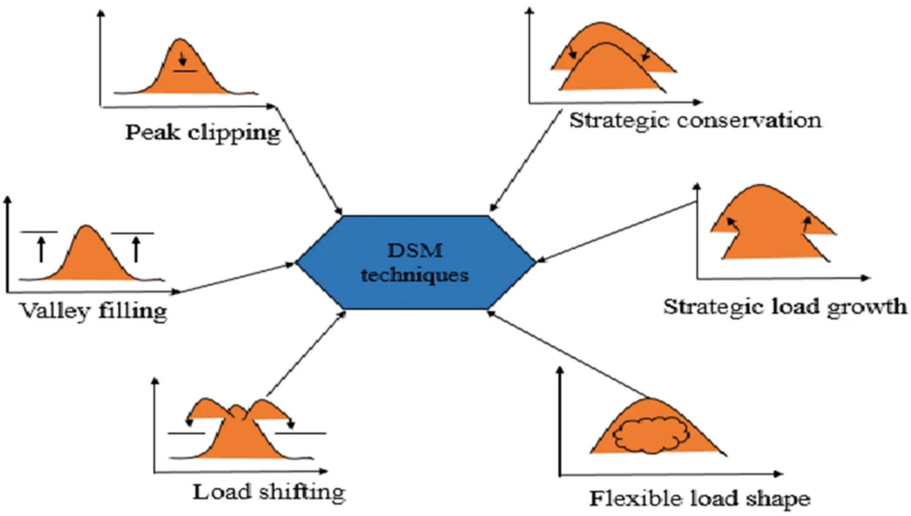


Figure 52: The Demand Side Management techniques to alleviate peak periods

Another strategy that can be implemented for electricity monitoring is the time of use pricing scheme, where community members shift their energy consumption to periods when electricity costs are lower or when sufficient photovoltaic energy is generated. This mechanism relies on predictive models to optimise energy usage.

To further enhance smart load integration and control, as well as enable demand response programs, several tools can be utilised, such as home automation systems, smart thermostats and programmable appliances. These solutions allow energy consumption to be adjusted based on availability, grid signals and demand response programs. This approach enables energy providers and grid operators to temporarily reduce or defer demand during peak periods, particularly in winter months, when photovoltaic energy production is insufficient to meet the overall demand.

Moreover, artificial intelligence and machine learning play a significant role in demand side management, particularly in energy forecasting models. These technologies can predict energy generation and consumption patterns while dynamically adjusting energy loads in real time to optimise power flows.

The benefits of demand side management include lower energy costs, as REC consumers can optimise electricity usage and reduce overall expenses across the community. Additionally, DSM enhances grid stability by efficiently distributing loads, preventing supply interruptions such as blackouts and minimising the risk of infrastructure damage. Another key advantage of this strategy is the increased self consumption of renewable energy, ensuring that a higher percentage of locally produced energy is utilised within the community [29].

Social and environmental impacts of RECs

Another key area where municipalities play a key role is in addressing the social and environmental impacts of establishing a REC. By granting citizens greater control over energy production and consumption, RECs promote transparent decision-making and foster a cooperative ownership model. This shift reduces reliance on centralised energy utilities, encouraging communities to take an active role in the transition to renewable energy.

Figure 53: The concept of social community

Beyond governance, RECs contribute to local economic development by stimulating supply chains for renewable energy technologies, fostering job creation and supporting carbon free industries. From an environmental perspective, RECs help reduce CO_2 emissions by decreasing dependency on fossil fuels [30]. By minimising transmission losses across the grid, these decentralised energy systems improve overall system efficiency.

The role of Distributed Energy Resources (DERs) in RECs

One of the key advantages of RECs is their ability to generate and consume electricity locally within the same primary substation, reducing dependence on the central grid. To promote renewable energy adoption, solar photovoltaic systems are the most widely used technology in RECs due to their scalability, affordability and ease of installation. In regions with high wind potential, wind turbines can also serve as a key energy source, allowing prosumers to contribute to local electricity generation. In areas with sufficient water resources, micro hydroelectric systems provide a continuous renewable energy supply, helping to diversify the community's energy mix.

To enhance self consumption and increase grid independence, RECs can integrate battery energy storage systems (BESS). These storage solutions allow surplus energy generated during peak production hours to be retained for use during high demand periods or at night when solar energy is unavailable. In addition to battery storage, alternative energy storage solutions such as pumped hydro storage and hydrogen systems can be deployed, depending on geographic conditions and economic feasibility [31].

Beyond energy storage, demand side management plays a key role in balancing energy supply and demand within RECs. Smart technologies, such as automated demand response systems and time of use tariffs, enable consumers to adjust their consumption patterns based on energy availability and cost fluctuations, optimising energy efficiency.

There are several real world examples of Distributed Energy Resource (DER) integration in RECs. In Germany, energy communities operate as decentralised energy hubs, combining rooftop solar PV, wind power and other renewable energy sources to achieve high levels of self consumption across the community. Similarly, in Denmark, the Rifkin Island Energy Project demonstrates the successful integration of wind power, solar PV and district heating systems, making the island completely energy independent from the central grid.

Grid resilience and local communities

Grid resilience refers to a network's ability to withstand and recover from disruptions, including extreme events such as blackouts, cyberattacks or equipment failures.

Several strategies (particularly well known in the US) can enhance grid stability in RECs, such as the implementation of microgrids and islanding mode operation. However, these technologies are not yet widely available in Italy as part of REC incentives. One key topic currently under discussion is the integration of electrochemical battery energy storage systems, including lithium-ion and flow batteries, which allow prosumers to store excess energy for later use. In future energy communities, electrochemical batteries are expected to become increasingly prevalent, contributing to the development of more efficient and self-sufficient energy systems.

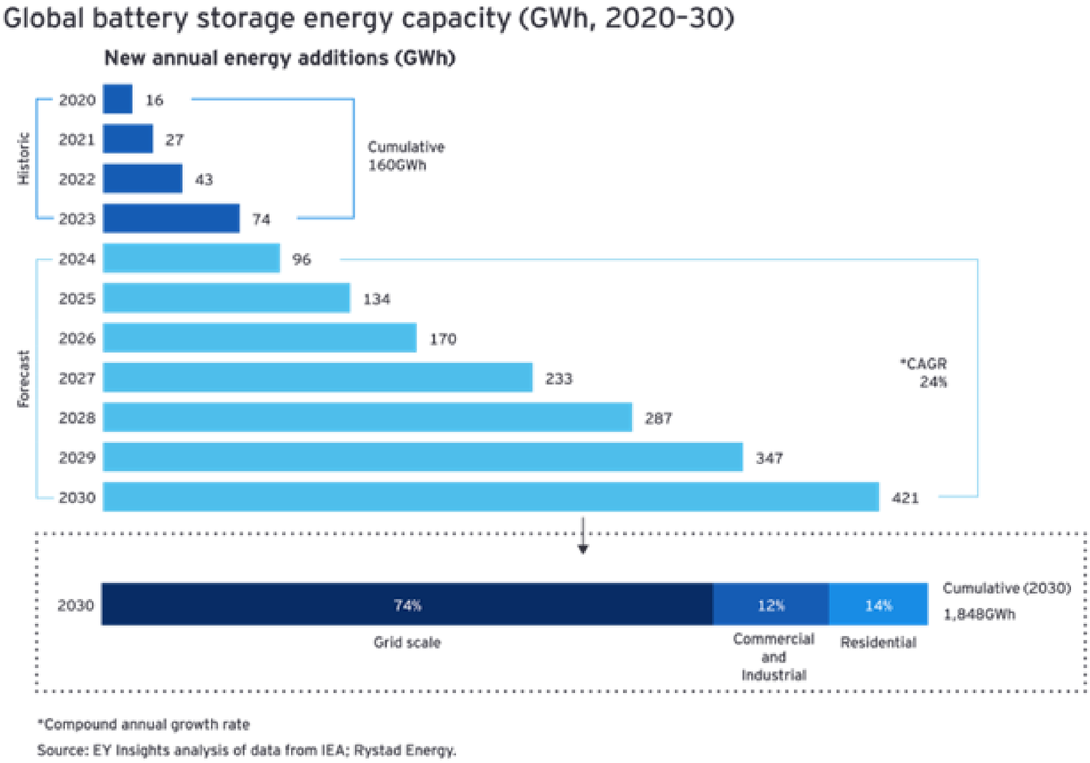


Figure 54: Battery storage capacity 2020-2030

As shown in Figure 55, there is a global upward trend in battery energy storage capacity installations. By 2030, total installed capacity is projected to be nearly five times higher than in 2024.
Another important approach to increasing grid resilience is the integration of multiple RES alongside photovoltaics. By incorporating various renewables, such as wind, hydroelectric power or biomass, energy systems can better meet electricity demand, ensuring a more stable and continuous supply when photovoltaic generation is insufficient.
Additionally, as the number of RECs increases, the cybersecurity of grid infrastructure becomes a critical concern. The introduction of secure protocols, encryption mechanisms and anomaly detection systems are essential, especially as the growing digitalisation of smart grids and RECs increases the risk of cyberattacks and privacy breaches [32].
Enhancing grid resilience not only reduces the likelihood of blackouts and temporary system failures but also lowers maintenance costs, making energy infrastructure more reliable and cost effective in the long run.

Vehicle to grid (V2G) electrification in RECs

Traditional heating systems rely on fossil fuels such as natural gas, crude oil and coal, which contribute significantly to carbon emissions. RECs play a crucial role in decarbonising the heating sector by promoting

renewable based heating solutions, such as electric heat pumps powered by clean electricity and solar thermal technologies for DHW or district heating networks.
Beyond heating systems, RECs can also support sustainable mobility by integrating locally sourced renewable energy into electric vehicle charging infrastructure. Advanced solutions, such as Vehicle to Grid (V2G) technology, enable bidirectional charging, allowing EVs to act as temporary energy storage units that can inject power back into the REC when needed, thereby contributing to grid stability and energy flexibility [33], [34].

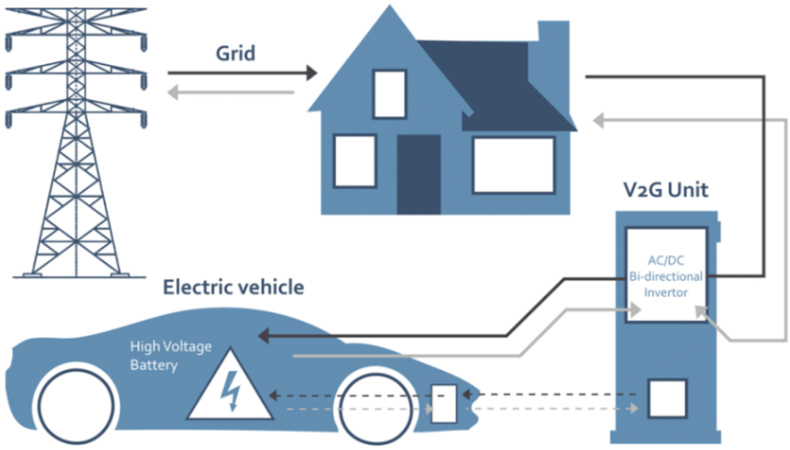


Figure 55: V2G power Exchange [35]

The integration of V2G technology within RECs plays a key role in enhancing energy flexibility, self sufficiency and grid stability. By enabling bidirectional energy exchange, EVs can store excess renewable energy when generation is high and inject power back into the grid when demand increases. This capability not only improves the self consumption of renewable energy but also reduces dependence on external power sources.

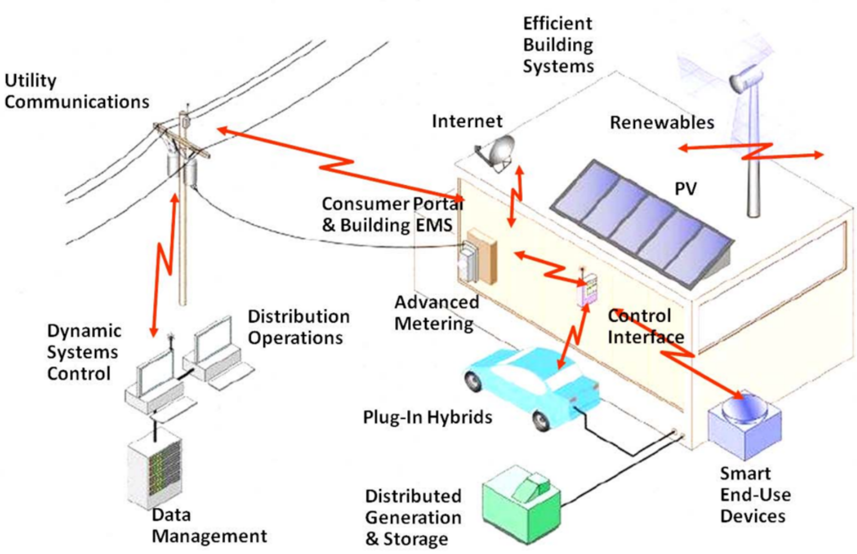


Figure 56: V2G power flow exchanges [36]

The aggregated power profile of a REC, denoted as $P_A(t)$, is influenced by three key factors:
- Community energy demand $P_D(t)$ which is the total electricity consumption by members.
- Local renewable generation $P_G(t)$ which is energy produced by solar PV, wind turbines or other RES.
- Net energy contribution from $P_{EV}(t)$, which can be positive (discharging into the grid) or negative (charging from the grid).

This relationship is mathematically expressed as:

$$P_A(t) = P_D(t) - P_G(t) + \sum_{v=1}^{N} P_{EV}^{(v)}(t)$$

Where:

- $P_A(t)$ represents the aggregated power demand seen by the grid.
- $P_D(t)$ is the total energy demand from consumers in the REC.
- $P_G(t)$ is the local renewable energy generation.

- $P_{EV}^{(v)}(t)$ is the power exchanged by each EV, where if:

- $P_{EV}^{(v)}(t) > 0$ it is discharging to the grid.
- $P_{EV}^{(v)}(t) < 0$ it is charging from the grid.

The objective of the V2G aggregator is to optimise the charge/discharge cycles of EVs so that the deviation between the actual aggregated power profile $P_A(t)$ and the target load profile $P_T(t)$ is minimized with the minimum of:

$$\min |P_A(t) - P_T(t)|$$

This function ensures that the power balance remains stable, reducing fluctuations in grid demand and maximizing the use of renewable energy.

Beyond energy optimization, V2G introduces economic incentives for EV owners. By discharging energy during peak demand hours when electricity prices are higher and charging when prices are lower, EVs can generate financial returns:

$$R_{EV}(t) = P_{EV}^{(v)}(t) \cdot C(t)$$

Where:

- $R_{EV}(t)$ represents the revenue from selling energy;
- $P_{EV}^{(v)}(t)$ is the power supplied by the EV.
- $C(t)$ indicates the real time electricity price.

This mechanism transforms EVs from passive energy consumers into active participants in the REC, promoting a peer to peer energy exchange model where members trade energy based on real time needs. Despite its advantages, V2G integration in RECs faces several technical, regulatory and infrastructure challenges. A key concern is battery degradation, as frequent charge/discharge cycles can impact EV battery lifespan. However, advancements in battery management systems and smart charging algorithms are helping to optimise charging patterns, extending battery health and improving long term performance.
Regulatory barriers also slow down V2G deployment, as existing energy policies often lack clear frameworks for bidirectional energy exchange. Many national regulations do not yet fully recognise EVs as decentralised energy resources, making policy updates essential to encourage widespread adoption.
Infrastructure limitations present another challenge. Municipalities and grid operators must collaborate to develop robust infrastructures that support dynamic energy exchange within RECs.
Beyond V2G, several obstacles must be addressed to effectively electrify heating and mobility within RECs. High upfront investment costs for heat pumps, solar thermal systems and EV charging stations can act as financial barriers, particularly for smaller RECs. Moreover, large scale electrification increases demand on local grids, requiring the integration of smart grid technologies and flexible load management solutions to optimise energy distribution and prevent grid congestion.

Results and final considerations

Data descriptions

This thesis conducts a detailed analysis of energy consumption data to simulate the establishment of a new REC on the island of Ischia. All data used in this study were obtained from real electricity bill records for the reference year 2023.

Consumers within the Ischia community play an important role in the system by actively contributing to the efficient distribution and optimisation of shared energy. The community includes residential households, commercial businesses and public infrastructure, each with distinct energy needs. Private households typically exhibit higher consumption during evening hours, as residents return home from work and use household appliances, lighting and heating or cooling systems. Conversely, commercial activities, such as the supermarket within the community, maintain a more stable daytime energy demand, primarily driven by lighting, refrigeration systems and operational equipment.

Public buildings, such as the school, have an energy demand concentrated during daytime hours and the academic year, with a significant decrease during the summer holidays. On the other hand, the bus station presents a different consumption pattern, because its energy usage is distributed throughout the entire day, with peak demand occurring in the evening due to area lighting and operational logistics.

Furthermore, the community includes two EV charging stations, allowing renewable energy produced during peak photovoltaic generation hours to be utilized efficiently. By implementing intelligent management, vehicle charging can be optimised to occur during peak solar production hours, minimizing energy waste and reducing the reliance on the national grid.

As the energy consumption data are based on real measurements, community members consider it highly reliable.

Energy results achieved

Based on real data, a study was conducted to evaluate both a baseline scenario and an optimised scenario for the energy community.
In the baseline scenario, the community comprised three prosumers: the school, the Hotel Continental and the EAVBUS station, with a total installed PV capacity of 379 kW on the rooftops of the buildings. Through multiple simulations, the optimised scenario identified the ideal PV capacity as 264,5 kW. This configuration was designed to maximise self consumption, ensuring that the largest share of generated energy was consumed within the community rather than being fed into the grid.

The results indicate that the optimal self consumption rate for the Ischia energy community reaches 84%, a highly favorable parameter for energy communities. This percentage represents the proportion of energy directly utilised by consumers within the community, reducing reliance on the national grid. Additionally, this configuration leads to higher financial incentives, as self consumption plays a significant role in determining the community's benefits.

To contextualise these results, the self consumption rate of the REC can be compared with other existing energy communities. For instance, the "San Giovanni a Teduccio" energy community, located a few kilometers from Ischia, has a 30 kW PV system and achieves a self consumption rate of approximately 50% [10]. Similarly, the "Napoli Est CER" records a 55% self consumption rate, while the "Magliano Alpi" community in Piemonte achieves around 60%. These comparisons highlight the superior efficiency of the optimised Ischia energy community, demonstrating its effective energy management and high degree of local energy utilisation [37], [38].

Economic results

An economic analysis was subsequently conducted, considering capital expenditure (CAPEX) and operational expenditure (OPEX) as the primary costs. On the revenue side, calculations were made for each prosumer, taking multiple factors into account. Specifically, revenues include direct self consumption, representing the portion of energy consumed on-site rather than purchased from the grid, direct energy sales through dedicated withdrawal, the premium tariff and the share of incentives received. Then, a small portion of revenue comes from avoided network costs and ARERA contributions.

The comparison between costs and revenues was structured to evaluate the breakeven point, focusing on when the investment turns profitable, as assessed through net present value (NPV) analysis. The NPV was calculated for all three prosumers in both the baseline and optimised scenarios. The results indicate that in the optimised scenario, the investment achieves a positive return within 10 years, demonstrating a shorter payback period compared to the baseline case.

From a broader community perspective, it is also essential to consider the formation costs associated with establishing an energy community. These costs depend on the chosen legal structure and amount to a few thousand euros. Furthermore, additional members within the Ischia primary substation area can join the community at any time, increasing the number of consumers and/or producers at a later stage. This flexibility enhances the overall impact and financial sustainability of the REC.

Project benefits and critical analysis

One of the most significant outcomes of this study is the high self consumption rate achieved in the optimised scenario, reaching 84%. A high self consumption rate directly reduces reliance on the national grid, aligning with the core principle of energy communities which is alleviating the load on centralised power networks and promoting more distributed and sustainable energy systems.

Another positive result highlighted in the study is the optimisation of energy management, achieved through the integration of advanced monitoring technologies for real-time production and distribution tracking. The use of smart meters plays a key role in ensuring the transparent management of consumption and production data, allowing for dynamic balancing of energy supply and demand among community members. This level of precision improves the overall efficiency of the community and enhances the stability of the local energy network.

Among the environmental benefits, one of the most notable aspects is the reduction in CO_2 emissions. Even on a small scale, establishing an energy community helps reduce the number of users dependent on the national grid, which is still largely powered by fossil fuel power plants. By maximising local renewable energy production and consumption, the REC actively contributes to a cleaner and more sustainable energy transition.

From an economic perspective, the community benefits from multiple financial incentives, including the premium tariff, the ARERA contribution and revenues generated from surplus energy sold to the external grid through dedicated withdrawal. These incentives, combined with high self consumption efficiency, have resulted in shorter payback periods for the initial investment.

Limitations of the REC

Despite its numerous advantages, the Ischia REC still presents some limitations that could be addressed to further improve its performance and long term sustainability.

One of the most pressing challenges is the absence of an energy storage system. Many users still rely on the national grid when photovoltaic generation is unavailable, particularly in the evening and at night. The adoption of battery storage systems would significantly increase the community's independence from the grid, enabling more efficient demand side management, especially during peak periods. By storing excess energy produced during the day, the REC could further reduce grid dependency.

Another critical aspect is the community's reliance on state incentives, which currently ensure the project's financial sustainability. While the existing incentive structure enables a solid return on investment, any future policy changes or reductions in subsidies could negatively impact the financial viability of the community. Developing alternative revenue models, such as private investments or corporate partnerships, could help mitigate this risk and ensure long term stability.

From a technical perspective, integrating different prosumers and consumers presents a significant challenge. The process of simultaneously managing real time photovoltaic system production and electricity demand has required a detailed, case by case analysis, conducted primarily using Excel spreadsheets. Implementing more advanced energy management algorithms could further enhance the synchronisation of supply and demand, reducing inefficiencies in distribution.

On an economic level, the high initial investment cost remains a potential barrier for new members, particularly for prosumers considering joining the community. However, several alternative financing mechanisms could help address this issue. Crowdfunding models, traditional bank loans or municipal investments (similar to initiatives in Germany and other European countries, where the state co-invests alongside citizens) could provide a more inclusive and scalable business model. These approaches would encourage broader participation and make the REC model more accessible to a wider range of stakeholders.

While these challenges persist, they do not overshadow the significant benefits of the REC. Addressing these limitations through technological, financial and regulatory improvements would further strengthen the project.

Challenges and new opportunities

A key challenge in optimising the Ischia REC is the implementation of DSM systems. These systems enable synchronisation between energy consumption and production, optimising the use of high energy appliances and equipment during peak solar energy availability. Automated load control for both residential and commercial users can reduce surplus energy injected into the grid and significantly improve the community's overall efficiency.

Another crucial strategic element for the expansion and long-term stability of the REC is the involvement of new members, including additional residents, local businesses and public institutions. Expanding the energy community to include a broader range of consumers and producers would create a more balanced demand profile, ensuring greater economic sustainability. Integrating commercial enterprises and public services with high daytime energy demands would allow for optimal utilisation of locally produced renewable energy, further reducing dependence on the national grid.
By implementing these strategies, the REC could further consolidate its model of efficiency and sustainability, ensuring a more resilient and economically advantageous energy system for all its members.

Furthermore, according to the latest provisions of the Italian Minister Picchetto Fratin during the Key Energy trade fair on 5 March 2025, the PNRR's contribution to access the 40% incentive on the initial investment will be extended to municipalities up to thirty thousand inhabitants and thus can be an interesting opportunity for all prosumers included in the community because the municipality of Ischia counts almost twenty thousand inhabitants. In addition to the incentives discussed during the thesis, these will be able to benefit from an additional contribution, if this government measure becomes reality [39].

Conclusions

This study evaluated the feasibility and benefits of establishing a REC on the island of Ischia. By reducing dependence on the national grid and promoting a renewable and sustainable energy approach, this model demonstrates how decentralised energy production and consumption can improve efficiency and economic viability in local areas such as Ischia. The simulations carried out during this study underscore the critical role of regulatory and financial support in facilitating the implementation of energy communities, ensuring greater access to incentives and funding mechanisms.

From a practical perspective, targeted investments by private sector stakeholders, including residential users and businesses, could accelerate the transition. In other words, encouraging greater participation from both public and private entities would not only strengthen the financial stability of energy communities but also contribute to a broader societal shift towards renewable energy adoption.

Looking to the future, further research will focus on the integration of storage systems, which would improve energy autonomy within the community. Moreover, interconnecting multiple RECs could optimise energy sharing within the grid, contributing to the development of more resilient and interconnected energy systems. On a national scale, the widespread adoption of RECs could significantly reduce energy costs, improve grid stability and facilitate the transition towards a more decentralised and sustainable energy infrastructure.

Furthermore, technological advancements will also play an important role to improve the energy community performance. The development of smart grids, real time demand side management systems and automated load balancing could maximise the energy efficiency and optimise the distribution of locally produced electricity. These innovations will increase the flexibility of community members, by allowing them to adapt to vary consumption patterns and market conditions.

In conclusion, the REC of Ischia stands as proof that an energy model based on self consumption, energy sharing and active community participation is not a utopian vision, but rather a practical and effective solution for achieving sustainability and energy efficiency at both local and national levels. As the energy transition progresses, it is expected that more and more communities will be established, reinforcing the shift towards a cleaner, more autonomous and community driven energy landscape.

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