Politecnico di Torino

Master of Science in Climate Change
Department of Environment and Land Engineering
Graduation session of March 2024

Design of a Renewable Energy Community in Frassinetto, Piedmont: technical and economic analysis

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A.y 2023/2024

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Abstract

The shift towards sustainable energy sources is crucial to reduce and mitigate the impacts of climate change. In this context this thesis proposes the creation of a Renewable Energy Community in Frassinetto (TO), Piedmont, as a model for addressing global environmental issues at the local level. The research began with the evaluation of the hourly energy production over an average year using PVGIS, by strategically placing photovoltaic plants throughout the town in accordance with locations identified by the municipal administration. Concurrently, energy consumption patterns were estimated based on monthly electricity bills provided by the Municipality, and battery storage capacity was calculated in order to maximize Frassinetto's independence from the national electricity grid. Considering that energy production usually exceeds consumptions, the surplus generation has been retrieved and, by leveraging the concept of virtual energy consumption within an Energy Community framework, potential participants who can virtually consume the excess energy can be identified. To conclude, an economic analysis was conducted considering the installation costs of photovoltaic systems and batteries, as well as the incentives provided by the GSE (Gestore Servizi Energetici) for the Energy Communities. The savings accrued by Frassinetto from reduced reliance on the national grid were also factored in. The cash flow obtained over the 30-year plant lifetime revealed a return on investment of 9-10 years, which makes the project viable.

1. Introduction

1.1. Climate change

Climate change refers to long-term changes in temperature and weather patterns and it is induced by natural internal processes but mainly by the external forcings, i.e., anthropogenic activities. In fact, since the 1800s, the intensive use of fossil fuels for power generation, the deforestation, the increasing livestock farming and the use of fertilisers rich in nitrogen, have been among the most impacting causes of climate change, with global surface temperatures that reached +1.1 °C above 1850-1900 in 2011- 2020 [1] [2]. The main gases related to the human activities are the carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) and they represent the most significant contributors to climate change. Indeed, the global surface concentration of CO_2 has increased up to 417.06 ppm and now it is 50% higher with respect to the pre-industrial levels as shown in Figure 1. [3]

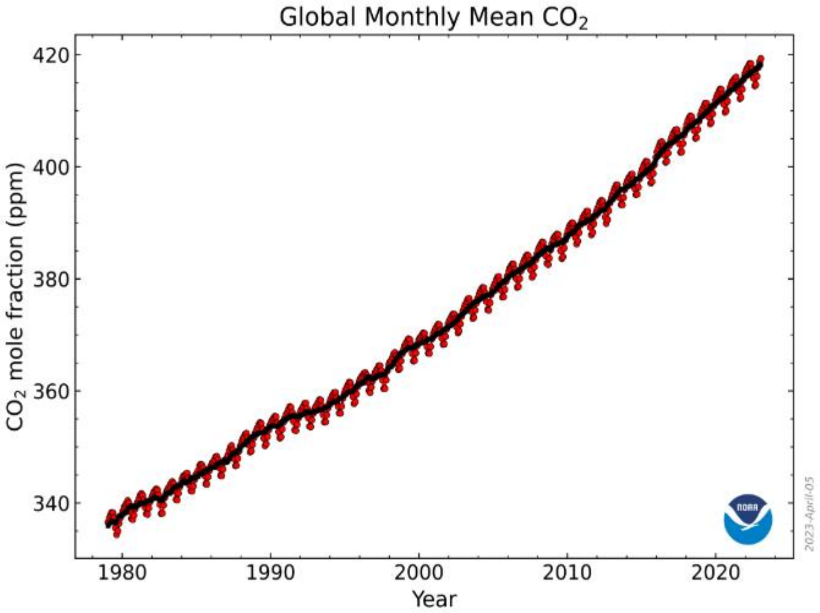


Figure 1: Global monthly mean CO_2 [3]

Methane instead, is less abundant than CO_2 but it has a much higher Global Warming Potential (GWP_{CH4} = 28) and for this reason it is able to trap heat easily. Methane levels in atmosphere have reached 1911.9 ppb in 2023 and its concentration is more than two and a half times the pre-industrial level. [3]

The Nitrous oxide is the third-most significant human-induced greenhouse gas and its concentration rose up to 335.7 ppb mainly due to production of fertilizers in the agricultural sector and to the dentification of soils. The N_2O has a Global Warming Potential equal to 265 which makes its contribution non-negligible to the global greenhouse effect, despite having a trace concentration in atmosphere [3].

The consequences that the increasing concentration trends of gases have on the climate include not only the temperature rise, but also water scarcity, more widespread fires, rising sea levels, floods, ice melting and less frequent but more intense rainfalls.

A key aspect is to understand how people and societies are facing the challenges related to changing climate. Often the most vulnerable ones are the most exposed because of geographical or economic reasons, but it is also important to underline that usually the most affected societies are the ones that have contributed the least to current climate change. This is particularly evident in high mountains regions where climate change and rising temperatures are leading to the melting of glaciers and the modification of local flora and fauna, even though there, human activities are significantly lower than in a city [4].

Anyway, there are already different solutions to face climate change and the main actions consist in reducing the emissions reaching net zero by 2050, financing the development of renewable energy sources and of Energy Communities. The main objective is to generate clean energy to reduce reliance on fossil fuels as much as possible, but also to find adaptation solutions to the actual climate conditions.

1.2. Energy Communities

The Energy Communities represent a virtuous model based on the idea of resources sharing and are associations composed by public or private bodies, the consumers, who can team up to produce clean energy to cover their own needs and to share the surplus [5]. This idea brings important benefits from the environmental, economic and social point of view since these communities have a strategic role in building a more sustainable and safe future [5]. The fundamental concept on which the Energy Communities are based is the virtual consumption: the consumers not directly connected to the photovoltaic plant, do not consume physically the produced renewable energy, but only virtually (virtual consumer). In fact, each user equipped with a plant for the electrical energy generation for the self-consumption, share the energy in excess to other individuals connected to the smart grid. The only limitation is that a user can participate to the Energy Community only if it is located on Low Voltage (LV) electricity networks under the same High Voltage – Medium Voltage (HV – MV) energy transformer station (primary cabin). In Figure 2 an example of primary cabins map in the North of Italy is reported [6].

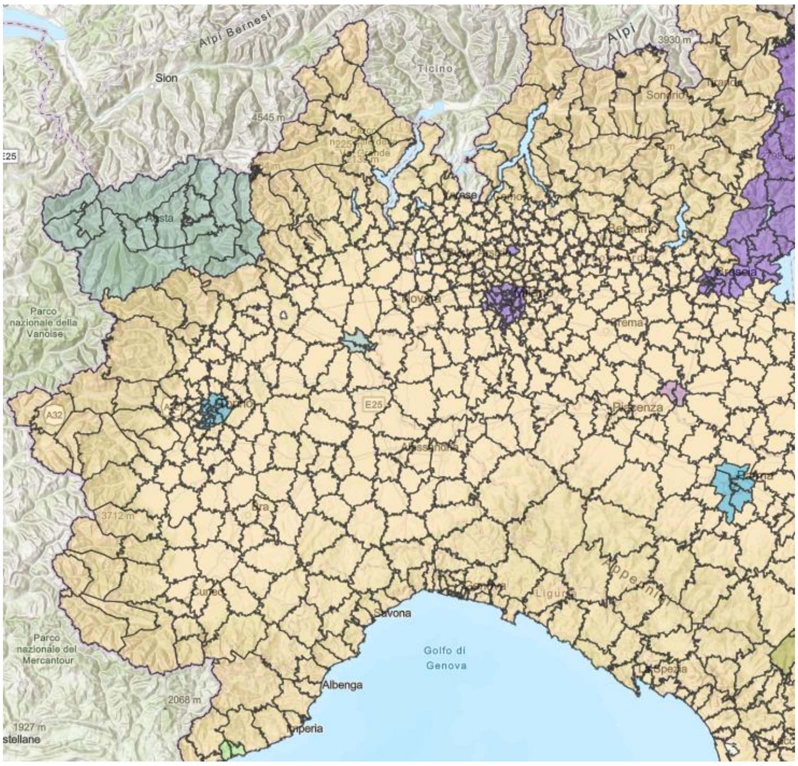


Figure 2: Primary cabins map [6]

Another important aspect is that the Energy Community must include only renewable plants with total installed power not higher than 1 MW but each one must have singularly a power not greater than 200 kW. The functioning scheme of an Energy Community is summarized in Figure 3 highlighting the concept of the virtual consumers who are connected to the grid and not directly to the energy community. [6].

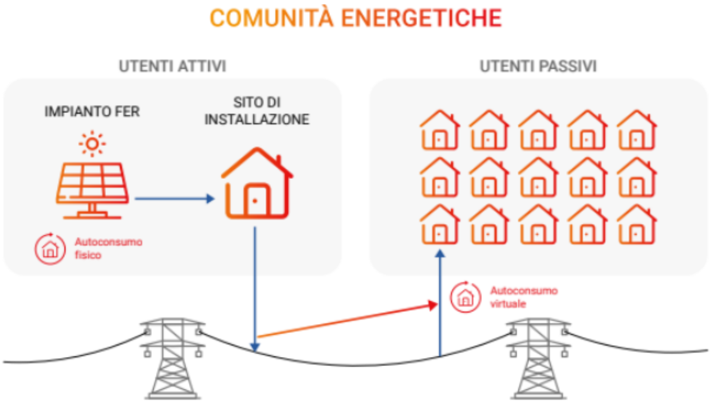


Figure 3: Functioning scheme of an Energy Community [5]

1.3. NODES project and local impacts in Frassinetto

The aim of the present thesis is the study and dimensioning of an Energy Community in Frassinetto (TO), a small Municipality of the Metropolitan city of Turin, in Piemonte region, situated at 1050 m a.s.l. (Figure 4). This idea arises from the fact that Frassinetto is included among the areas selected for the PNRR project "M2C1 Inv. 3.2 Green Communities which aligns with SPOKE N4 - Digital and Sustainable Mountain of the NODES - Digital and Sustainable North West project". The main suggested actions include producing energy from local renewable sources, such as hydroelectric, wind, and photovoltaic power, improving energy efficiency, and developing sustainable tourism [7].

The idea is in fact to exploit the available natural resources and to implement the already existing renewable plants with storage systems and more efficient technologies to design a Green Community.

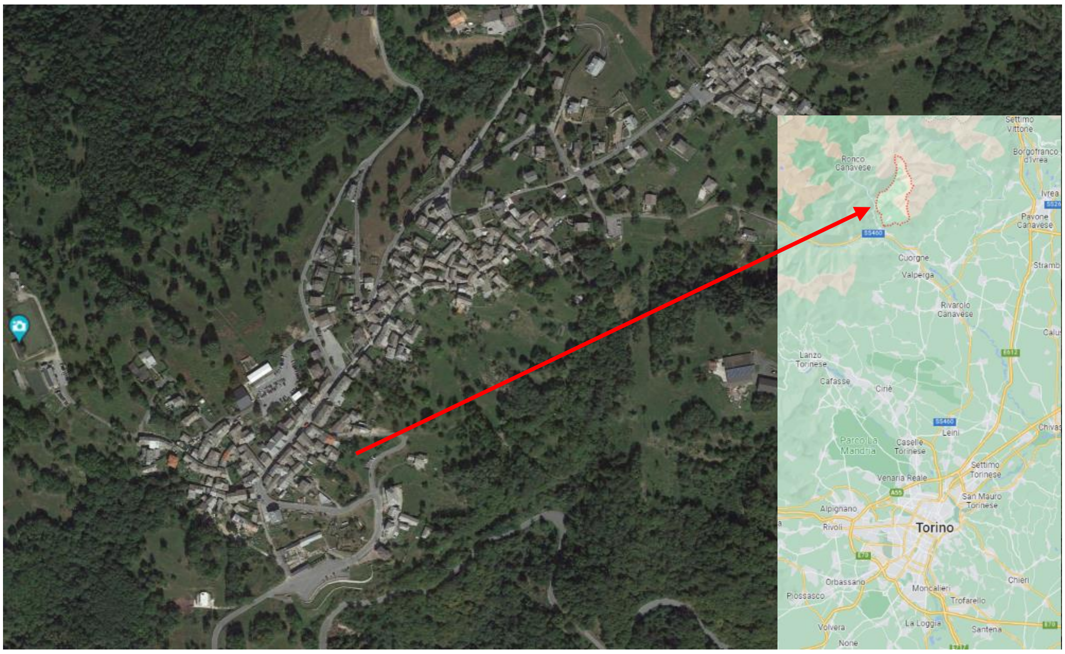


Figure 4: Frassinetto [8]

The proposal of creating there a Renewable Energy Community (REC) arises from the fact that generally the mountainous areas are affected a lot by climate changes; about the 43% of the Piemonte region is characterized by mountains, and the Alps are known to be a hot-spot, meaning that the effects of climate change are much more noticeable [8]. For this reason, it is fundamental to study how the climate has changed over the years to understand which are the required actions to be implemented to fight climate change. The data collected by Arpa Piemonte [9] shows an intensification of the extreme events besides to the temperature increase.

The maximum and minimum temperature anomalies of the Piemonte region over the period of simulation (2006 – 2100), with respect to a reference period (1976 – 2005), show a statistically significant positive trend and the most important aspect to be mentioned is that for the higher elevations (> 1500 m), this behaviour is much more pronounced [9]. Frassinetto, being located at 1050 m a.s.l., is directly involved and in Figure 5 it is reported the plot of the mean annual temperature trend over the period 1979 – 2020 locally in Frassinetto.

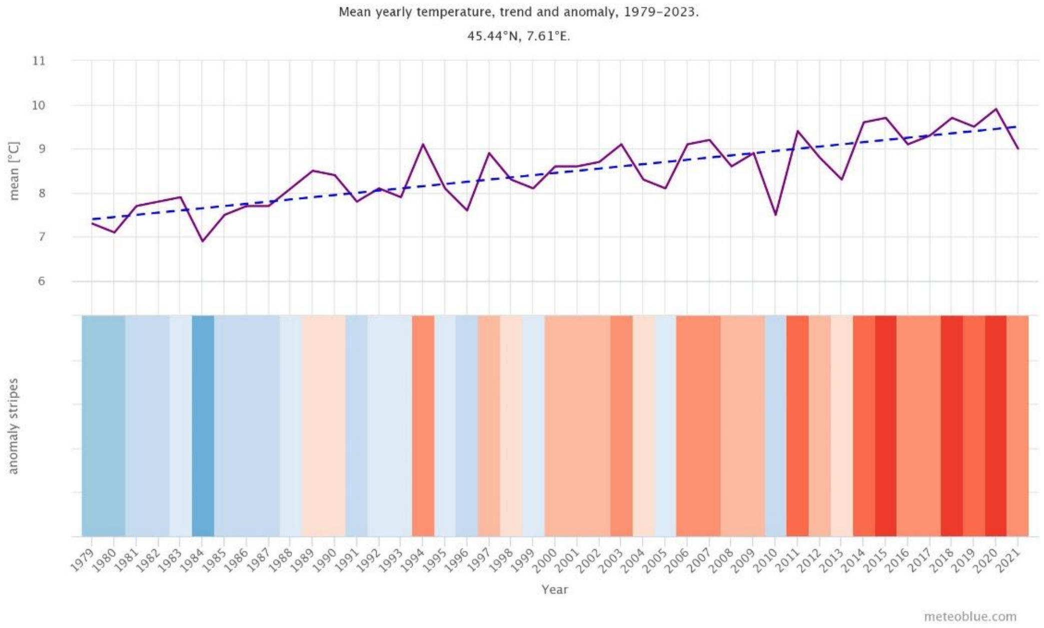


Figure 5: Mean yearly temperature trend and anomaly [10]

The lower part of Figure 5 shows the anomaly stripes, and each color represents the mean temperature of that year, in blue the colder years and in red the warmer ones. It is visible a considerable increase of this variable by looking at the intensification of the reddish stripes.

The precipitations follow a less pronounced trend characterized by a slight decrease between 1979 and 2020 but, what is noticeable, are the less frequent but more intense rainfall events [10]. This is confirmed by the plot reported in Figure 6 that shows the mean yearly precipitation trend and the anomaly stripes, green for the humid years and brown for the dryer ones.

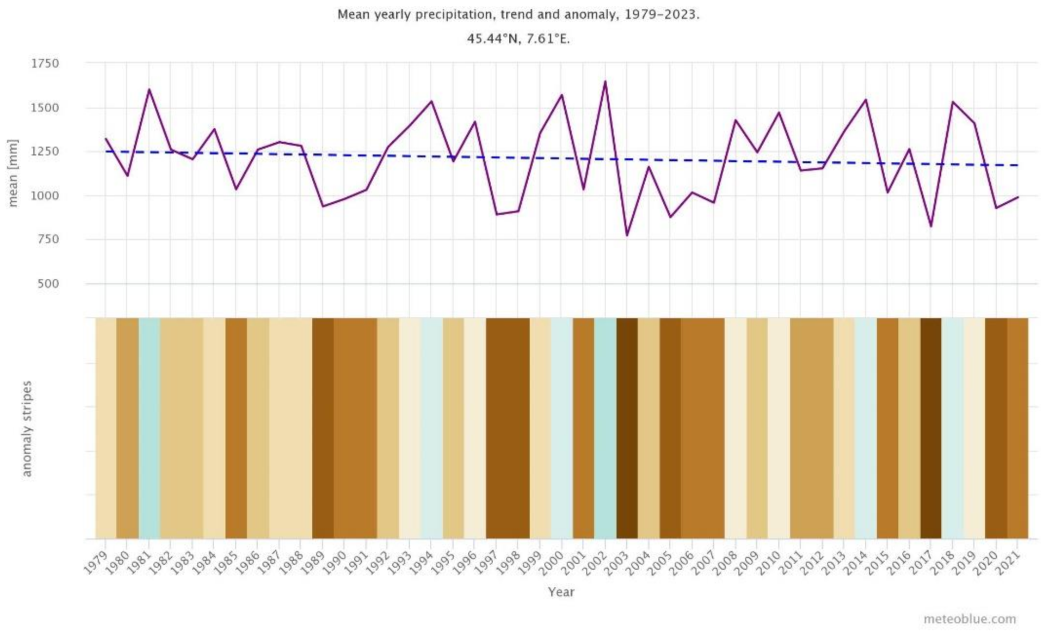


Figure 6: Mean yearly precipitation tend and anomaly [10]

Given these premises an energy transition is required and small municipalities such as Frassinetto represent a good starting point to develop the concept of renewable Energy Communities.

2. Available natural resources at Frassinetto (TO)

To be able to start the design phase of the Energy Community, the local available natural resources must be analysed.

2.1. Sun

The variable to be analysed in order to understand whether a photovoltaic plant can be suitable for the selected location is the solar irradiance. It represents the power per unit area received from the sun in the form of electromagnetic radiation, and it is measured in $[\frac{W}{m^2}]$ [11]. The solar irradiance at the Earth's surface is function of many variables: the distance of the selected point from the Sun, the atmospheric conditions and the tilt of the surface on which the irradiance is calculated. Other two important parameters are the angular height of the sun in the sky with respect to the horizontal plane, which depends on the latitude of the location, on the hour and on the day of the year, and the azimuth, meaning the angle of the surface relative to the South direction (-90° is East, 0° is South, 90° is West) [11]. To obtain data regarding the photovoltaic production it's important to select the beam (direct) irradiance and the diffuse component on the tilted plane, discarding the reflected component. The first one is the fraction that reaches the ground without the atmospheric attenuation while the second is the one that arrives at the ground after being scattered or reflected by the atmosphere [11]. From the map reported in Figure 7 of Global Solar Atlas website [12], it can be noticed that, even if Frassinetto is located in a mountainous site, the direct normal irradiation assumes not optimal but intermediate values of about 1465 $\frac{kWh}{m^2}$ per year [12].

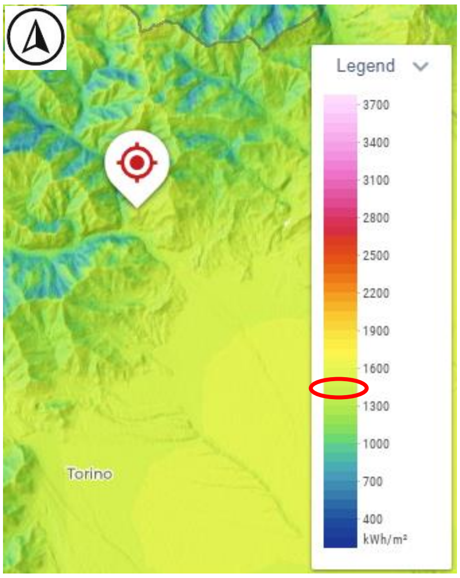


Figure 7: Direct normal irradiation in Frassinetto [12]

Moreover, using the tool PVGIS, which will be detailed in Chapter 3, and setting the solar radiation database to PVGIS-SARAH2, it's possible to retrieve the monthly in-plane irradiation for a fixed angle by setting the optimization of the tilt and the azimuth (Figure 8). The optimum slope angle and azimuth are respectively 41° and -2° [11].

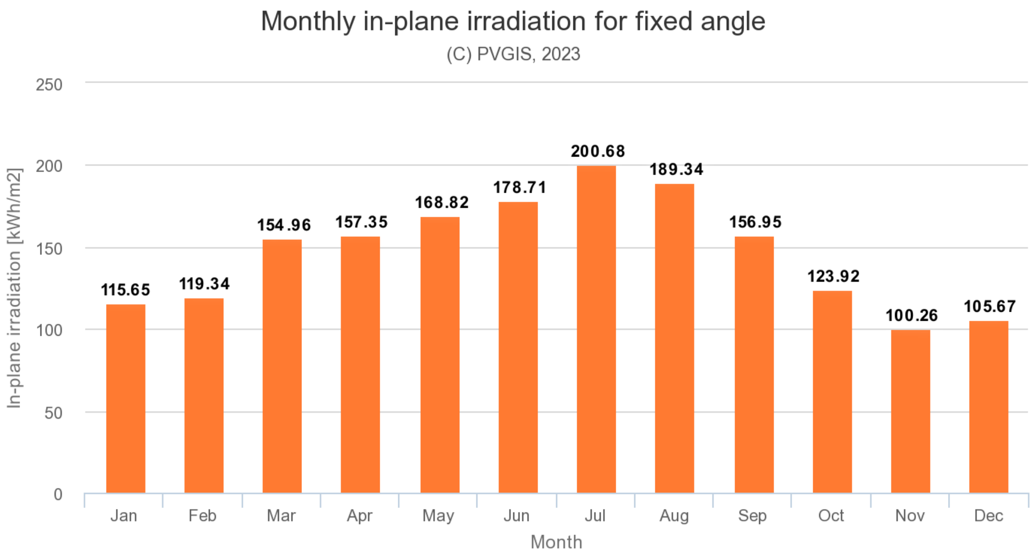


Figure 8: Monthly in-plane irradiation for fixed angle in Frassinetto [11]

From these results it can be said that Frassinetto is quite suitable for the installation of a photovoltaic plant mainly because it is well exposed to South and the irradiance values are acceptable to ensure a good photovoltaic energy production.

2.2. Wind

The wind is the other atmospheric variable that has been analysed in order to evaluate the possibility to place wind turbines right over Frassinetto, where there are mountains which may be windier with respect to the village. The exact location in which the wind turbines can be located is shown in Figure 9 and it is called Punta Quinseina, at 2344 a.s.l which belongs to Alpi Graie [13].

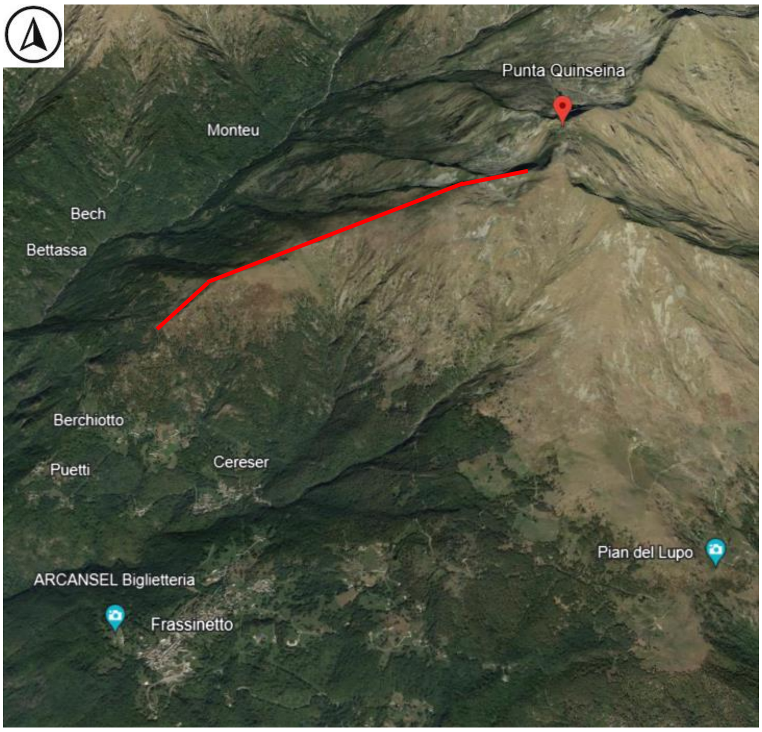


Figure 9: Location of the wind turbines [13]

The idea is to exploit the area marked with the red line and, at this purpose, the local wind data are required. The Global Wind Atlas [14] has been used to retrieve the mean wind speeds in the location under analysis, both at 100 m and 50 m above the ground. In Figure 10 the results are reported. The black pointer is Frassinetto and the blue marker is Punta Quinseina; on the right of the images the legend shows the mean wind speed. It is evident that in the selected location, the wind does not overcome the intensity of $4 \frac{m}{s}$ and for this reason, the wind turbines may not be the best solution since their usual cut-in velocity is 3 - $4 \frac{m}{s}$ [15].

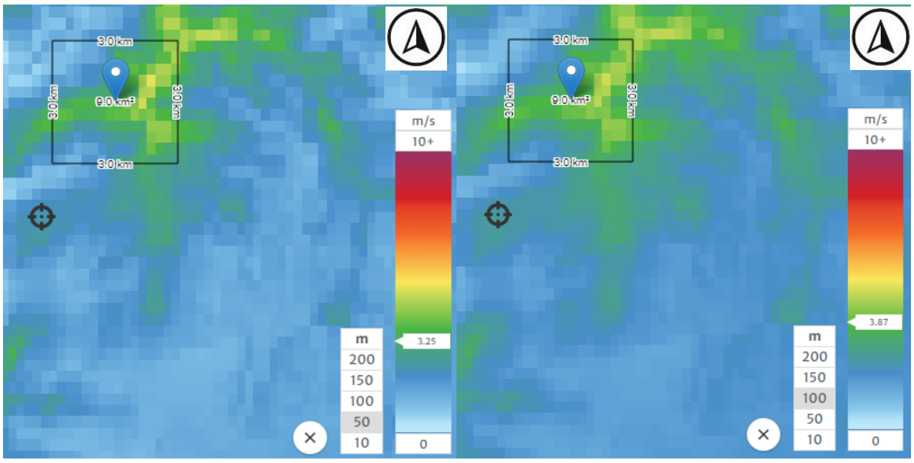


Figure 10: Mean wind speed at 50 m and 100 m [14]

In order to further deepen the analysis, PVGIS website [11] can be exploited since it releases the information about the hourly wind speed at 10 m above the ground from 2005 to 2020. From these data it is possible to plot the probability distribution at different heights, understanding which is the most frequent intensity. Also in this case the chosen database is PVGIS-SARAH2.

To be able to do this, with the equation 1, the wind speeds at 50 m and at 100 m starting from the one at 10 m, has been calculated [16].

Equation 1: Calculation of the wind speed at 50 m and 100 m [16]

$$w_{speed}@50m = w_{speed}@10m \times \frac{\ln\left({}^{50}/_{z_0}\right)}{\ln\left({}^{10}/_{z_0}\right)}$$

$$w_{speed}@100m = w_{speed}@10m \times \frac{\ln\left({}^{100}/_{z_0}\right)}{\ln\left({}^{10}/_{z_0}\right)}$$

In equation 1 z_0 is the roughness length in Punta Quinseina is 0,03 [14] (farmland with open appearance) as shown in Figure 11.

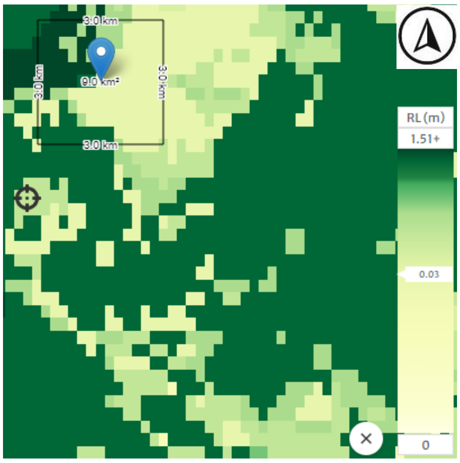


Figure 11: Roughness length in Punta Quinseina from Global Wind Atlas [14]

Then, the Probability Density Functions (PDF) of the wind speed at 10 m, 50 m and 100 m have been obtained and reported in Figures 12, 13, 14.

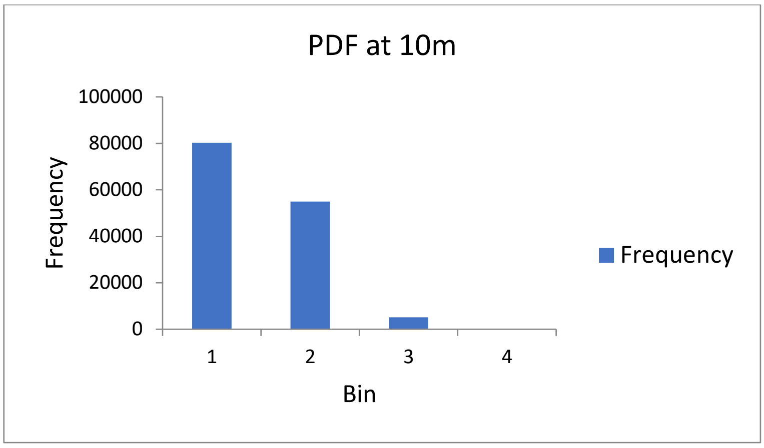


Figure 12: PDF at 10 m

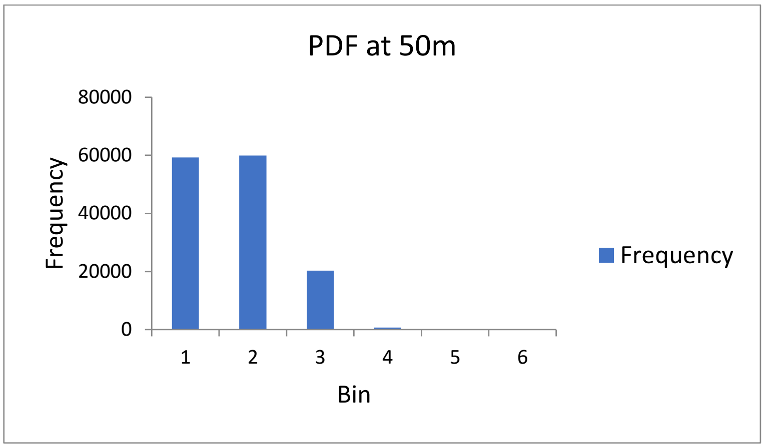


Figure 13: PDF at 50 m

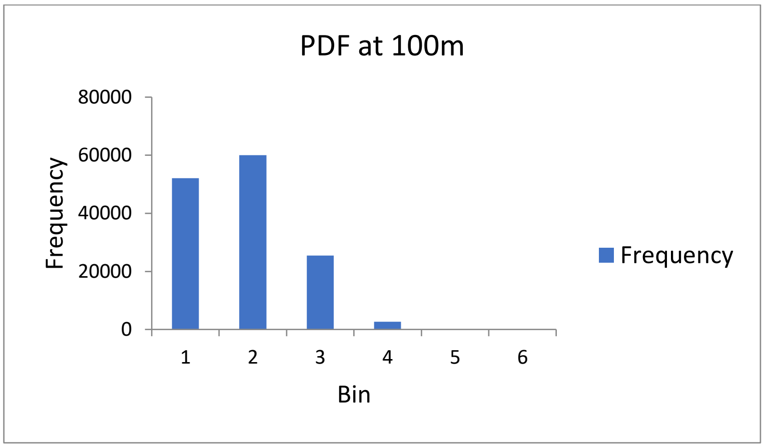


Figure 14: PDF at 100 m

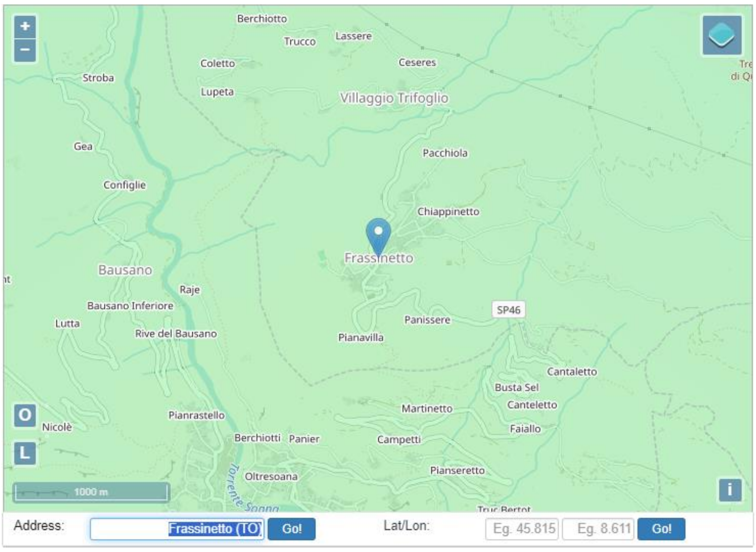
From these results it can be confirmed that Frassinetto is not a windy location, since even at 100 m above the ground, the most frequent wind speed is 2 $\frac{m}{s}$, consistently with the outcomes of the Global Wind Atlas website. Given these premises the installation of the wind turbines is not suggested.

3. PVGIS methodology

The Photovoltaic Geographical Information System (PVGIS) [11] is an open-source web application used to obtain data on solar radiation (direct, diffuse and reflected) and photovoltaic production in most parts of the world. In the present thesis, PVIGS has been used to carry out all the analysis related to the installation of photovoltaic plants to create the Frassinetto Energy Community. Indeed, from the above considerations, the sun is the only potentially exploitable natural resource in the locality.

The begin using PVGIS, the first step is to select the location on the map: a lateral interface appears in which there is the possibility to observe the monthly energy output by selecting the radiation database, the type of photovoltaic technology, the installed peak power, the slope and the azimuth. In addition, there is the possibility to download the monthly, daily and hourly data in an Excel Worksheet by deciding the time series length (from 2005 to 2020), the database, the mounting type (fixed, tracking), the slope and the azimuth. In the time series the photovoltaic output power and the radiation components can be downloaded.

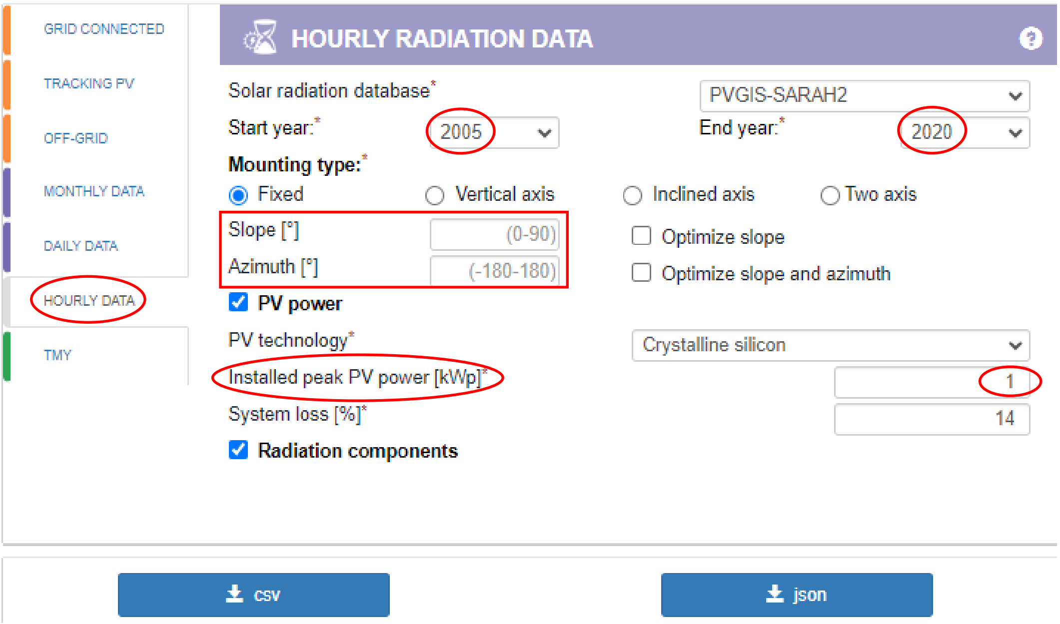
As previously mentioned, the first step is to select the location of Frassinetto on the map as shown in Figure 15.



Address: Frassinetto (TO)

Figure 15: Selection of the location in PVGIS [11]

Then, in order to have a rough estimate of the monthly photovoltaic production, the grid connected plants energy output can be considered. However, to perform a more accurate analysis, the hourly data of irradiance from the 1/01/2005 to the 31/12/2020 must be used exploiting, in this way, all the available data. To do this, separated calculations have been carried out for each location in which the photovoltaic plants will be installed.



Solar radiation database* PVGIS-SARAH2

Start year:* 2005

End year:* 2020

Mounting type:*

● Fixed ○ Vertical axis ○ Inclined axis ○ Two axis

Slope [°] (0-90)

Azimuth [°] (-180-180)

☐ Optimize slope

☐ Optimize slope and azimuth

☑ **PV power**

PV technology* Crystalline silicon

Installed peak PV power [kWp]* 1

System loss [%]* 14

☑ **Radiation components**

Figure 16: Hourly data download procedure [11]

The hourly data from 2005 and 2020 have been downloaded from the "hourly data" window (Figure 16). Subsequently, the solar radiation database, the start and end years, the mounting typology, the slope and azimuth must be set. After these steps, PVGIS gives the possibility to download the radiation components (direct irradiance, diffuse and reflected all on the inclined plane) expressed in [$\frac{W}{m^2}$], the photovoltaic system power in [W], the sun height in [°], the air temperature at 2 m in [°C] and the wind speed at 10 m above the ground in [$\frac{m}{s}$]. Regarding the PV power, in Figure 16, it can be seen that the user has to select the photovoltaic technology, the installed peak power in [kW] and the system losses. This last parameter, usually set at 14% [11], consists in all the losses of the system which cause that the power delivered to the grid is actually lower than the power actually produced. They comprehend the losses in the cables, the dirt over the panels and the fact that over the years the system tends to lose its initial power of a few percent, depending on the modules typology [11] . However, to carry out all the subsequent analysis, the radiation components have been the only ones exploited, disregarding the PVGIS photovoltaic power output and calculating it manually. This decision was made to consider both the efficiency of the chosen photovoltaic panels and the occupied surface.

4. State of the art

4.1. Actual photovoltaic production

The following Chapter assesses the actual photovoltaic production in Frassinetto. The information reported has been retrieved thanks to the involvement of the mayor of the Municipality, who kindly provided all the documents related to the existing plants. In Frassinetto, at the moment, there are two photovoltaic plants installed in 2011. The first one is installed over the roof of the cemetery and the other over the sport facility, both shown in Figure 17. At present, the produced electricity is sent to the grid instead of being exploited locally and in this section the actual photovoltaic production in these two locations is calculated using PVGIS.

Through Google Earth [13] (Figure 17), the amount and the size of the panels over each roof can be obtained, as well as the tilt of the surfaces.

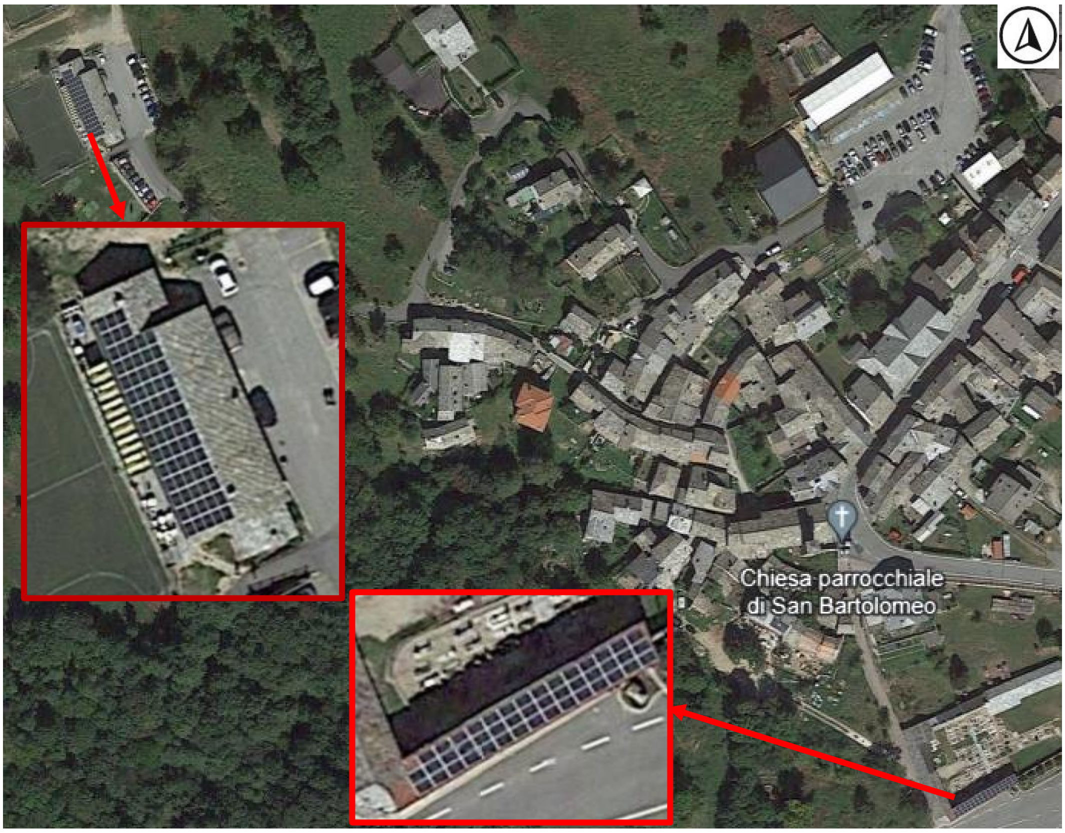


Figure 17: Location of the two existing photovoltaic plants [13]

Given the previous three points, PVGIS has been used to obtain the hourly data of direct and diffuse solar irradiance by properly setting the slope and the azimuth of each location. The downloaded time-series is of 15 years and, in order to handle a smaller dataset, the average year has been calculated thus obtaining an irradiance value for each hour of one year.

With these data, the power produced per hour can be computed applying the equation 2 reported below:

Equation 2: Power calculation

$$Power = (I_{direct} + I_{diffuse}) * A * n * \eta$$

Where:

- I_{direct} and $I_{diffuse}$ are respectively the direct and the diffuse solar irradiance expressed in $[\frac{W}{m^2}]$
- A is the area of one panel
- n is the number of panels installed
- η is the efficiency

The module type used for this analysis is the JKM250M-60 (250 W) which is the same model as those currently installed. This panel type is characterized by an area of 1.6368 m^2 and an efficiency of 0.1527 [17].

4.1.1. Cemetery plant

The cemetery plant is composed by 44 photovoltaic panels, 250 W each, installed with a tilt of 9° and an azimuth of -30° (-90° is East, 0° is South and 90° is West), for a total of 11 kW installed. In Figure 18 is reported the plot of the hourly production of the plant for the average year and, as expected, the behaviour of the production changes over the year due to the seasonality. The major contribution is during summer mainly because the cemetery roof is not much tilted and for this reason the production is higher when the sun is at higher zenith. Regarding the azimuth, this plant is well oriented since, despite it is not perfectly South facing, the angle is closer to 0°.

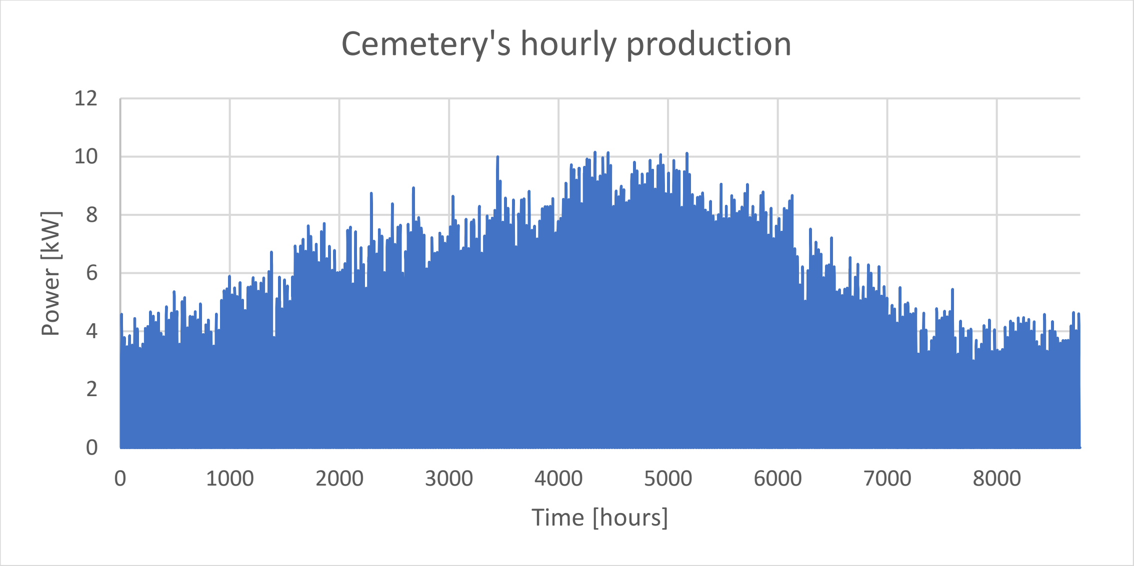


Figure 18: Cemetery's hourly production

In Figure 19 is shown the chart of the monthly production of the cemetery plant that has been calculated summed up all the hourly values for each month.

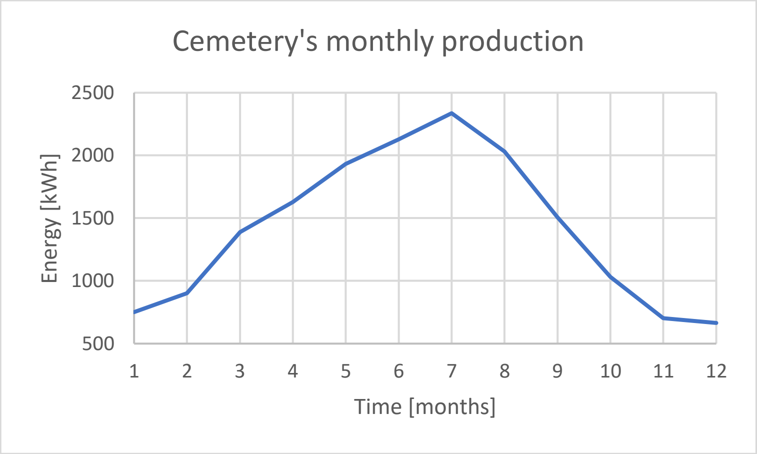


Figure 19: Cemetery's monthly production

4.1.2. Sport facility plant

The sport facility plant has 71 panels identical to the ones used for the Cemetery, 16° tiled and with an azimuth of 65°, for a totality of 18 kW installed. In Figure 20 is reported the hourly plant production which is generally higher than the cemetery one mainly because there is a higher number of panels installed and the roof is more tilted. In this case the azimuth is not the optimal one since it is more West oriented and for this reason, there will be a higher production in the afternoon than in the morning.

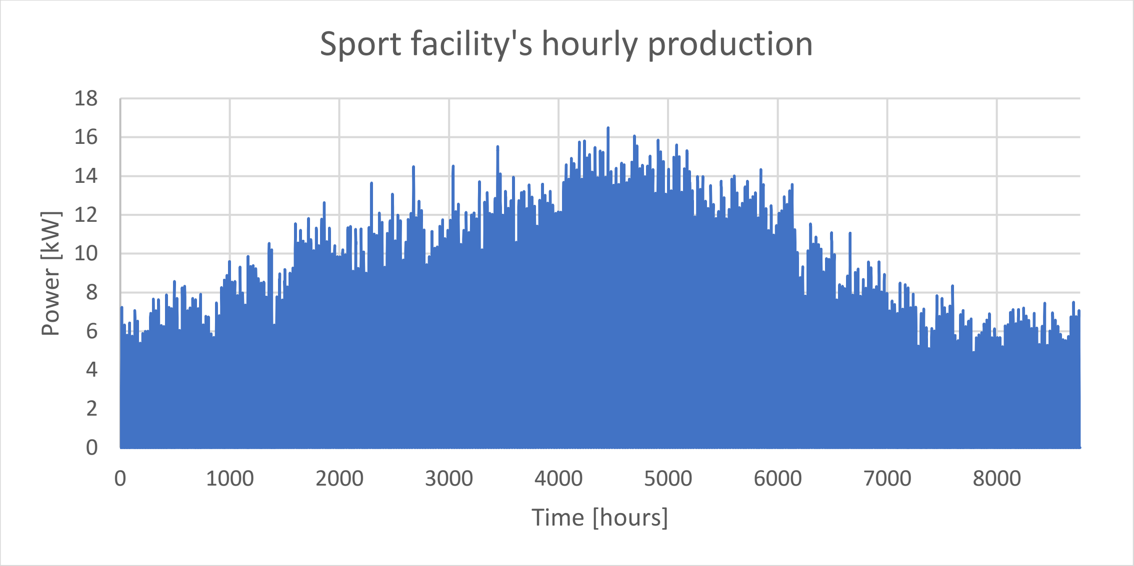


Figure 20: Sport facility's hourly production

In Figure 21 is plotted the behaviour of the monthly production which has its peak on July almost reaching the value of 4000 kWh. From this chart it can be also noticed that there is a higher variability of the production during the average year with respect to the cemetery plant. This is mainly due to the azimuth of the surface that, being more West oriented, does not guarantee a good performance during the winter season, despite being the surface more tilted.

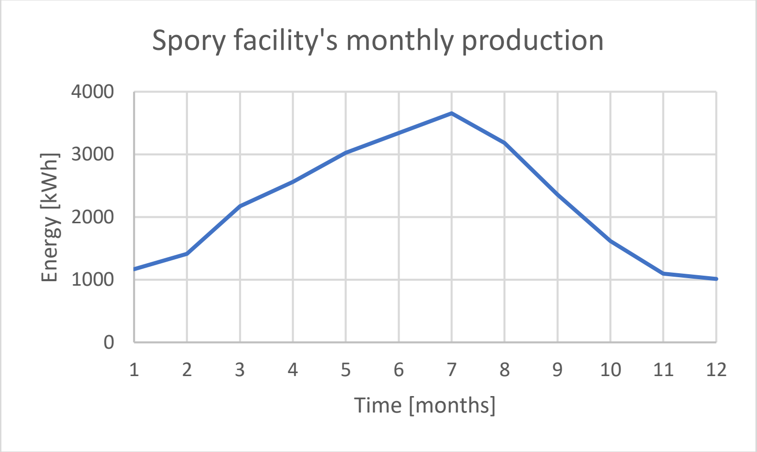


Figure 21: Sport facility's monthly production

4.2. Actual Consumptions

In this section the evaluation of the electrical consumptions of Frassinetto is carried out in order to understand whether the actual photovoltaic production is enough to cover them all or not. This analysis has been done exploiting the bills' monthly electrical consumption values kindly provided by the Frassinetto Municipality for each user. Then, in Chapter 8, they will be scaled to hourly values, to be consistent with the photovoltaic production estimation, to be able to retrieve the required size of the storage system.

4.2.1. Families

The families' electrical consumptions were the only missing information. To estimate this, starting from the aerial view of Frassinetto and considering that it is a small mountainous town, a reasonable approximation can be to assume a distribution of houses with two or three people. To obtain the consumptions of the entire Municipality, the starting point has been to consider the average number of permanents resident that, according to the information retrieved from the mayor, is around 270. A further aspect that needs to be considered is the fact that during summer Frassinetto becomes a holiday destination, meaning that the number of inhabitants usually increase of about 1000 units. To obtain the monthly consumption values, several assumptions were required since the exact distribution of the families of Frassinetto was not available. Regarding the permanent residents (270), it has been considered that half of them lives in apartments for two people and the remaining half lives in flats for three people. The monthly electrical consumptions of a family of two and three people are reported in Table 1; these data have been retrieved by considering different bills and by calculating an average value.

Table 1: Monthly families' consumptions

Months	2-people families' consumptions [kWh]	3-people families' consumptions [kWh]
1	60	124
2	60	126
3	62	118
4	49	141
5	74	124
6	72	105
7	57	102
8	45	93
9	50	120
10	79	133
11	79	139
12	85	145

These monthly values are reported for only one house and for this reason they must be multiplied by the number of houses. An example of possible houses distribution can be to consider 67 houses for two and 45 for three people.

Considering the tourism contribution in the summer months, it has been supposed that tourists are hosted in 200 houses and their impact must be taken into account in the consumption's estimation. To obtain this additional information, it is assumed that it can be retrieved by summing the total consumptions of permanent residents and multiplying this value by two. This calculation comes from the fact that the permanent residents occupy 112 houses and the tourists are hosted in about 200 houses. The results are shown in Table 2. It is important to note that this is a simplified hypothesis that does not consider the potential behaviour of tourists or their precise distribution among households. However, it provides an initial understanding of how tourism can impact consumption patterns.

Table 2: Tourists' electrical consumptions

Months	Tourists' consumptions [kWh]
1	0
2	0
3	0
4	0
5	0
6	19098
7	16845
8	14400
9	0
10	0
11	0
12	0

At this point all the data required to calculate the total monthly families' consumptions are available and can be plotted as shown in Figure 22.

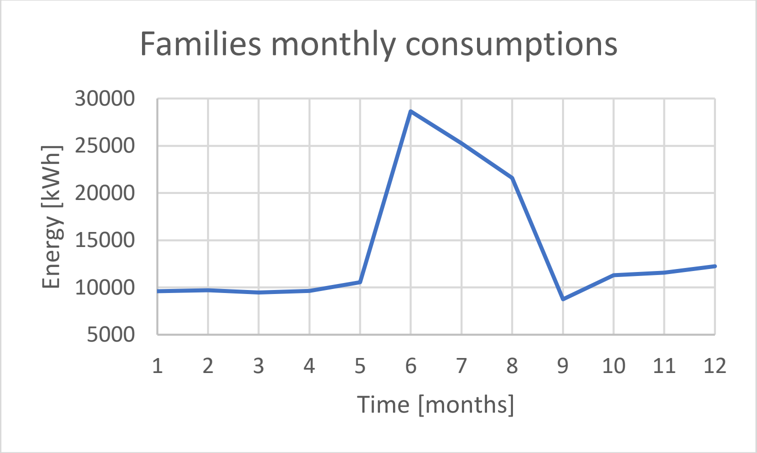


Figure 22: Families monthly consumptions

In Figure 22 it can be noticed that, as expected, in the summer season the consumptions grow considerably due to the tourists' contribution reaching values above 20000 kWh on June, July and August. For the rest of the year the curve has an almost constant behaviour with values around 10000 – 15000 kWh.

4.2.2. Cemetery

Regarding the Cemetery consumptions analysis, the Frassinetto Municipality provided the monthly bills of 2019, 2020 and 2021 and from them, the average has been calculated and plotted in the graph reported in Figure 23.

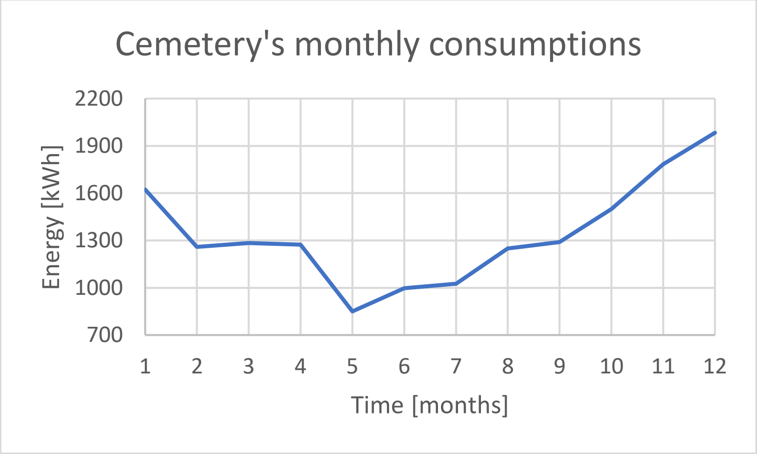


Figure 23: Cemetery's monthly consumptions

From the plot in Figure 23 it can be noticed that the electrical consumptions grow considerably during the winter season and this can be attributable to a more intensive use of the external lights.

4.2.3. Sport facility

The electrical consumptions of the Sport facility have been retrieved from the bills of 2019, 2020 and 2021 that the major provided and, as for the Cemetery, the monthly values have been obtained from the average, done for each month, of the reported consumptions in the three bills. The result is reported in Figure 24 and the behaviour of the curve shows that, as expected, the sporty area is much more used during summer. This is consistent with the facts that the football pitch and the locker rooms, due to the winter rigid temperatures, are mainly exploited during the summer season also in the evening which cause higher consumptions due to the lights required for the players and the electricity required in the changing rooms.

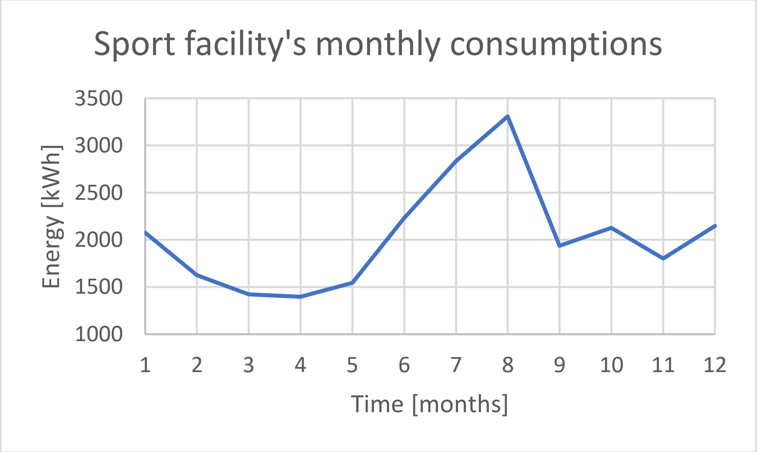


Figure 24: Sport facility's monthly consumptions

4.2.4. Town Hall

The monthly electrical consumptions of the Frassinetto Town Hall have been retrieved from the average of the bills of 2019, 2020 and 2021. The result is shown in Figure 25 and present a peculiar behaviour since it is not homogeneous throughout the year: as expected, the highest consumptions are concentrated in the winter months probably due to a more intensive use of electricity for the interior lighting but also due to possible external Christmas lights. Confirming this, it can be noticed that on December the consumption is about 1200 kWh, on January is slightly greater than 800 kWh and in the other months it has lower values around 500 – 700 kWh.

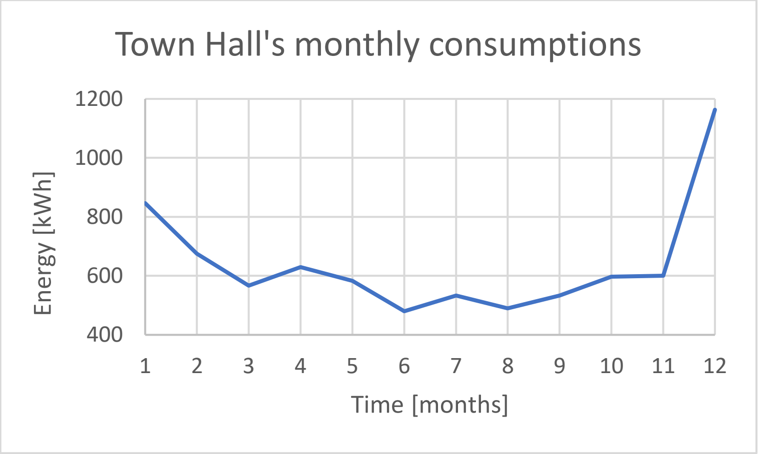


Figure 25: Town Hall's monthly consumptions

4.2.5. SS. Annunziata

The SS. Annunziata is a house near the Town Hall of Frassinetto that host a cooperative which promotes social activities for people with disabilities. As for the other structures, also in this case the mayor provided the bills of 2019, 2020 and 2021; as shown in Figure 26 the highest consumptions are in winter and in summer that are the months in which Frassinetto is busier.

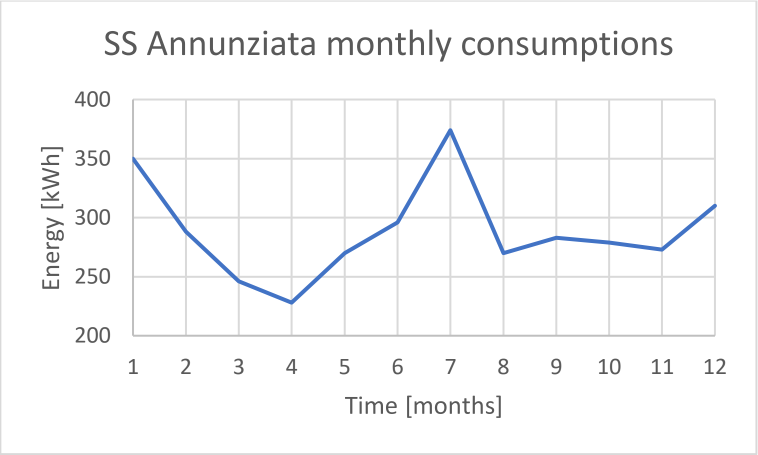


Figure 26: SS Annunziata monthly consumptions

4.2.6. Public lighting

The public lighting consumption estimation has been performed starting from the monthly bills of 2019, 2020 and 2021 of the two POD (Point of Delivery). To obtain a single value, the sum between the values of each POD has been performed and then averaged over the available years to retrieve the monthly consumptions for the average year. The result is reported in Figure 27 and present quite high values since the public lighting is used each night and, especially in winter, it remains switched-on for many hours. In the bills there was an anomaly in the month of February since the consumptions resulted to be too low with respect to the values of December and January. For this reason, the February consumption has been changed and set to a more reasonable value equal to 6250 kWh.

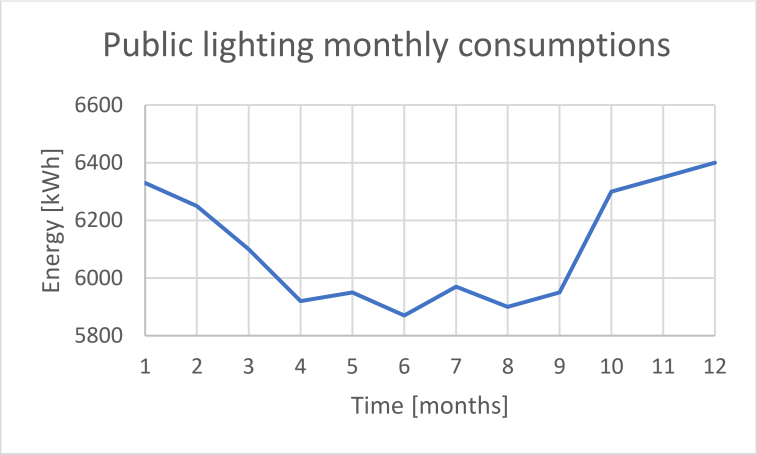


Figure 27: Public lighting monthly consumptions

4.3. Comparison between actual production and consumption

In this sub-Chapter the comparison between the actual photovoltaic production (the Cemetery and the Sport facility plants) and the actual consumptions is developed. As expected, the production is not enough to cover the consumptions because the two existing plants are too small. In Figure 28 is reported the graph of the comparison and it can be noticed that the production curve (in yellow) reaches its maximum of about 6000 kWh in July while the consumptions (in green) assume values of around 35 MWh in the summer season and in the other months vary between 20 MWh and 25 MWh.

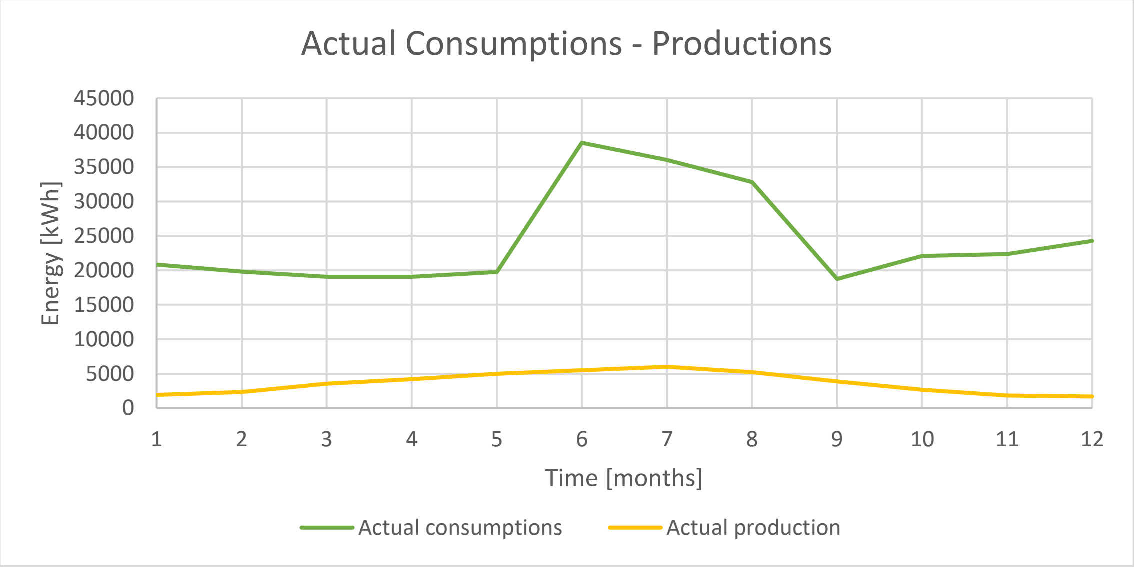


Figure 28: Actual consumptions-productions

From this result it can be get that the implementation of new photovoltaic plants in the available areas can be an important action towards the constitution of an Energy Community, which can be as independent as possible from the national electricity grid also sharing the potential surplus with some virtual consumers.

5. Additional consumptions estimation

In the present work, it has been considered also the addition of sustainable tourism-oriented utilities in order to exploit the available areas with the purpose of requalifying them. The idea is to add a camper area equipped with a bar and some bungalows all located in the south of Frassinetto, reported respectively in red and light blue in Figure 29.

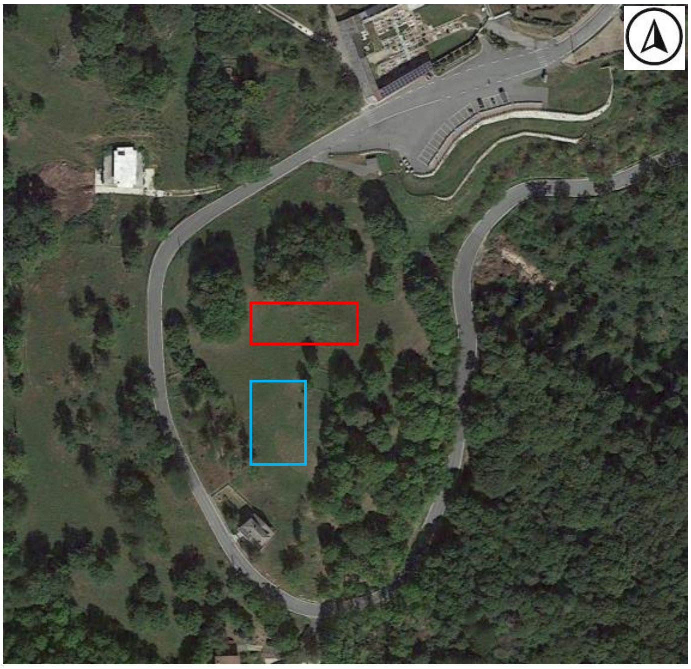


Figure 29: Camper area and bungalows locations

The decision of adding new utilities has been taken also because they can be exploited for the installation of new photovoltaic plants in order to increase the total capacity, thus decreasing the dependence on the national grid especially during summer, when the energy production is favoured and the electrical consumptions are higher.

5.1. Camper and bar area

The camper area has been drawn with AutoCAD to have an idea of the space that it can occupy. The sketch is shown in Figure 30 and it contains the capers' charging stations, a bar (20m x 10m) and a W.C. area (10m x 5m). It has been decided that a reasonable number of stations is six, each 8m x 10m so that there is also some additional available space for the comfort of the tourists. To estimate the electrical consumptions of these components the charging stations for the campers and the bar have to be taken into account.

Figure 30: Layout of the camper area

Starting with the recharging stations it has been stated that two are required, with three plugs 6 A each; in addition, the chosen ones have also three water taps [18]. The plugs deliver 6 A at a voltage of 220 V and from that, the power P required for each one can be retrieved with the equation 3.

Equation 3: Recharging station power calculation

$$P = I * V = 6 * 220 = 1320\, W$$

From this, by assuming that each camper remains plugged in for about 3 hours per day, the daily electrical consumption E_{daily} can be obtained with equation 4.

Equation 4: Recharging station daily energy calculation

$$E_{daily} = P * t = 1320 * 3 = 3960\ {}^{Wh}/_{day * camper} = 3.96\ {}^{kWh}/_{day * camper}$$

Then to calculate the total electrical consumption of the campers, few assumptions are required regarding the number of vehicles expected to reach Frassinetto every month and in which periods of the year. The considered months are from May to September but the following are realistically conceivable with a different turnout of campers: 3 on May, 4 on June, 6 on July, 6 on August and 3 on September. With these values, all the required information to calculate the consumptions for each month are available and with the equation 5 they can be obtained.

Equation 5: Recharging stations monthly energy calculation

$$E_{total} = E_{daily} * d * n\ [{}^{kWh}/_{month}]$$

Where:

- E_{daily} is the daily electrical consumption of one camper

- d is the number of days in each month
- n is the number of campers expected in each month

The calculated monthly electrical consumptions are reported in the plot in Figure 31.

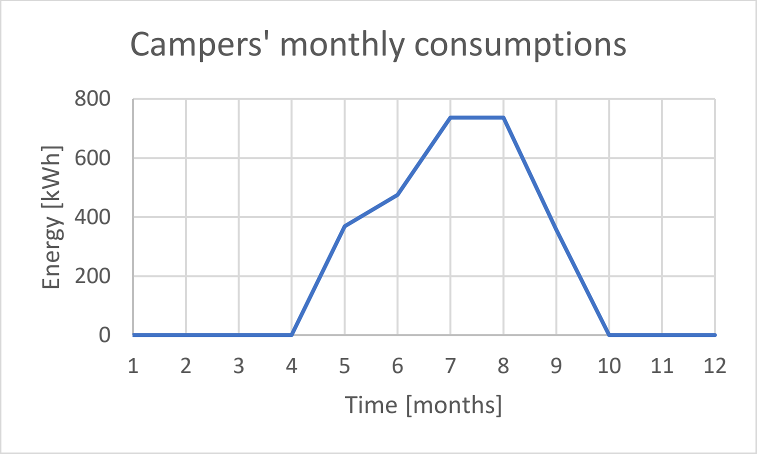


Figure 31: Campers' monthly consumptions

Regarding the bar of the camper area, it has been considered opened only in the summer months, when the campers occupy the area. The exact values have been retrieved form the bills of a small bar that kindly provided three years of data and from them an average monthly value has been calculated. The graph with the behaviour of the bar electrical consumptions is reported in Figure 32.

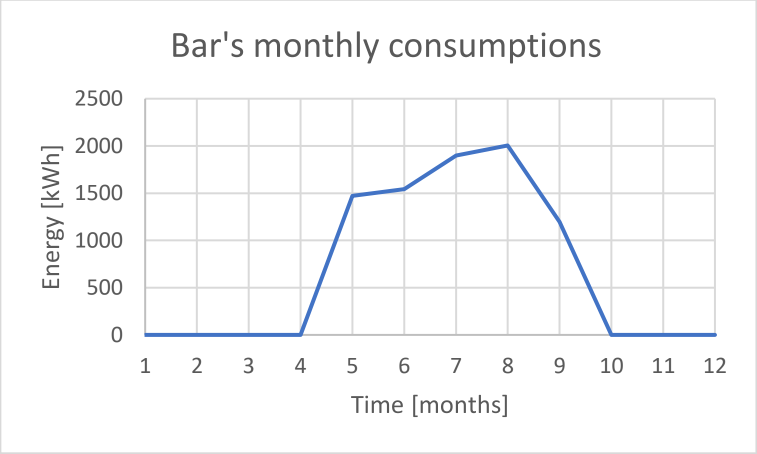


Figure 32: Bar's monthly consumptions

5.2. Bungalows

In addition to the caper area, the available space below it has been exploited by adding a group of five bungalows whose location and dimensions are shown in Figure 33. These tiny houses are expected to host part of the summer tourists and they will be occupied only from May to

September, as for the campers. It has been considered that on May only two bungalows will be opened, on June and September four and on July and August all five.

Figure 33: Bungalows' location [19]

Regarding the estimation of the electrical consumptions of each bungalow, a house of two people has been used as reference given that the square footage of one bungalow can be considered similar to the one of small two-room apartment. Given these premises, the monthly consumption of one bungalow has been set to 60 kWh and then this value has been multiplied by the number of bungalows opened in each month. The plot of the monthly electrical consumptions of the bungalows is shown in Figure 34.

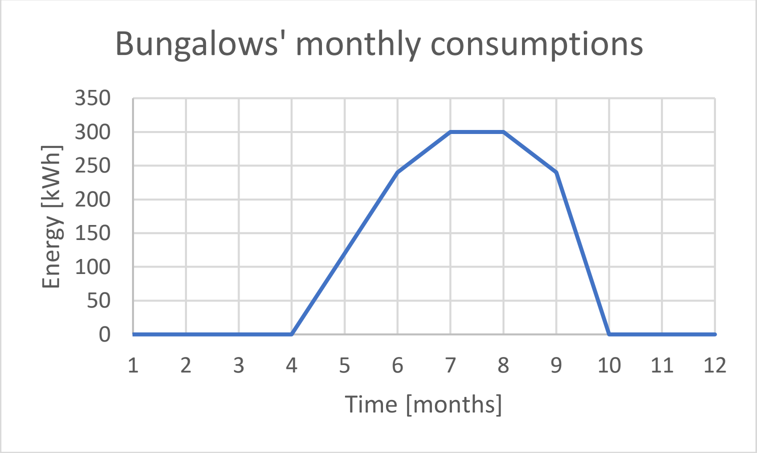


Figure 34: Bungalows' monthly consumptions

6. Photovoltaic production considering different scenarios

In this Chapter, the design of the new photovoltaic plants is carried out according to different scenarios, with the aim of covering the estimated electrical consumption. Frassinetto has a lot of available space that can be covered with panels in order to reach the objective of creating an Energy Community as independent as possible from the national electricity grid. The locations have been selected by involving the major in every decision to avoid problems with the allowances and to perform a project that is as real as possible so that it could be replicable.

Some plants have been designed in already existing areas such as the wall below the car parking, the roofs of the cemetery and of the sport facility, the lawn under the wall and the roof behind the Municipality. All these locations are reported in Figure 35 pointed with the orange arrows.

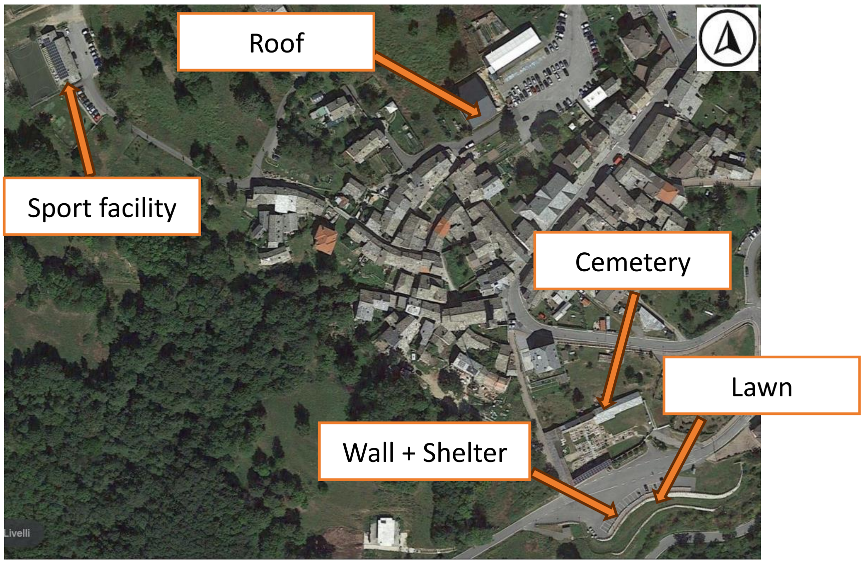


Figure 35: New photovoltaic plants locations [13]

Moreover, to add some installed power, additional solutions have been considered such as the roof of the bar of the camper area, the roofs of the bungalows and a photovoltaic shelter installed immediately over the lawn and the wall, which covers the car parking. For all the plants a reasonable choice as photovoltaic panels are the Unical Multivolt monocrystalline modules - 425 W which have an area of 1.9527 m^2 and an efficiency of 0.2176 [20]. Those are photovoltaic modules of last generation equipped with NType multi-busbar cells that bring a greater reflectance, thus ensuring higher output power. Moreover, they have an almost constant performance over time since the guaranteed power after 30 years is the 87.4% of the initial one [20]. For each location, the photovoltaic power has been retrieved by applying Equation 2, accurately modifying the irradiance contribution the number of panels installed, the area and the efficiency. In order to retrieve the exact number of modules installable in each location, the Solar Edge website [19] has been used since it allows one to manually draw the exploitable area, to select the desired type of panels and their orientation and tilt. Moreover, it gives also the possibility to set the spacing between the rows in case the plant is installed over a flat surface. Once set all the parameters, the rendering of the plant is available and it is easy to retrieve the number of modules for each location.

6.1. Camper area

In the context of the camper area, being the selected surface completely free from any environmental and legal constraint, there was the possibility of developing different scenarios in order to understand which can be the best positioning solution for the photovoltaic panels. In both the developed solutions, the only parameter that has been changed is the slope of the bar's roof. Regarding the azimuth, in both cases, it has been chosen equal to zero, meaning that the roof is South facing.

6.1.1. Tilt 39°

The first scenario developed is the one with the bar's roof 39° tilted, with azimuth equal to 0° and 55 panels. In Figure 36 is shown the render of the structure with the photovoltaic panels placed only over the part of the roof oriented to South [19].

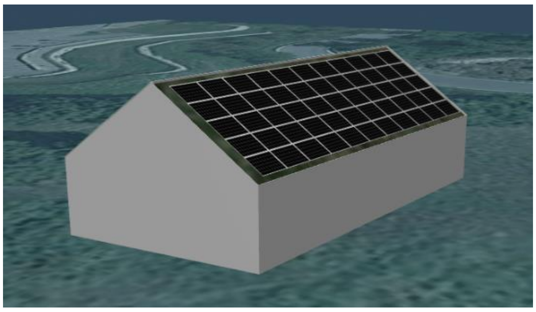


Figure 36: Rendering of the camper area's plant, tilt = 39° [19]

In Figure 37 it is reported the plot of the estimated hourly production of the average year which is higher in summer but, being the roof 39° tilted, also in winter the production is acceptable resulting in quite homogeneous production throughout the year.

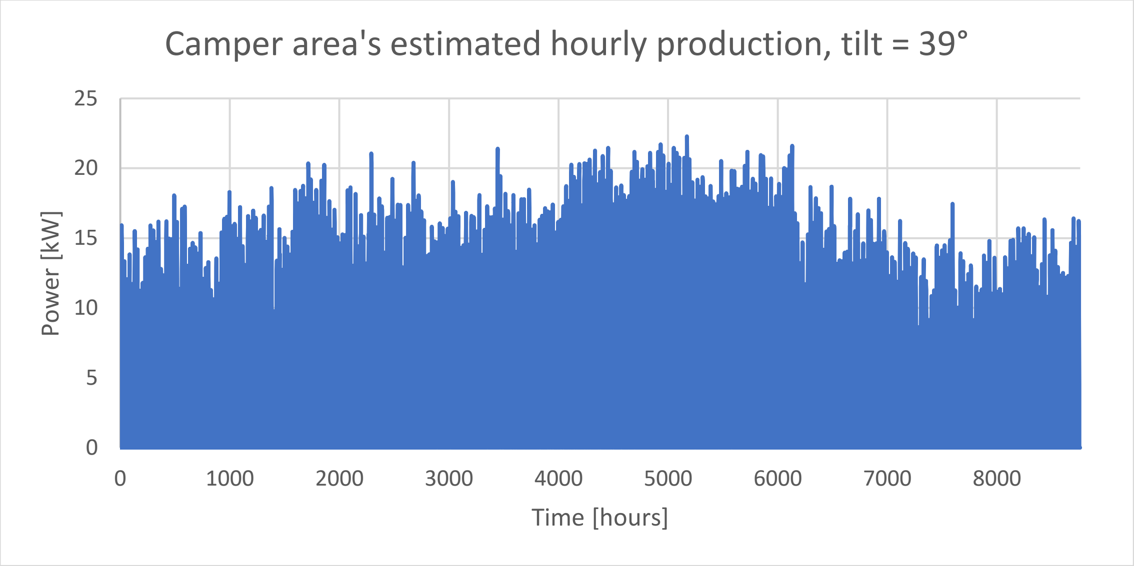


Figure 37: Camper area's estimated hourly production, tilt = 39°

6.1.2. Tilt 22°

In this second scenario, the roof is 22° tilted and the panels are 99 and the azimuth is the same as in the previous case. The render of the bar is reported in Figure 38 with the panels added all over the roof: in this case the tilt is less than in the previous case but there are more panels.

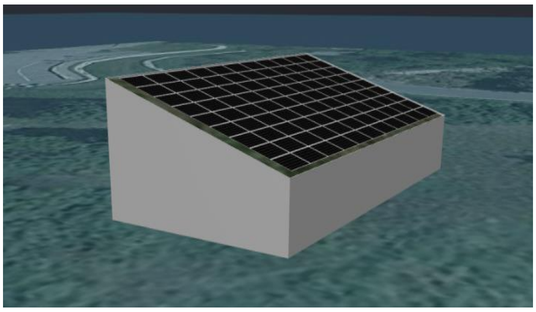


Figure 38: Rendering of the camper area's plant, tilt = 22° [19]

The result of the hourly energy production is shown in Figure 39 and the production assume a less homogeneous behaviour throughout the year, being much higher during summer and much lower in winter mainly due to the different tilt of the roof.

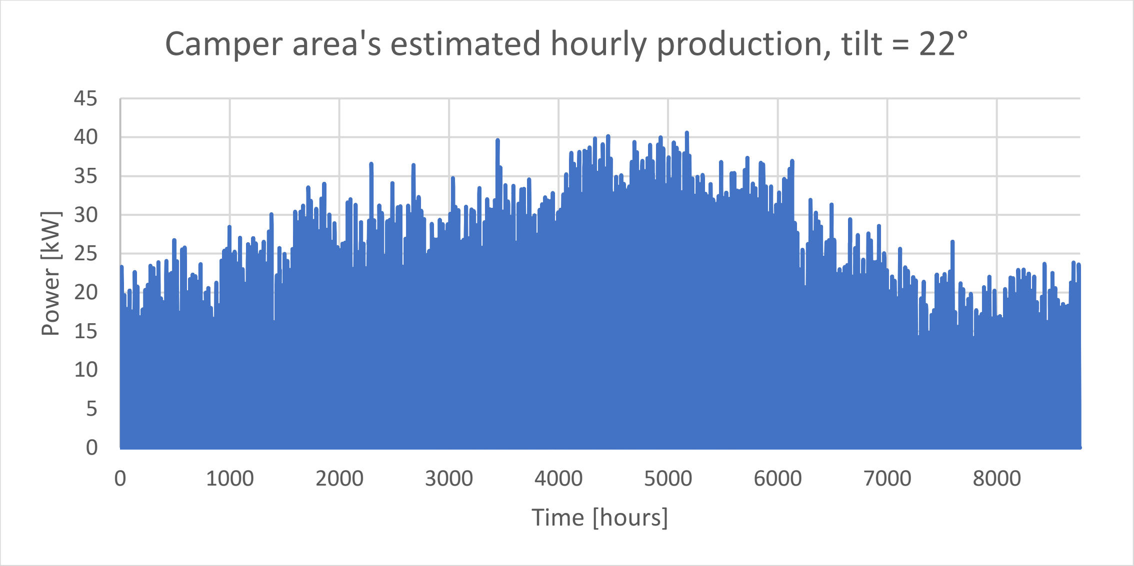


Figure 39: Camper area's estimated hourly production, tilt = 22°

In Figure 40 it is reported the comparison between the production in the two scenarios developed. As previously explained, in the 39° tilt scenario the values do not vary a lot during the year, resulting in a more homogeneous behaviour, while in the other one, being the roof less tilted, the values do not assume a constant trend. The total yearly energy production in the first scenario (39°) is 40614 kWh while in the second one (22°) is 70939 kWh.

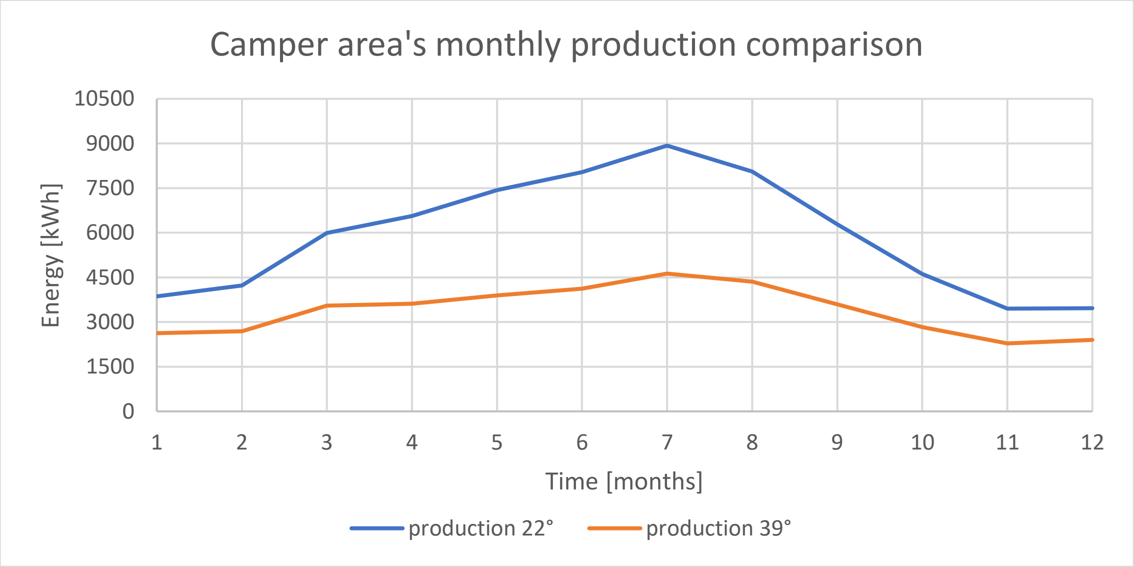


Figure 40: Camper area's monthly production comparison

6.2. Bungalows

As for the camper area, also the bungalows are totally free from constraints and, for this reason, there has been the possibility to develop two scenarios of production by changing the tilt of the roofs and the number of photovoltaic panels installed.

6.2.1. Tilt 40°

In this first scenario the roof of each bungalow is South-facing, 40° tilted and there are 75 panels installed. In Figure 41 is shown the render of the area with the five bungalows with the panels added over the part of the roof oriented to South. The shading between the structures, which can lead to a decrease in production, has not been taken into account since the bungalows are sufficiently separated from each other.

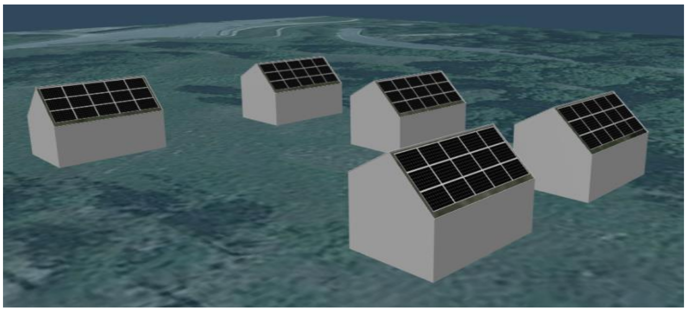


Figure 41: Rendering of the bungalows' plant; tilt = 40° [19]

In Figure 42 is reported the chart of the hourly photovoltaic production of the average year in which it is possible to notice that the maximum power values of about 30 kW are reached in July. From this plot it can be seen that the production varies in a not so wide range between 15 kW and 30 kW, mainly because the roof is enough tilted to ensure a quite homogeneous productivity over the year.

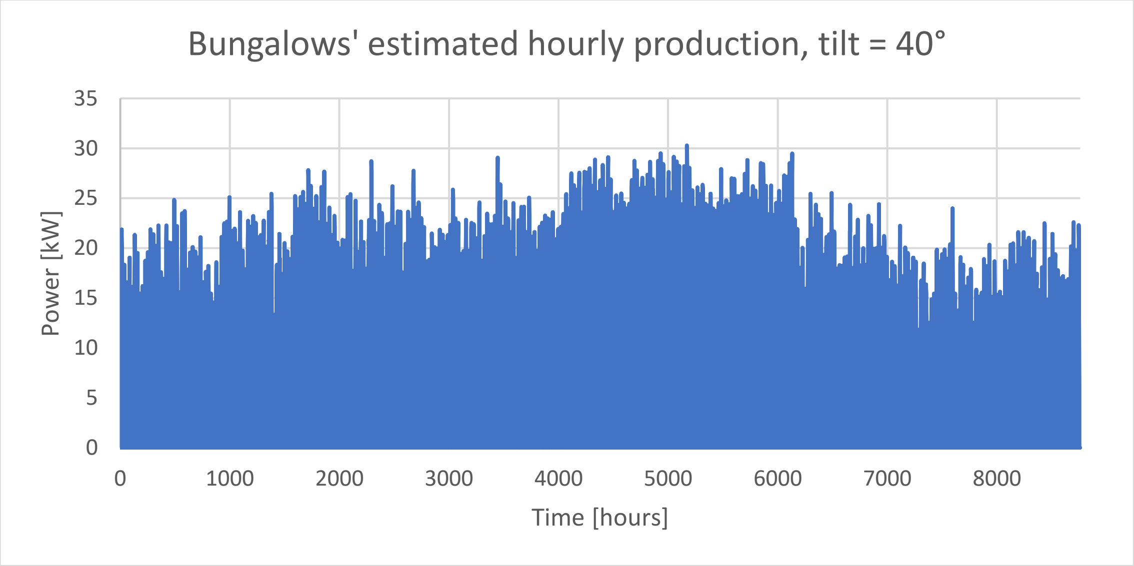


Figure 42: Bungalows' estimated hourly production, tilt = 40°

6.2.2. Tilt 10°

In this scenario it has been decided that the bungalows' roofs have the structure shown in Figure 43 to be able to install more photovoltaic panels but with a lower inclination. In particular the panels are 125, the tilt is 10° and the azimuth is 0° (South oriented).

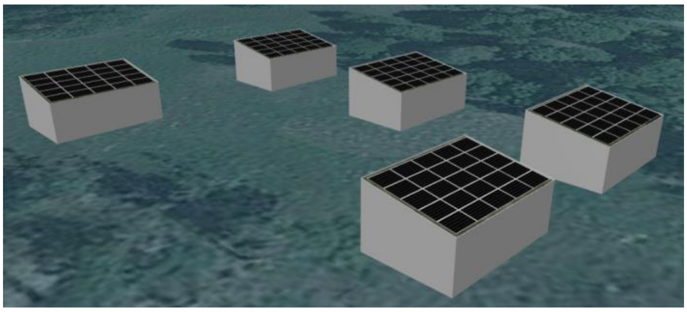


Figure 43: Rendering of the bungalows' plant, tilt = 10° [19]

In Figure 44 is reported the plot of the hourly production of the average year for this plant configuration. Being the roofs less tilted than the ones in the previous scenario, the power production assumes a more variable behaviour throughout the year, with values between 20 kW and 50 kW.

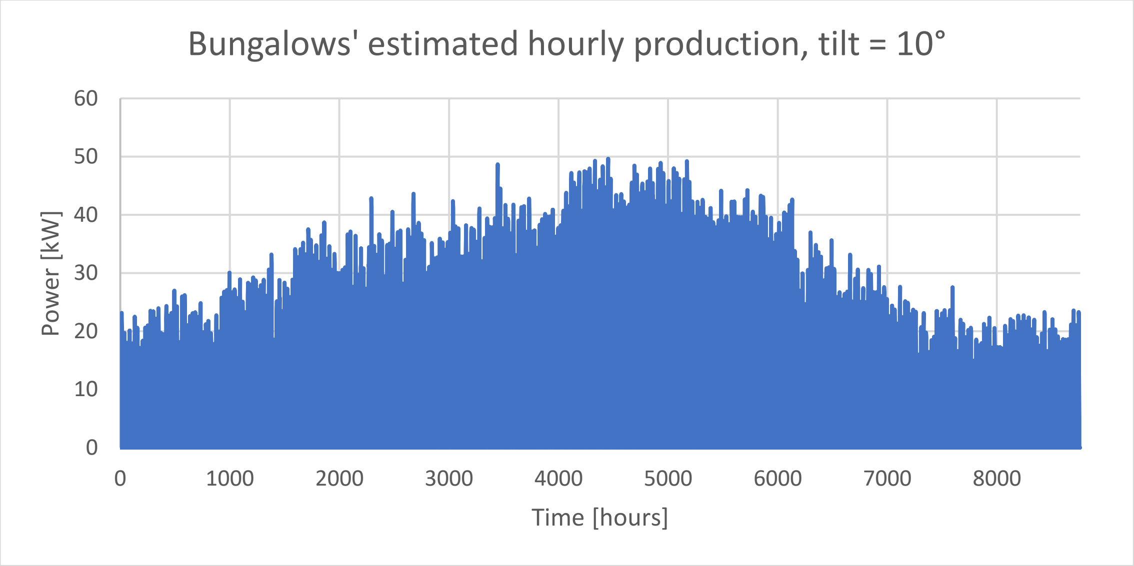


Figure 44: Bungalows' estimated hourly production, tilt = 10°

In Figure 45 the comparison between the monthly behaviours of both the developed scenarios is reported. From this, it can be noticed that the energy production of the 10° scenario is considerably higher than the other one. This mainly because, despite the lower inclination of the roofs, the number of panels is higher, resulting so in a greater production all over the year. Regarding the 40° scenario, the resulting energy has a more constant behaviour with less variability since the selected tilt is the optimal one. But, since the purpose of this work is to cover as much as possible the electrical consumptions and that the bungalows are open only during summer, the 10° scenario is preferable since it ensures a much higher production during summer, and a lower one during winter when the structures are closed.

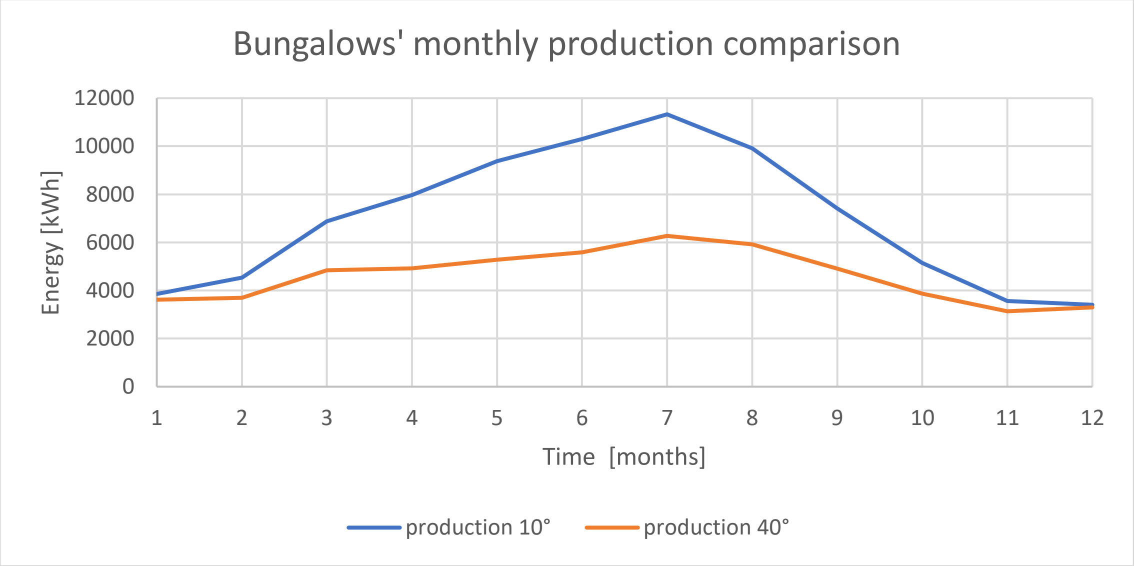


Figure 45: Bungalows' monthly production comparison

6.3. Cemetery

The cemetery plant already exists but it has been installed in 2011 and for this reason its productivity is no longer the best. For this reason, it has been decided to substitute the plant with a new one and to expand it to the building behind as shown in Figure 46. In this new configuration the panels over the roof pointed in red are 26 with a tilt of 9° and azimuth equal to -30° (South-East) while the panels over the building pointed in green are 46, 23° tilted and azimuth -23° (South-East).

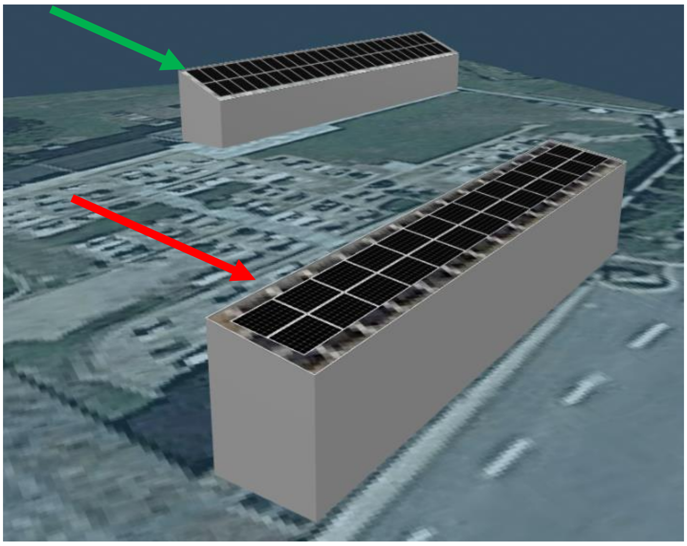


Figure 46: Rendering of the cemetery's plant [19]

In Figure 47 it is reported the total hourly photovoltaic production retrieved from the sum of the two plants' productions. In this configuration the energy output results to be greater than the actual one just because the new plant is more extended. The expansion of the plant to the roof behind leads to a marked increase in the production since the roof is more tilted (23°), better South oriented and the panels added are 46. The fact that the new panels have a bigger size (425 W) than the currently used ones (250 W), is not affecting the result because the 425 W are larger and the number of panels that can be installed decreases as a consequence. In the actual configuration the modules are placed only over the roof pointed in red and they are 44 while in the new design, over the same roof, the panels are 26.

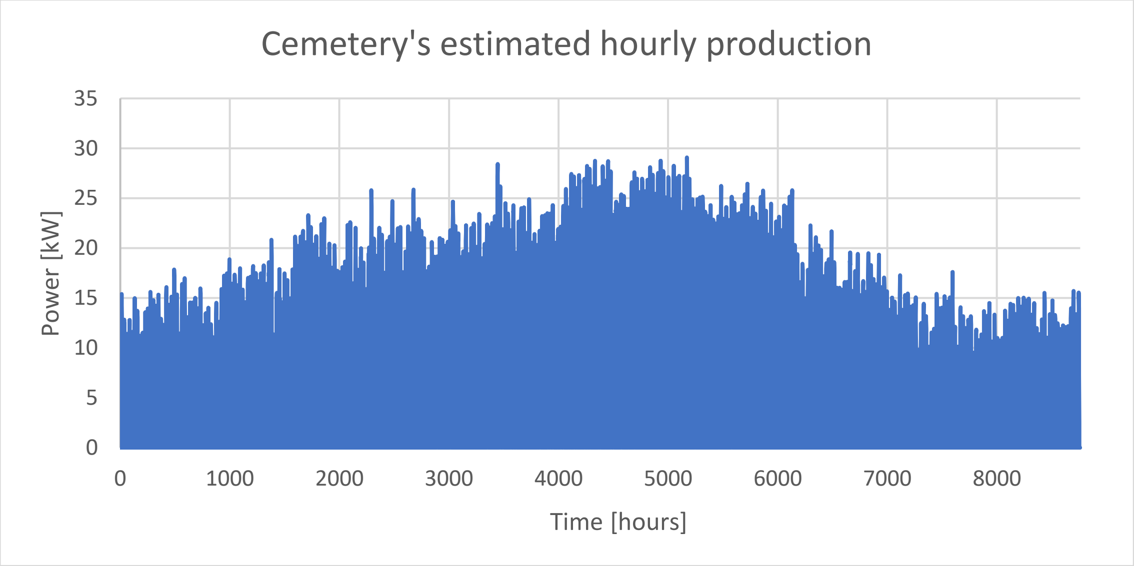


Figure 47: Cemetery's estimated hourly production

6.4. Sport facility

The actual sport facility plant described in Chapter 4.1.2 has been substituted by a new one so that the productivity can remain at an acceptable level for longer time. In the new designed configuration, the panels added are 60, the tilt of the roof that is 16° and an azimuth of 65°. The estimated energy production in this new configuration is not much different from the previous one since the panels used now are 425 W and have larger dimensions, while the modules used in the old configuration were 250 W, leading to a smaller area occupied. The annual production of this plant is 38221 kWh and, since the roof is not much tilted, it is mainly concentrated in the summer season as shown in Figure 48.

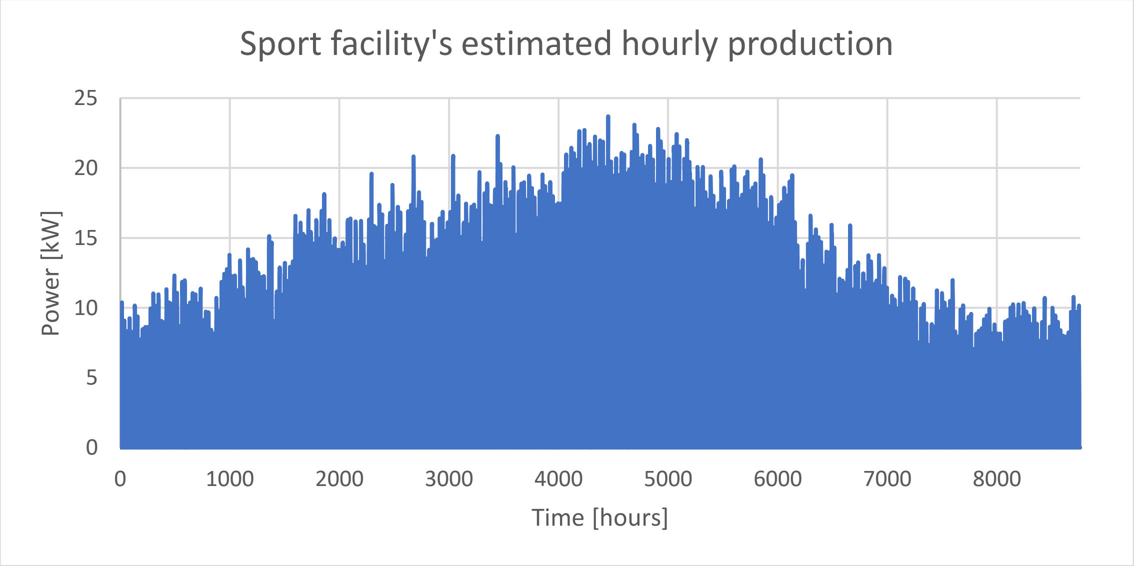


Figure 48: Sport facility's estimated hourly production

6.5. Wall

The wall under analysis is situated in the South of Frassinetto and it extend for 60 m with a height of about 4 m and it is 90° tilted. In this context, two scenarios have been developed: the first considering that the panels are attached to some supports that allow them to be 60° tilted and the other one in which the panels are directly added over the wall with a slope of 90°. In both the scenarios the modules are 171 with an average azimuth of -30°.

6.5.1. Tilt 60°

In this configuration the panels can be placed at 60° thanks to some supports added over the wall surface. The modules are placed as shown in Figure 49: in the left part, where the wall is 3 m height, the rows of panels are only 3 while, moving to the right part of the picture, the wall is almost 5 m height and the rows of panels are 4.

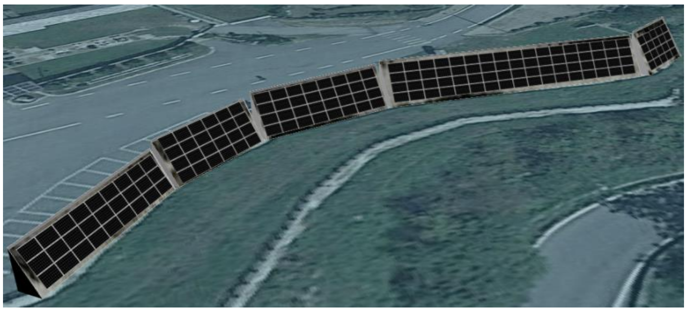


Figure 49: Rendering of the wall's plant, tilt = 60° [19]

In Figure 50 it is reported the plot of the hourly production which is has quite homogenous behaviour throughout the year due to the fact that also during winter, when the sun is lower, being the surface sufficiently tilted, the production assumes values similar to the summer ones.

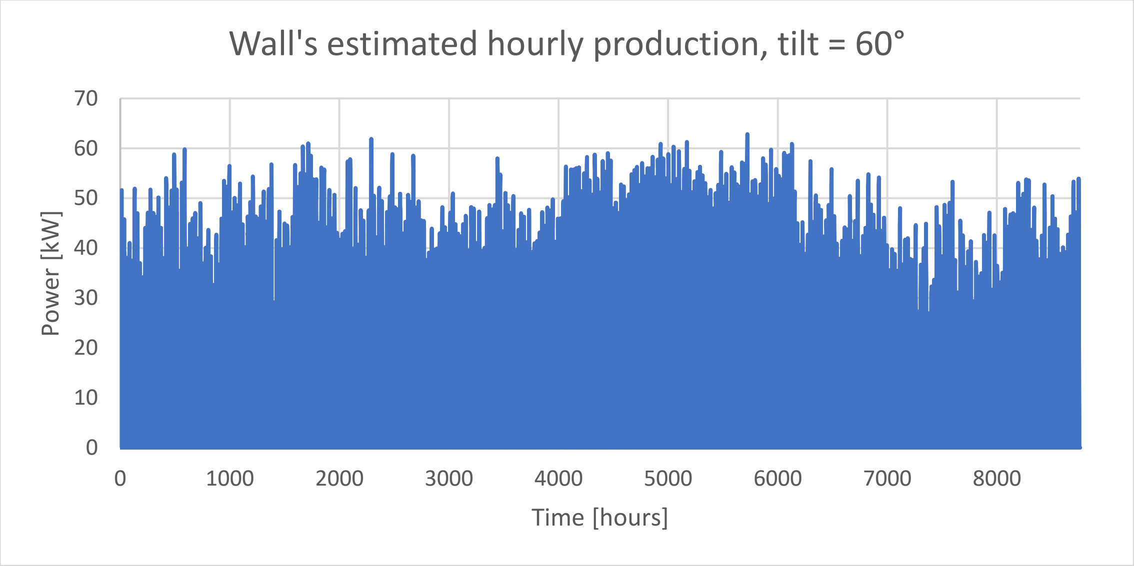


Figure 50: Wall's estimated hourly production, tilt = 60°

6.5.2. Tilt 90°

In this scenario the panels are directly added over the wall surface without any support. The behaviour of the power production of the average year reported in Figure 51 shown a peculiar trend, with the production that assumes higher values during the winter season with respect to the summer (e.g. in June 5800 kWh while in January 7300 kWh). This is because during summer the sun is higher in the sky and hits the surface of the panels with a greater angle thus leading to a lower energy production.

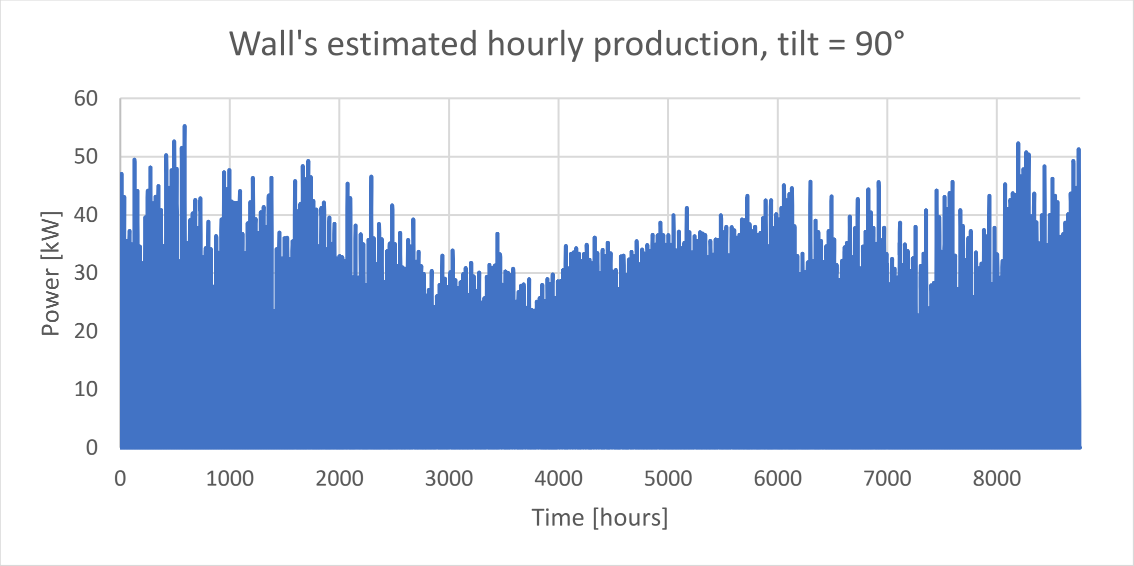


Figure 51: Wall's estimated hourly production, tilt = 90°

In Figure 52 is reported the plot with the comparison of the monthly energy production of the two developed scenarios. The best choice is to add the supports over the wall and put the panels at 60° to ensure a higher summer production.

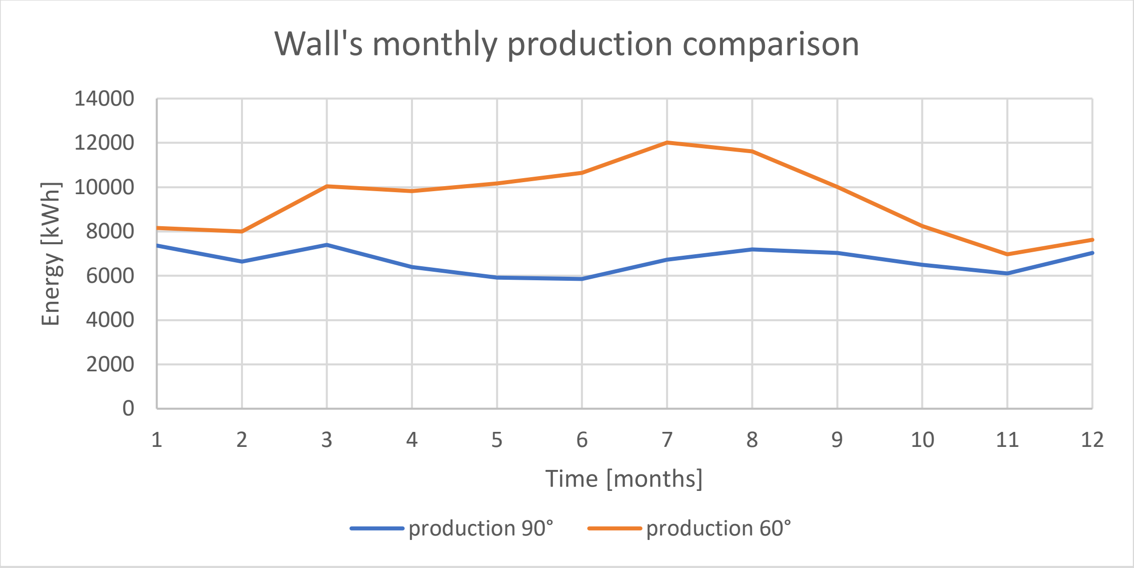


Figure 52: Wall's monthly production comparison

6.6. Shelter

The photovoltaic shelter has been added in the car parking immediately over the wall with the aim of increasing the energy production by exploiting the available space but also to give the possibility to install in the future, some car recharging stations. The rendering of the shelter is reported in Figure 53 and the panels are 138, 9° tilted with an overall azimuth of -27°.

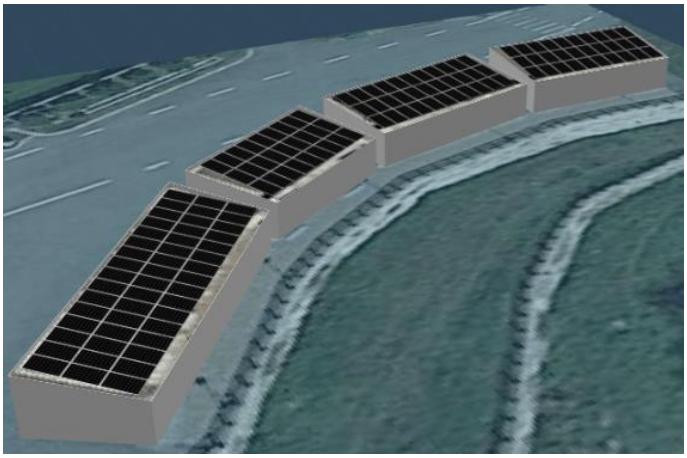


Figure 53: Rendering of the shelter's plant [19]

In Figure 54 it is reported the hourly power production which is considerably higher in summer, reaching values of about 55 kW in July. The annual energy production resulting from the sum of the hourly values of the average year is 90876 kWh.

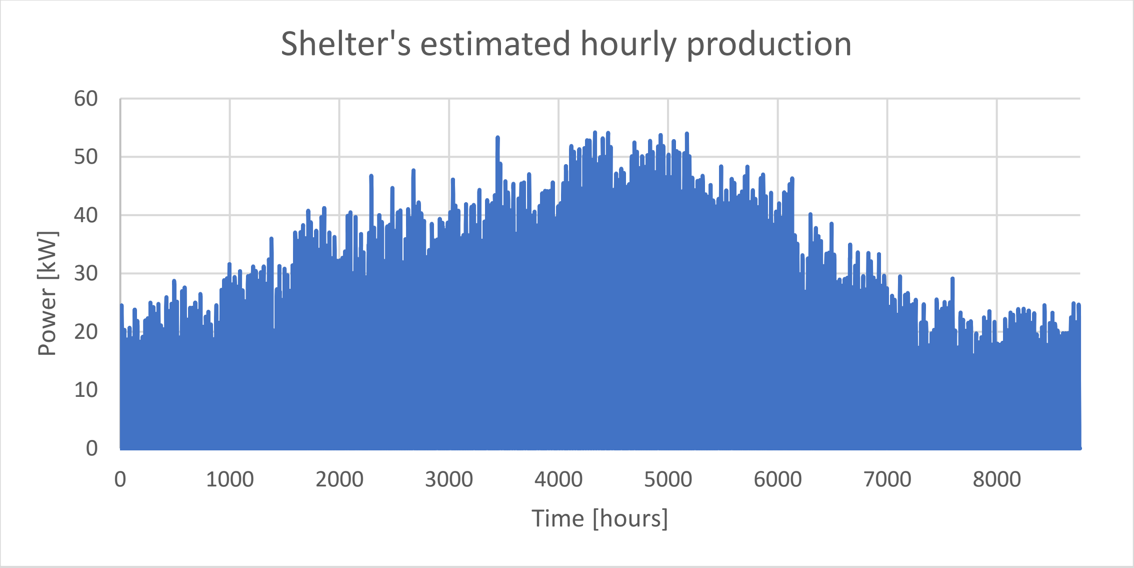


Figure 54: Shelter's estimated hourly production

6.7. Lawn

The lawn under analysis is located at the foot of the wall and it is an area free from any constraint with an available surface of 530 m^2. Being the surface totally flat, the designer of the plant is free to decide the tilt of the panels, the azimuth and also the number modules to add. In this context it has been decided to develop three different scenarios by keeping the azimuth always equal to 0° (South-facing) and by varying the tilt and the number of modules installed. A very important aspect that has been considered is the shading between the rows of panels. The employed procedure started with the research of the minimum value of sun's zenith in Frassinetto which occurs the 21 of December and it corresponds to 18° at noon [21]. By considering that value and accurately calculating the distance between the rows, no panel will be covered by those in front on any day of the year, since it represents the worst case. Subsequently, on AutoCAD, the minimum distance between the rows of panels has been retrieved by drawing, as shown in Figure 55, the sun's ray in orange with the inclination of 18°, and the PV panels in blue with their dimensions, considering that they are placed horizontally. All the linear measurements are reported in centimetres and, as a result, it has been obtained that the minimum distance between the rows of panels 15° tilted, is 95.39 cm. Moreover, to develop the different scenarios, the tilt of the panels has been changed and new distances have been retrieved as a consequence.

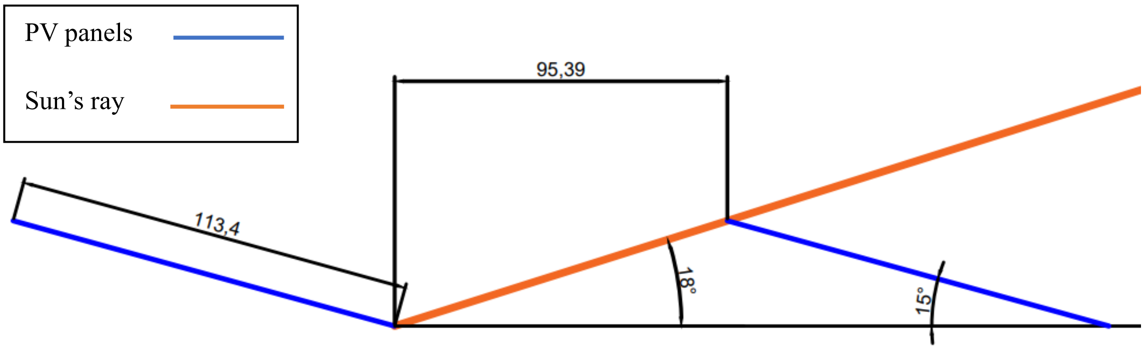


Figure 55: Spacing between the PV panels

In the three developed scenarios the tilt of the panels and the number of modules has been varied: less but more tilted panels or more modules less tilted. From that it is possible to catch that a trade-off exists between the number of units and the inclination. In the following Chapters the analysis is developed to obtain the best design solution.

6.7.1. Tilt 15°

In this scenario the installed panels over the lawn are 111, 15° tilted, South-facing and with a raw separation of 1 m. The maximum hourly production is about 45 kW reached in July as shown in Figure 56, and the total annual energy production is 76827 kWh.

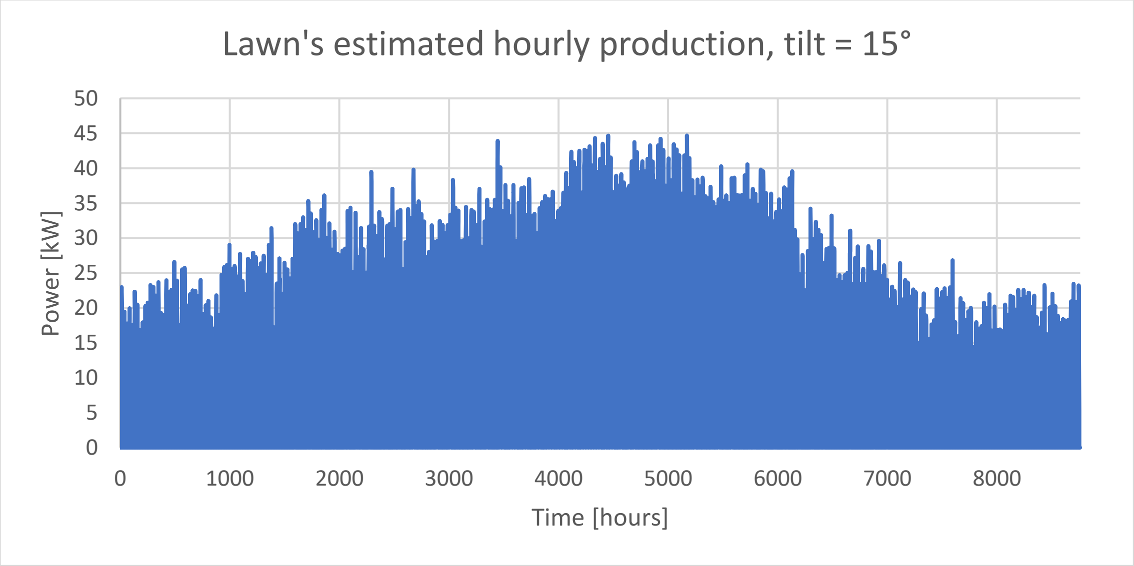


Figure 56: Lawn's estimated hourly production, tilt = 15°

6.7.2. Tilt 30°

In this configuration the panels added are 90, less than in the previous scenario, and they are 30° tilted, closer to the optimal inclination. In this case the annual energy production is 66027 kWh and the maximum hourly production is around 37 kW, as shown in Figure 57, both lower than the values of the first scenario.

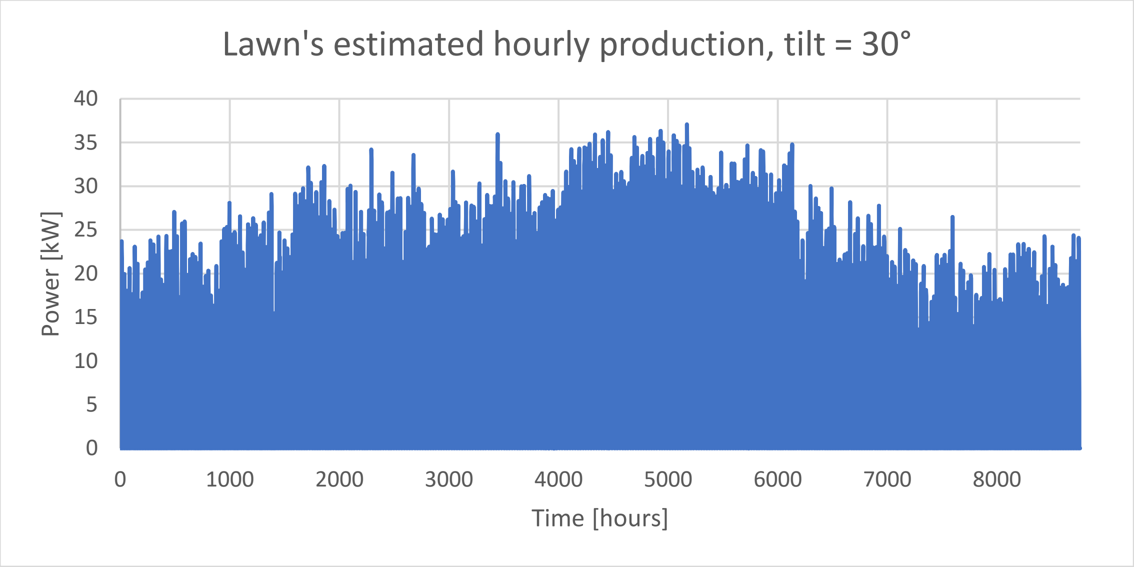


Figure 57: Lawn’s estimated hourly production, tilt = 30°

6.7.3. Tilt 40°

In this scenario the panels are placed at the optimal tilt for Frassinetto that is 40°, but the number of modules added is 78 since the required spacing between the rows to avoid the shading has increased. In this configuration the annual energy production is equal to 57564 kWh which is considerably lower to the previous ones meaning that, despite the modules are placed at the optimal slope, it is better to add more panels but less tilted to obtain a greater production.

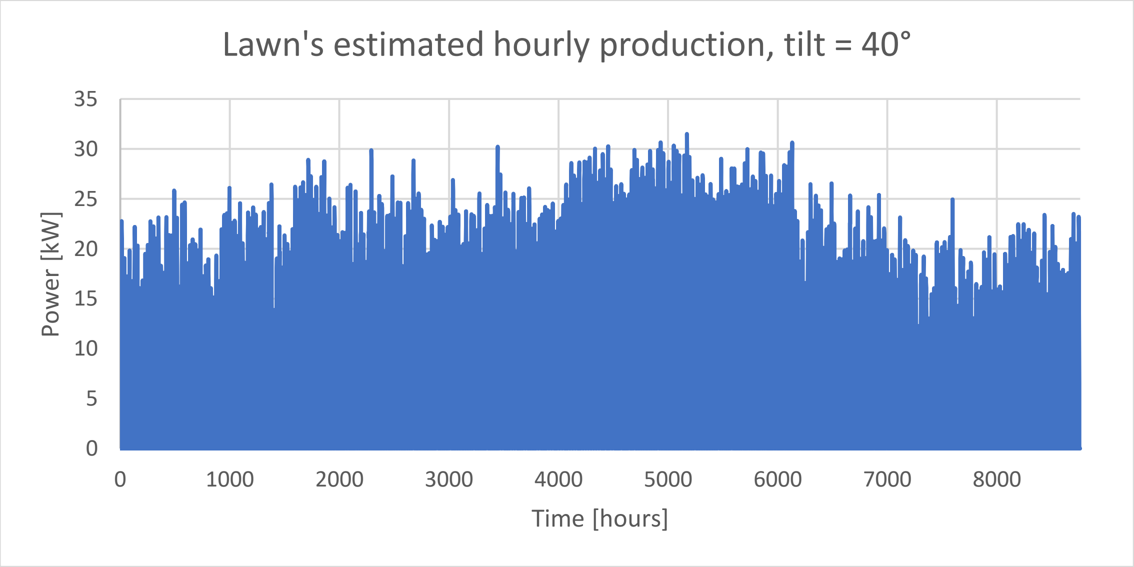


Figure 58: Lawn’s estimated hourly production, tilt = 40°

In Figure 59 is reported the comparison between the monthly energy production of the lawn's plant in the three scenarios developed. The best configuration is the one with the photovoltaic panels 15° tilted, which ensures a significant energy production in summer, reaching 10 MWh in July. In the winter season the generated energy does not vary a lot between the three scenarios, settling around 3000 – 4000 kWh.

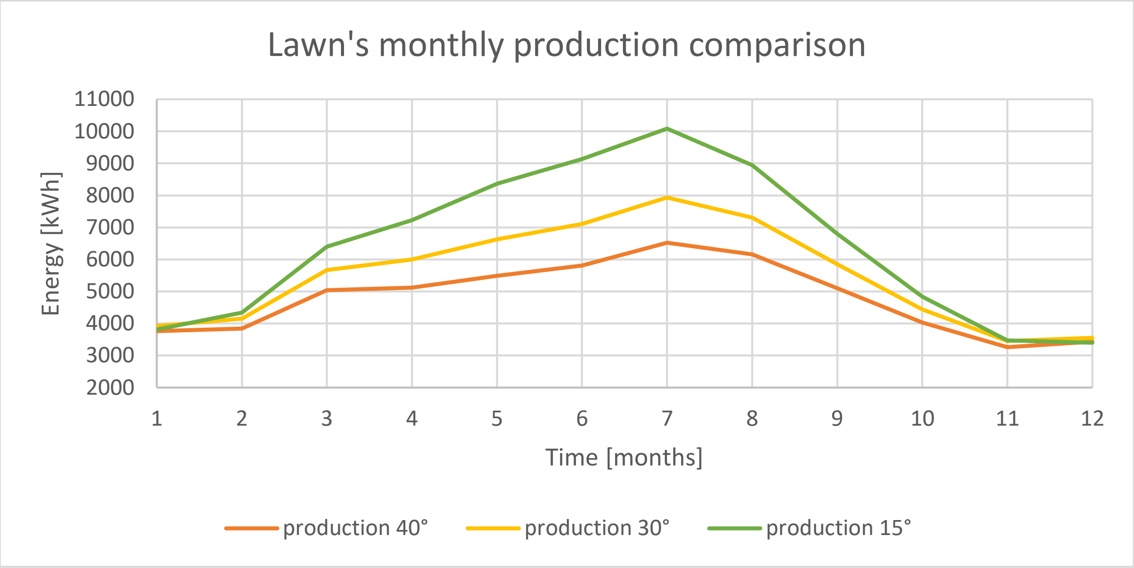


Figure 59: Lawn's monthly production comparison

The interesting aspect that deserves to be mentioned is that in this case, the best options has been to increase the installed power, meaning the number of panels, rather than put only a few at the optimal tilt. The choice made is a direct consequence of the fact that the purpose of this work was to produce as much energy as possible by exploiting the available space. The surplus can be fed to the electrical network or can be shared with the virtual consumers of the Energy Community to benefit from the incentives.

6.8. Roof

The last plant installed in Frassinetto it is located near the Town Hall and it occupies a quite spacious roof 11° tilted. This structure has been built for recreative purposes mainly linked to the Municipality activities. The panels installed are 84 and the roof has an azimuth of -32°. The estimated hourly production is reported in Figure 60 and the maximum value of power almost reaches 35 kW in correspondence to the months of June and July.

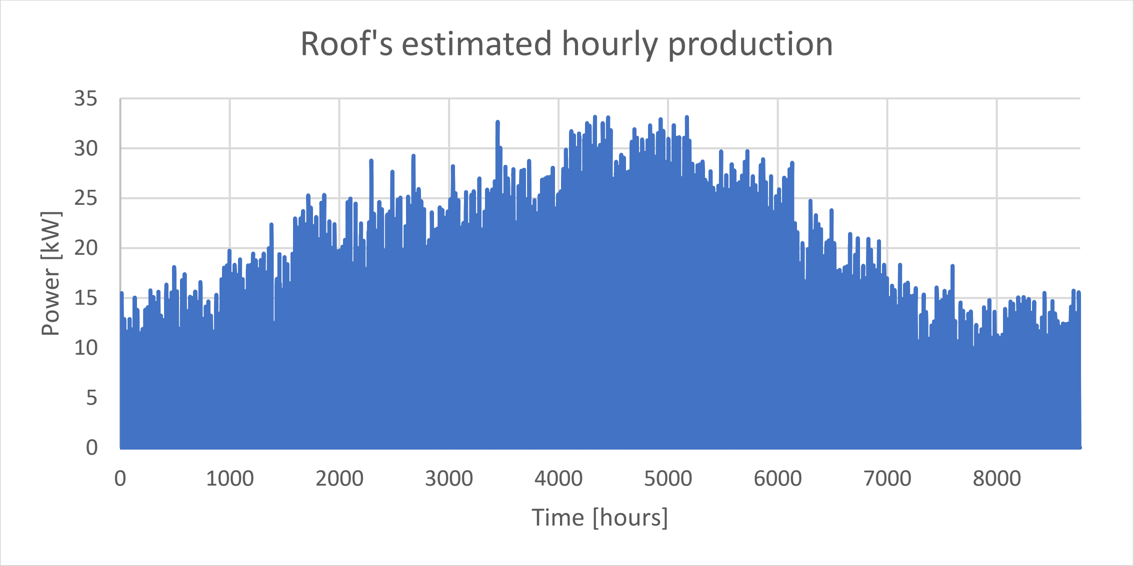


Figure 60: Roof's estimated hourly production

7. Best result

In this Chapter the optimal configuration of all the plants of all scenarios is presented. In this context, it should be emphasised that this work aimed to maximise energy production, without considering cost optimisation. This was the methodology applied because, as the Municipality of Frassinetto has a lot of space available, it can be used as a production area that can share the energy generated with other virtual consumers, even in other municipalities. Furthermore, with regard to costs, with the creation of an Energy Community, one is entitled to various incentives that will be presented and discussed in Chapter 9.

Given these premises the optimal plants' configurations are listed below:

- Camper plant: 99 panels, tilt 22°, 0° azimuth;
- Bungalow plants: 125 panels, tilt 10°, 0° azimuth;
- Cemetery plant: 72 panels (26, tilt 9°, -30° azimuth and 46, tilt 23°, -23° azimuth);
- Sport: 60 panels, tilt 16°, 65° azimuth;
- Wall: 171 panels, tilt 60°, -30° azimuth;
- Shelter: 138 panels, tilt 9°, -27° azimuth;
- Lawn: 111 panels, tilt 15°, 0° azimuth;
- Roof: 84 panels, tilt 11°, -32° azimuth.

In Figure 61 the total monthly energy production is reported in which, for each month, the productions of each plant have been summed up. From this plot it can be noted that the maximum value reached is in July and it is 74 MWh while the lowest is 27 MWh and it is in December.

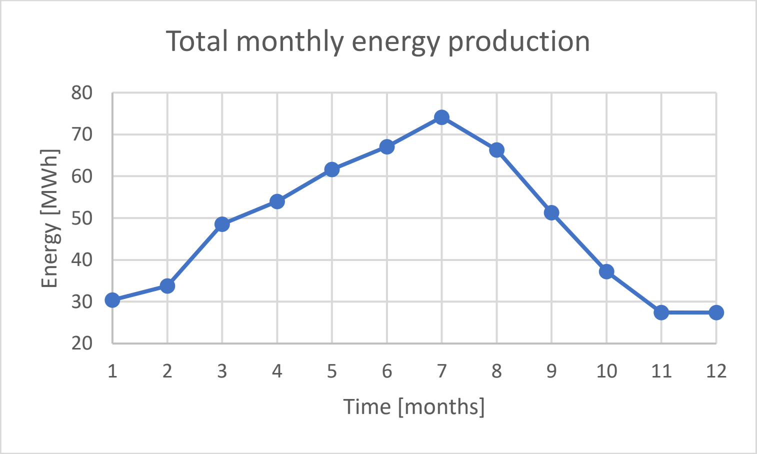


Figure 61: Total monthly energy production

Now that all the energy productions have been defined, the comparison between the consumptions and the productions of Frassinetto can be performed by plotting, as shown in Figure 62, the two curves which represent the behaviours of the monthly values.

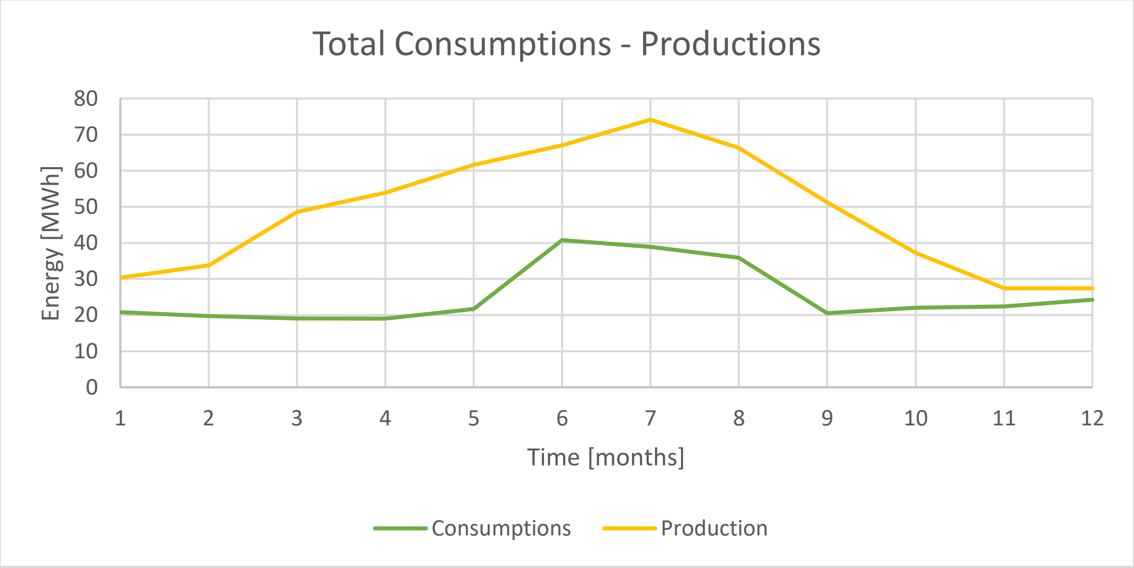


Figure 62: Total consumptions-productions

From this plot it can be observed that, for each month, the production curve is always above the consumption one: in winter the two curves are closer to each other, especially in December, while in summer there is a substantial gap between the two due to a marked increase of the production. This huge surplus will be shared with the virtual consumers of the Energy Community so that Frassinetto can receive more incentives and try to reduce as much as possible the return on the investment.

On the other hand, another design strategy could have been implemented by performing the plant sizing according exactly to the consumptions of Frassinetto, and trying to keep the production and consumptions curves as close as possible, not sharing energy but only self-consuming it. In this way the installed power would have been less and thus also the initial investment.

8. Storage estimation

In this Chapter the estimation of the storage system is carried out in order to favour the self-consumption of part of the energy produced with the installed photovoltaic plants. To develop this analysis, all the electrical consumptions listed in Chapters 4 and 5 need to be scaled from monthly to hourly values since the storage devices are usually sized according to the behaviour of the production and consumption hourly curves. The photovoltaic production is already available at hourly scale while the consumptions are reported in the bills as monthly values and, for this reason, they need to be properly scaled.

The methodology used to perform this task has been to consider the percentage value (weight) of the consumptions in each band (F1, F2, F3) for each month, easily retrievable from the total consumption value and the one of each band reported in the bills. Once obtained these values, each hour of the year has been associated to one band:

- F1 band from 8 a.m. to 7 p.m.
- F2 band from 7 a.m. to 8 a.m. and from 7 p.m. to 11 p.m.
- F3 band from 11 p.m. to 7 a.m.

After this association, the number of hours of each month belonging to each band have been counted. At this point the value of electrical consumption for each hour can be obtained by applying the equation 6 reported below by using the "IFS" Excel function depending on the band associated to each hour:

Equation 6: Hourly consumptions calculations

$$Hourly\ consumptions\ (F1) = \frac{monthly\ consumptions * band\ F1\%}{n°\ hours\ in\ F1}$$

$$Hourly\ consumptions\ (F2) = \frac{monthly\ consumptions * band\ F2\%}{n°\ hours\ in\ F2}$$

$$Hourly\ consumptions\ (F3) = \frac{monthly\ consumptions * band\ F3\%}{n°\ hours\ in\ F3}$$

Once obtained the hourly consumption values, the daily ones are calculated through the "SUMIF" Excel function for the average year. This further step is required in order to better visualize the behaviour of the values in one year and the result is shown in Figure 63.

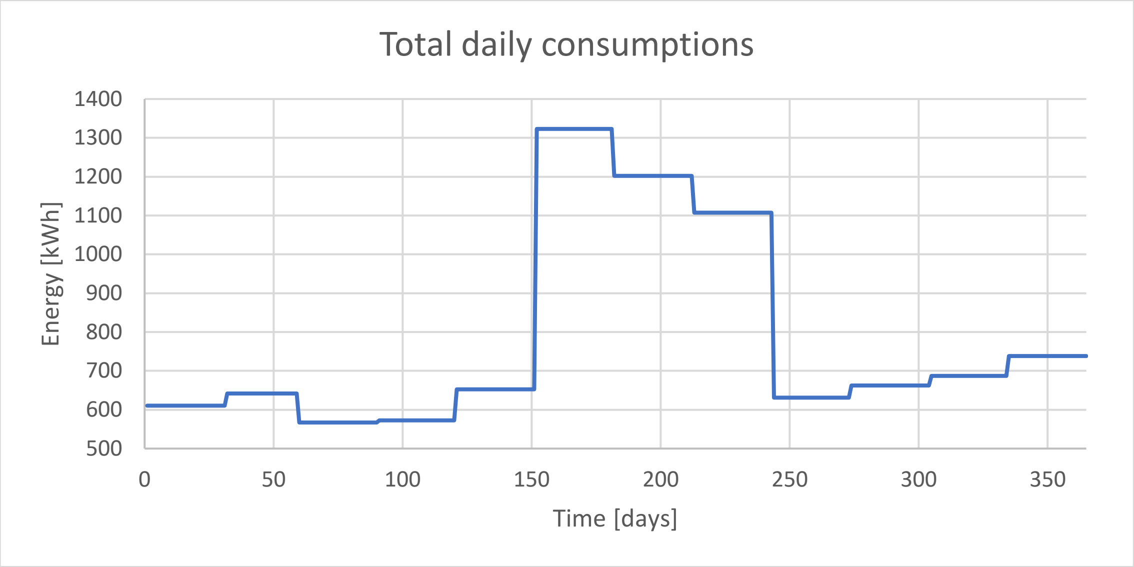


Figure 63: Total daily consumptions

From Figure 63 it is clearly visible that the electrical consumptions are higher during summer when there is the tourism and the bungalows and camper area are opened.

A more precise analysis could have been achieved with access to consumptions every quarter of an hour but, since these data were not available, the subsequent calculations are performed with the results of the methodology explained above.

In the following sub-Chapters different storage estimations have been performed, starting from the calculation of a unique storage device, useful for a pre-feasibility study, and then two real systems in which the battery is placed near the selected plants.

8.1. Total storage

In this section a pre-feasibility study has been developed by sizing the storage system starting from the sum of all the plants' productions and all the consumptions. This represent only the starting point of a more specific analysis, since it is impossible to recreate such a system in reality. On the other hand, this approach is useful to have a rough idea of the costs and the viability of the developed project.

To perform the sizing of this storage system, the first thing to do is to have the vectors of the total hourly productions and consumptions for the average year. As a second step, the difference between the hourly production and consumption values must be calculated and then, with the "SUMIFS" Excel function, the sum of only the positive differences is calculated for each day. After this step, the storage device has been sized according to the minimum surplus in such a way that the system can be always filled throughout the year without any waste. The day of the year with the minimum surplus resulted to be the 21 of November and, in Figure 64 the production and consumption curves are plotted. As expected, the production is higher than the consumption in the central hours of the day reaching a maximum of almost 120 kW, while the consumptions are more or less constant between 20 kW and 40 kW.

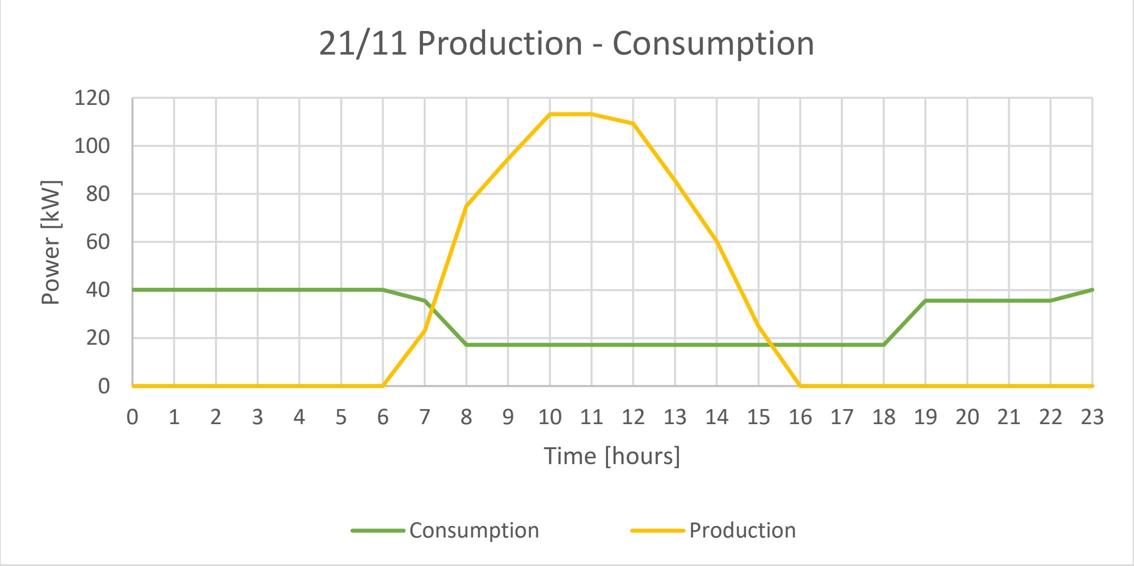


Figure 64: 21/11 production-consumption

To be clearer, in Table 3 there are the productions, the consumptions and their differences reported for each hour of the 21 of November. To obtain the size of the storage system, the sum of the orange-highlighted values must be computed; these amounts represent the difference only when the production is greater than the consumption. The result obtained though this sum represent exactly the calculation reported in equation 7:

Equation 7: Calculation of the daily minimum surplus

$$Surplus_{min} = \int_{hour=8}^{hour=15} (production - consumption)\, dt = 538{,}52\, kWh$$

From this, considering that the batteries chosen for this purpose are the UNICAL ones (10,24 kWh each) [22], to obtain the number of batteries required, the equation 8 must be applied:

Equation 8: Number of batteries calculation

$$n_{batteries} = \frac{538{,}52}{10{,}24} = 52{,}58$$

Once obtained this number, through an excess approximation, the required number of batteries is 53 and consequently the size of the storage device results to be 542,72 kWh as reported in equation 9:

Equation 9: Storage size calculation

$$Storage\ size = n_{batteries} * \frac{kWh}{battery} = 53 * 10{,}24 = 542{,}72\, kWh$$

Furthermore, it is possible to grasp whether the storge system is enough to cover the consumptions of the whole year or not, to understand if the plant can be completely independent form the grid. In order to do this, as a first step the sum of the blue-highlighted values in Table 3 must be computed by applying the equation 10. In this calculation the integral of the consumption curve is performed in the intervals in which the consumption is greater than the production (out-of-phase consumptions).

Equation 10: Out of phase consumptions calculation

$$Out\_of\_phase\ consumptions = \int_{hour=0}^{hour=7} consumption + \int_{hour=16}^{hour=23} consumption$$

Table 3: Productions, consumptions and their difference for the 21th November

hour	Consumption [kW]	Production [kW]	Prod-Cons [kW]
0	40.07	0.00	-40.07
1	40.07	0.00	-40.07
2	40.07	0.00	-40.07
3	40.07	0.00	-40.07
4	40.07	0.00	-40.07
5	40.07	0.00	-40.07
6	40.07	0.00	-40.07
7	35.58	22.98	-12.60
8	17.15	75.00	57.85
9	17.15	94.56	77.41
10	17.15	113.08	95.94
11	17.15	113.19	96.05
12	17.15	109.24	92.09
13	17.15	85.48	68.33
14	17.15	60.32	43.17
15	17.15	24.82	7.68
16	17.15	0.00	-17.15
17	17.15	0.00	-17.15
18	17.15	0.00	-17.15
19	35.58	0.00	-35.58
20	35.58	0.00	-35.58
21	35.58	0.00	-35.58
22	35.58	0.00	-35.58
23	40.07	0.00	-40.07

The equation 10 is applied to all the days of the year and then, to understand if the sized storage device is enough, for each day, the difference between the out of phase consumptions and the minimum surplus is performed as shown in equation 11:

Equation 11: Daily energy request from the grid

$$Daily\ energy\ to\ buy = Out\_of\_phase\ consumptions - Surplus_{min}$$

If this value is lower than zero it means that the storage capacity is enough to cover the consumptions of that day while, if it is higher than zero, the storage is not enough and there is the need to buy energy from the grid and the amount is the result of the equation 11.

With the storage system sized in this Chapter, the annual required energy is calculated in the equation 12:

Equation 12: Yearly energy request from the grid

$$Yearly\ energy\ to\ buy = \sum Daily\ energy\ to\ buy = 18798{,}33\ kWh$$

8.2. Public lighting in self-consumption with the wall plant

In this Chapter a storage system is developed to allow the public lighting of Frassinetto to be as independent as possible from the national electricity grid. This analysis represents a realistic feasibility study since this storage device, if coupled with one of the installed plants together and a hybrid inverter, can be connected to the Point-of-Delivery (POD) of the public lighting, thus allowing the self- consumption of energy. The selected photovoltaic plant for this case study is the wall one since it is located near the POD of the public lighting. To develop this analysis, the procedure used is the same as the one explained in Chapter 8.1: the starting point are the hourly values of production (of the wall plant) and consumption (of the public lighting). From them, the calculation of the daily energy surplus follows and the storage device is sized according to the minimum value. In this case, the day with the minimum energy surplus is the 31 of October and in Figure 65 the plot of the consumption and production curves is reported.

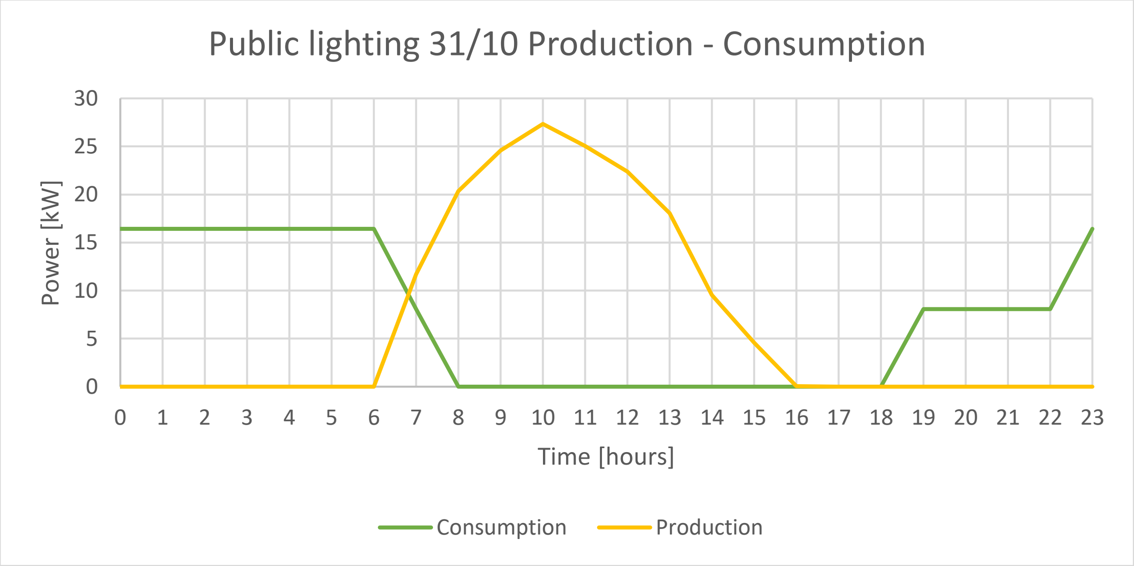


Figure 65: Public lighting 31/10 production-consumption

As expected, the public lighting consumption curve assumes value different from zero during the night, in the early morning and in the evening while in the central hours of the day the lights are switched off. The calculation of the energy surplus for the 31 of October, that represent the size of the storage device, is performed by applying the equation 13:

Equation 13: Calculation of the daily minimum surplus

$$Surplus_{min} = \int_{hour=7}^{hour=16} (production - consumption)\, dt = 155{,}57\ kWh$$

Being the batteries chosen 10,24 kWh each [22], to have a storage of 155,57 kWh, the number of batteries required is obtained with the equation 14:

Equation 14: Number of batteries calculation

$$n_{batteries} = \frac{155{,}57}{10{,}24} = 15{,}19$$

By a default approximation, the batteries that need to be installed are 15.

In addition, as done for the total storage system of Chapter 8.1, also in this case it is possible to retrieve the amount of energy to buy from the grid. This can be performed by following the methodology explained above by considering the out of phase consumptions for each day and by subtracting to them the minimum surplus as shown in equation 15:

Equation 15: Daily energy request from the grid

$$Daily\ energy\ to\ buy = Out\_of\_phase\ consumptions - Surplus_{min}$$

Then, to obtain the yearly value of energy bought from the grid, the equation 16 must be applied:

Equation 16: Yearly energy request from the grid

$$Yearly\ energy\ to\ buy = \sum Daily\ energy\ to\ buy = 4044{,}82\ kWh$$

This represents a very low amount considering that, without the storge system, Frassinetto would have to buy 62152,20 kWh every year to power the public lighting.

8.3. Cemetery in self-consumption with the cemetery plant

The analysis performed for the public lighting storage system, is developed also for the cemetery. This facility has a photovoltaic plant installed over the two available roofs and, for the storage sizing, only the 23° tilted plant has been considered as it properly satisfies the cemetery electrical consumptions. In this case the 21 of November is the day of the year characterized by the minimum surplus and in Figure 66 the plot of the consumption and production curves for that day is reported.

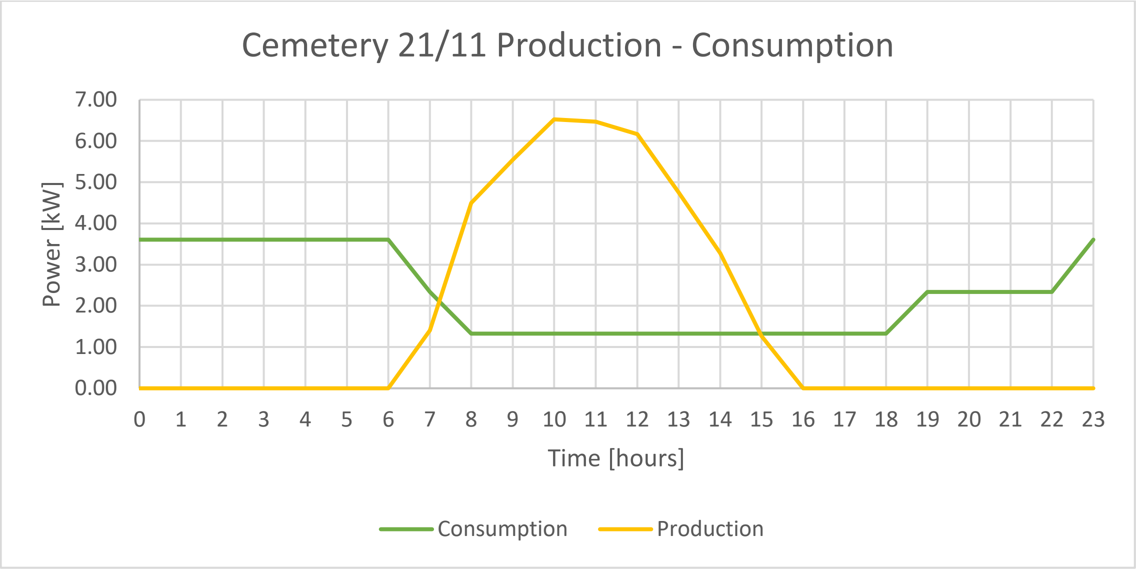


Figure 66: Cemetery 21/11 production-consumption

The energy surplus associated to the 21 of November is calculated with the equation 17 reported below:

Equation 17: Calculation of the daily minimum surplus

$$Surplus_{min} = \int_{hour=8}^{hour=14} (production - consumption)\, dt = 27{,}95\ kWh$$

With this value, the number of batteries required is retrieved with the equation 18:

Equation 18: Number of batteries calculation

$$n_{batteries} = \frac{27{,}95}{10{,}24} = 2{,}7$$

By rounding up this value, it resulted that the number of batteries, 10,24 kWh each [22], is 3. Moreover, it is possible to get the amount of energy to buy each year from the grid following the same methodology used for the public lighting. It resulted that with the storage system the cemetery needs to buy 2106,25 kWh per year while, without accumulation device, the annual energy request would be 14497,83 kWh. Also in this case it is worth noting that the storage contributes a lot to decrease the dependency of this facility from the national electricity network, bringing also important economic benefits which will be deepened in Chapter 9.

9. Cost analysis – Centralized storage

The economic analysis carried out in this Chapter is fundamental to understand whether the above-described project is economically viable or not. The plant configuration that has been analysed in this section is the one with the photovoltaic plants allocated according to the best solution exposed in Chapter 7, and the total storage device which takes into account all the productions and all the consumptions summed up as they are all located in a single place (developed in Chapter 8.1). Given these premises, it is important to state that this study represents only a pre-feasibility cost analysis: to obtain a more realistic result, the storage systems should be located near each single plant and should cover the electrical consumption of each Point-of-Delivery separately.

9.1. Capital cost estimation

In this section, the costs of all the components required for the installation of the photovoltaic plants has been estimated together with the costs for the battery sized in Chapter 8.1. To develop a well-organized analysis, all the plants has been considered independently, each one with its peak power. In Table 4, an example of investment estimation for the camper area plant is reported:

Table 4: Camper area investment estimation

Plant	Size [kW]	Description	Amount	Unitary cost	Total cost
Camper	42	PV module	99	242 €/modules	23958 €
		Labor + electrical devices	42	250 €/kW	10500 €

As a first step, in the second column, the size of the camper area plant is reported and then, in the "Description" column, all the items are listed: the photovoltaic modules, the electrical devices and the labour. Regarding the electrical devices and the labour, the reported unitary costs is in $[\frac{€}{kW}]$ [23]. In the last column the total cost of all the items is reported. The Table 4 has been done for all the photovoltaic plant of Frassinetto and the results of each one are reported in Table 5.

Table 5: Investment costs for each plant [23]

Plant	Size [kW]	Total cost
Camper	42.0	34458.00 €
Bungalows	53.1	43531.25 €
Cemetery	30.6	25074.00 €
Sport	25.5	20895.00 €
Wall	72.7	59550.75 €
Shelter	58.7	48058.50 €
Lawn	47.2	38655.75 €
Roof	35.7	29253.00 €

Table 6: Total installation cost

Total installation cost	299476.25 €

As reported in Table 6, by summing up all the contributions, is resulted that the total cost of the installation is 299476,25 €.

Regarding the inverters, due to the fact that in the pre-feasibility study there is a big centralized battery, to perform the coupling between the plant and the storage device, the only way is to install the hybrid inverters. These devices are the most expensive and their size is decided basing on the size of the entire plant. In this case study the total size of the plant is 365,4 kW and each hybrid inverter has a size of 30 kW which means that at least 12 devices are required. In Table 7 the result of the inverters' cost estimation is reported [23].

Table 7: Hybrid inverters cost [23]

Description	Amount	Unitary cost	Total cost
Hybrid inverter (30 kW)	12	12500 €	150000 €

At this point, the batteries contributions must be considered. As mentioned in the storage Chapter (Chapter 8.1), the selected storage devices are the UNICAL ones, 10,24 kWh each, meaning that 53 batteries are required [23]. In Table 8 the calculations for the costs are summarized

Table 8: Batteries cost [23]

Description	Amount	Unitary cost	Total cost
Batteries (10.24 kWh)	53	6230 €	330190 €

With these values, the capital cost (CAPEX) for the Frassinetto photovoltaic plant is the sum of the total installation, the inverters and the batteries costs as shown in equation 19:

Equation 19: CAPEX estimation

$$CAPEX = Total\ installation\ cost + Inverters\ cost + Batteries\ cost = 779666{,}25\ €$$

9.2. Operational costs estimation

In this section the estimation of all the operational costs is developed by considering all the expenses related to the maintenance of the plants, the substitution of the inverters and the batteries and the photovoltaic modules' decay in time. Moreover, the energy bought from the grid each year and the savings by not buying the energy already produced by the plant, have been considered.

The maintenance of the plant is fundamental to avoid the panels' efficiency loss and it must be executed periodically to ensure a longer plant lifetime. It basically consists in the modules cleaning, in the monitoring of the panels' efficiency and repairs in case of failure of the components. The costs related to those activities has been estimated to be the 1,5% of the initial investment and its contribution is considered each year [24].

The substitution of the inverter needs to be done every 12 years, as reported in the Unical documentation [25], and the costs related to that corresponds exactly to all the inverters' expenditure that is equal to 150000 €.

Another contribution to the operational costs is given by the batteries' replacement: as reported in the Unical documentation [22], the chosen storage devices have a 10-year warranty or 6000 charging cycles. Through this information, by dividing the maximum number of cycles by the number of days in a year, it has been retrieved that the substitution of the batteries should be done in between the 16th and the 17th year and, to be more conservative, it has been stated that they should be replaced every 16 years. The costs related to that corresponds to the batteries investment costs which is 330190 €.

In addition to these occasional expenses, the photovoltaic modules decay in time must be taken into account. As shown in Figure 67, the guaranteed power for the first two years is 99% and then it starts to decrease, following a linear trend, until the 30th year in which the ensured power is 87,4% [20].

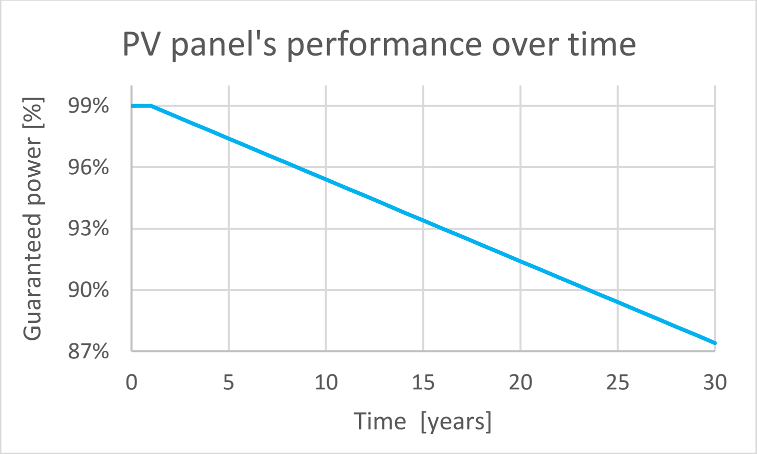


Figure 67: PV panel's performance over time

From that, it is possible to calculate the percentage decay each year through the equation 20:

Equation 20: %decay calculation

$$\%decay_{year} = \frac{99\% - 87{,}4\%}{30} = 0{,}387\%$$

This amount, once cumulated over the plant life-time, will be taken into account in the cashflow analysis presented in Chapter 9.4, in which the percentage yearly decay will be subtracted to the incomes resulting from the self-production of energy.

Moreover, in the operational costs' estimation, the expense related to the energy bought each year from the national electricity grid must be considered. The amount of yearly required energy has been retrieved in Chapter 8.1 and it is equal to 18798,33 kWh. By considering a value of electricity price of 0,225 $\frac{€}{kWh}$, retrieved by the bills of Frassinetto, the costs can be obtained with the equation 21:

Equation 21: Yearly expense

$$Expense = Energy\ to\ buy * \frac{€}{kWh} = 18798{,}33 * 0{,}225 = \ 4229{,}62\ €$$

The estimation of the revenues has been realized starting from the calculation of the total annual electrical consumption of Frassinetto as reported in the equation 22:

Equation 22: Annual consumptions estimation

$$Annual\ consumptions = \sum Hourly\ consumptions = 286139{,}48\ kWh$$

Then, considering the amount of energy that needs to be bought from the grid, it is possible to retrieve the energy not to be bought as already produced by the photovoltaic plants. This calculation is reported in equation 23:

Equation 23: Not bought energy estimation

$$Not\ bought\ energy = Annual\ consumptions - Energy\ to\ buy = 267341{,}15\ kWh$$

From this value, the annual saving can be retrieved by applying equation 24:

Equation 24: Savings calculation

$$Saving = Not\ bought\ energy * 0{,}225 \frac{€}{kWh} = 60151{,}76\ €$$

9.3. Economic benefits for Energy Communities

The Energy Communities, as described in Chapter 1.2, are based on the idea of sharing the energy produced in excess by the renewable plants with other virtual consumers. The only constraint is that they must be located on Low Voltage (LV) electricity networks under the same High Voltage – Medium Voltage (HV – MV) energy transformer station of the installed plants [6]. In this case study the designed production plants are all located in Frassinetto and, since the energy production is generally higher than the consumptions, the excess can be shared with any virtual consumer located inside the area subtended to the same primary cabin [6]. As the size of the designed photovoltaic plants in Frassinetto satisfy the constraint of being less than 1 MW, the Energy Community can be created and the virtual consumers of the shared energy may be a small village with not enough space for the plants' installation or single users such as a factory or a group of families. For those who create an Energy Community, some economic benefits are expected as reported in the ministerial order of 2023 [26] and in this Chapter the evaluation and the estimation of those revenues is carried out.

9.3.1. Energy cash back incentives (Feed-In-Tariffs)

According to the ministerial order [26], the feed-in-tariffs are ensured for 20 years and are regulated according to the MWh shared each year by the renewable plants. Moreover, for those who establish an Energy Community, a saving on energy costs is expected. Being the incentives based on the amount of MWh shared each year, it is fundamental to estimate how much is the energy in excess that the Energy Community of Frassinetto produces. To obtain that, for each day of the year the difference between the daily energy surplus and the annual minimum one must be performed as shown in equation 25:

Equation 25: Daily shared energy

$$Daily\ shared\ energy = Daily\ surplus - Surplus_{min} = Daily\ surplus - 538{,}52\ [kWh]$$

In Figure 68 is reported the chart of the daily shared energy which is greater during summer when the photovoltaic production is higher.

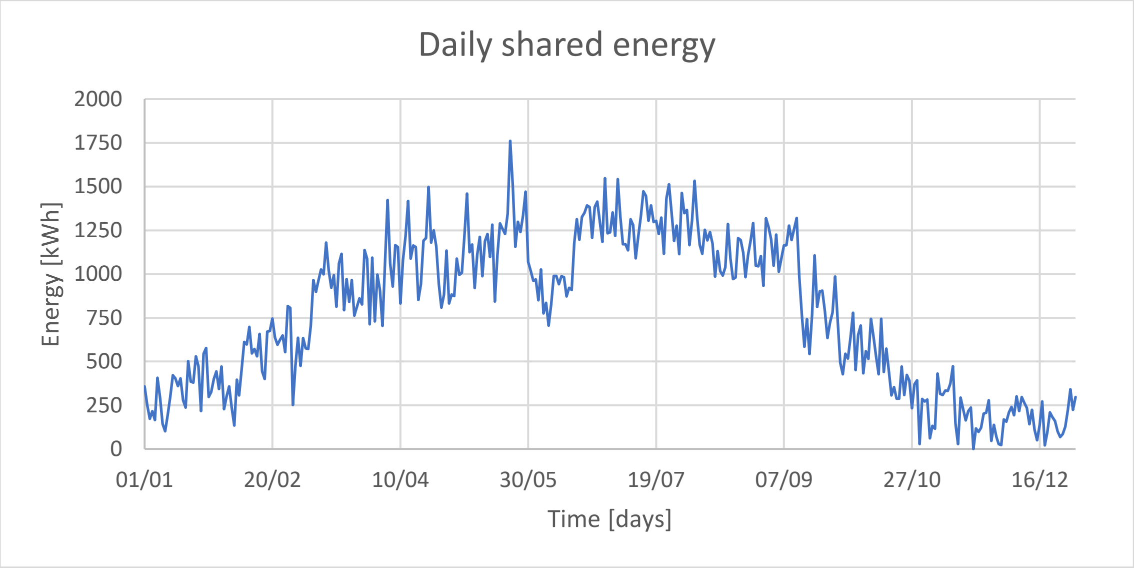


Figure 68: Daily shared energy

Then, by summing up all the daily values and by dividing it by 1000, the yearly shared energy expressed in MWh can be retrieved:

Equation 26: Yearly shared energy

$$Yearly\ shared\ energy = \frac{\sum Daily\ shared\ energy}{1000} = 284{,}21\ MWh$$

Once get this amount, it is possible to calculate the incentives retrievable from each MWh shared and the expected tariffs are reported in Table 9 [26].

Table 9: Incentives [26]

Plant size	**Tariffs [€/MWh]**	
	Fixed part	Variable part
size < 200 kW	80	0 ÷ 40
200 kW < size < 600 kW	70	0 ÷ 40
size > 600 kW	60	0 ÷ 40

Regarding the variable part of the tariffs, the ministerial order underline that for plant whose size is comprehended between 200 kW and 600 kW, the tariffs cannot exceed the 110 $\frac{€}{MWh}$ [26]. For this reason, the variable part has been considered equal to 20 $\frac{€}{MWh}$ so that the total tariff is 100 $\frac{€}{MWh}$. In Table 10 are reported the corrections to the tariffs above mentioned which takes into consideration the different levels of sun irradiance of the Italian peninsula. In the North of Italy, where there is less irradiance, the correction factor is higher while, for the Southern part, there are no expected tariff increases.

Table 10: Correction factors [26]

Geographical area	**Correction factor [€/MWh]**
South	0
Central	4
North	10

The designed plant has a size equal to 365,4 kW (200 kW < size < 600 kW) and it is located in Frassinetto that is in the Northern part of Italy. With this information and the tariffs listed in Table 9 and 10, the total annual incentives expected for the Energy Community of Frassinetto can be calculated as shown in equation 27.

Equation 27: Feed-in-tariff estimation [26]

$$
\begin{aligned}
Feed - In - Tarfiffs \\
&= (Fixed\ part + Variable\ part + Correction\ factor\ ) * \ MWh_{shared} \\
&= (70 + 20 + 10) * 284{,}21 = 28420{,}73\ \frac{€}{year}
\end{aligned}
$$

9.3.2. Non-repayable grant

The ministerial order states that for the municipalities with less than 5000 inhabitants, another important economic contribution (the non-repayable grant) is expected [26]. The provision of these capital grants can be up to 40% of the eligible costs for the creation of Energy Communities and collective self-consumption configurations [26]. In Table 11 there are the reported the maximum eligible investment costs for different sizes of plants:

Table 11: Maximum eligible costs [26]

Plant size	Maximum CAPEX [€/kW]
size < 20 kW	1500
20 kW < size < 200 kW	1200
200 kW < size < 600 kW	1100
600 kW < size < 1000 kW	1050

Given these data, it is possible to retrieve the magnitude of the non-repayable grant expected for the Energy Community of Frassinetto:

Equation 28: Non-repayable grant estimation [26]

$$grant_{non-repaybale} = size * max\ CAPEX * 0{,}40 = 365{,}4 * 1100 * 0{,}40 = 160787\ €$$

This amount has to be subtracted to the initial investment and results in a decrease of the CAPEX.

9.4. Cashflow analysis

In this Chapter all the previously mentioned costs and revenues are considered to perform the cashflow analysis in order to retrieve the payback time and to observe how the cumulative curve of the costs behaves during the plant's lifetime. The considered contributions are:

- Capex = -779666,25 €
- 40% non-repayable grant = 160787 €

From that, the initial investment becomes:

$$Investment = CAPEX + 40\%\ non\ repayable\ grant = -618879{,}25\ €$$

- Inverters replacement (every 12 years) = -150000 €
- Batteries replacement (every 16 years) = -330190 €

- Maintenance = 1,5% of CAPEX = -11695 €
- Energy bought from the grid = -4229,62 €
- Savings = 60151,76 €
- Feed-In-Tariff = 28420,73 €

From these values the total incomes, also considering the modules decay, and the total costs can be estimated as follows:

$$Total\ incomes = Savings + Feed\ In\ Tariff\ [\frac{€}{year}]$$

$$\begin{aligned} Total\ costs = {} & Investment\ (only\ the\ first\ year) + Inverters\ replacements \\ & + Batteries\ replacements + Maintainance \\ & + Energy\ bought\ from\ the\ grid\ \left[\frac{€}{year}\right] \end{aligned}$$

With these two values, the cashflow has been calculated each year, from year = 0 (plant installation) to year = 30 (end of life)

$$Cashflow = Total\ incomes - Total\ costs$$

Lastly, to obtain the cumulated cashflow, the cumulative sum of the yearly cashflow has been performed and is reported in Figure 69.

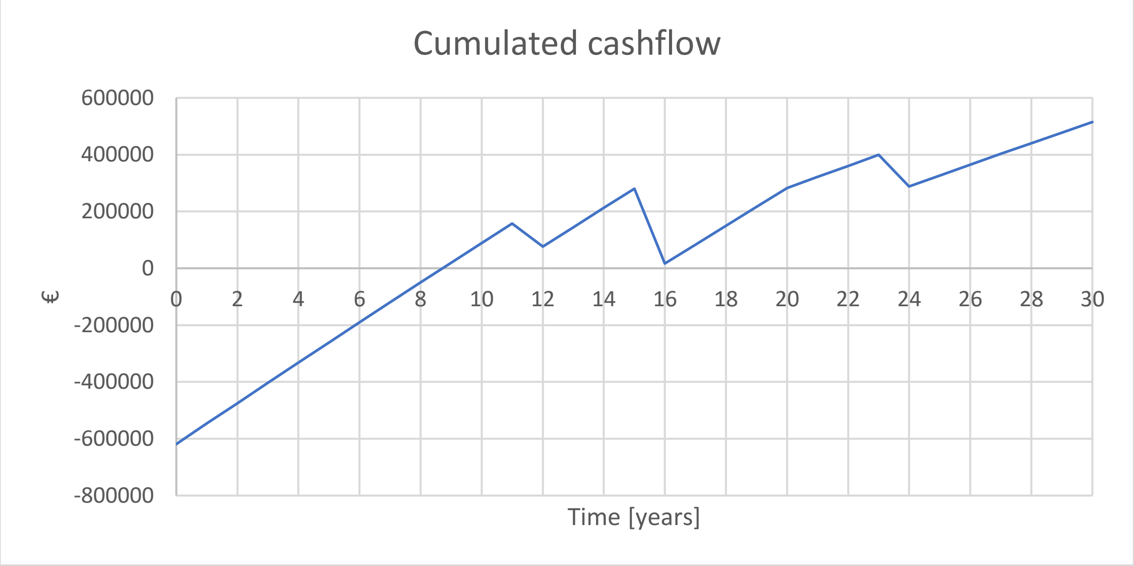


Figure 69: Cumulated cashflow

From this plot it can be seen that the cumulated cashflow has a positive trend over the entire plant lifetime mainly due to the feed-in-tariffs (ensured for the first 20 years) and to the savings from not buying a substantial part of the required energy from the grid. The three points in which the chart assumes a negative trend are in correspondence to the moments in which the batteries replacement (the 16th year) and the hybrid inverters substitution (the 12th and 24th years) occur. For this pre-feasibility study the payback time has been calculated applying the equation 29.

Equation 29: Payback time calculation [27]

$$PBT = 1 + n_y - \frac{n}{p} = 9{,}7\ years$$

Where:

- n_y = is the number of years after the initial investment at which the last negative value of cumulative cashflow occurs;
- n = is the last negative value of cumulative cashflow;
- p = is the value of cashflow corresponding to the first positive value of cumulative cashflow.

Moreover, the net present value can be retrieved and it corresponds to the last value of cumulated cashflow:

$$NPV = 514816\ €$$

In Figure 70 it is reported the comparison between the cashflows with and without the Energy Community. From this it is clear that in the scenario without the implementation of the renewable systems, the cashflow has a negative trend, meaning that Frassinetto will continue to lose money by buying all the required energy from the grid. In this scenario, after 30 years almost 2000000 € will be lost. On the contrary, with the Energy Community, even if the initial investment is huge, thanks to the annual incentives and to the contribution of the self-consumption, the Municipality will always earn money except for the years in which the inverters and the batteries need to be replaced.

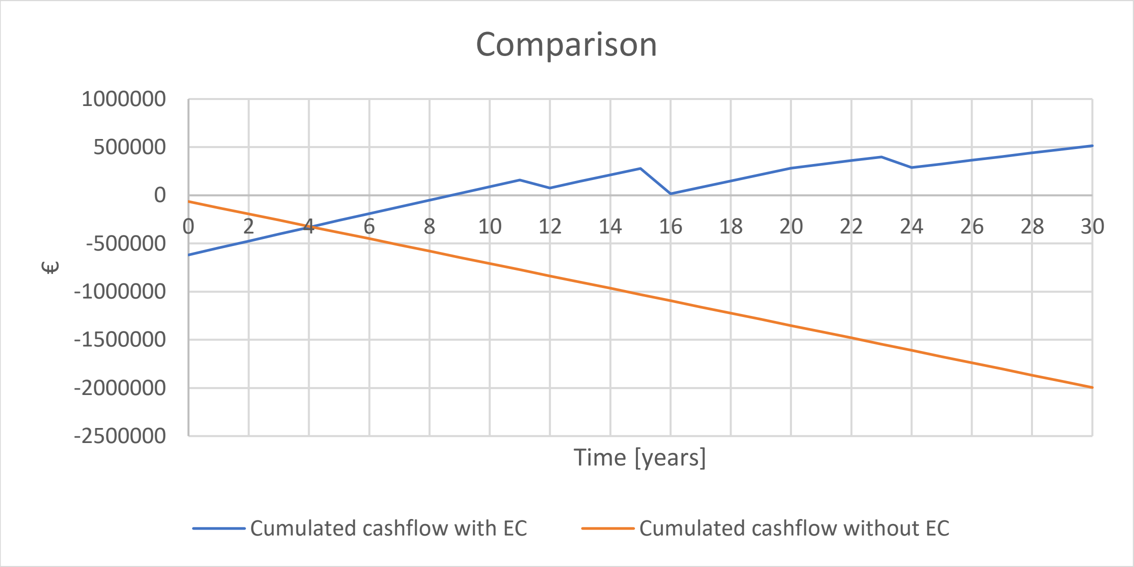


Figure 70: Comparison of the cumulated cashflows

10. Cost analysis – Distributed storage

In this Chapter the cost analysis is developed considering only the cemetery and the wall photovoltaic plants, whose storage system has been designed in Chapter 8 in order to cover part of the electrical consumption of the cemetery and the public lighting. This represent a more accurate analysis with respect to the one developed in Chapter 9 since, actually, the accumulation devices must be located near each single plant with a dedicated hybrid inverter to allow the self-consumption of the produced energy. In this Chapter, only two plants have been considered but the same study can be replicated for the other plants starting from the design of the single storage systems and following with the determination of the cashflows.

10.1. Capital cost estimation

Regarding the CAPEX estimation, the costs are summarized in Table 12. For both the plants, the hybrid inverters have been chosen to be able to add the two batteries designed in Chapters 8.2 and 8.3.

Table 12: Investment estimation [23]

Plant	Size [kW]	Description	Amount	Unitary cost	Total cost
Cemetery	30.6	PV module	72	242 €	17424 €
		Labor + electrical devices	31	250 €	7650 €
		hybrid inverter (30 kW)	1	12500 €	12500 €
		battery (10,24 kWh)	3	6230 €	18690 €
Wall	72.7	PV module	171	242 €	41382 €
		Labor + electrical devices	73	250 €	18169 €
		hybrid inverter (25 kW)	3	9750 €	29250 €
		battery (10,24 kWh)	15	6230 €	93450 €

As reported above, for each plant a set of batteries and hybrid inverters has been added and from these values, the total investment cost (CAPEX) for the installation of the two photovoltaic plants can be calculated by summing up all the contributions. The result is reported in Table 13 together with the inverters and batteries costs.

Table 13: CAPEX, inverters cost and batteries cost [23]

Description	Total cost
CAPEX	238515 €
Inverters	41750 €
Batteries	112140 €

10.2. Operational costs estimation

Regarding the operational costs' estimation, the same procedure used in Chapter 9.2 has been applied. The considered expenditures are the maintenance cost (1,5% of the CAPEX), the batteries and inverters replacement, respectively performed every 16 and 12 years and yearly the modules decay (0,38%). Moreover, the energy to buy from the grid must be accounted and the calculations of the required kWh per year has already been performed in Chapters 8.2 and 8.3 and the results are reported below in the equation 30.

Equation 30: Yearly energy to buy estimation

$$Energy\ to\ buy_{lights} = 4044{,}82\ kWh$$

$$Energy\ to\ buy_{cemetery} = 2106{,}25\ kWh$$

Then, always considering an electricity price of 0,225 $\frac{€}{kWh}$, the expenses are calculated in the equation 31:

Equation 31: Yearly expense calculation

$$Expense_{lights} = Energy\ to\ buy_{lights} * \frac{€}{kWh} = 4044{,}82 * 0{,}225 = 910{,}09\ €$$

$$Expense_{cemetery} = Energy\ to\ buy_{cemetery} * \frac{€}{kWh} = 2106{,}25 * 0{,}225 = 473{,}91\ €$$

In addition to those costs, the yearly savings related to the self-consumption must be calculated starting from the retrieval of the annual consumptions and the unbought energy. In the equation 32 are reported the annual consumptions of the public lighting and the cemetery.

Equation 32: Annual consumptions estimation

$$Annual\ consumptions_{lights} = \sum Hourly\ consumptions_{lights} = 62152{,}20\ kWh$$

$$Annual\ consumptions_{cemetery} = \sum Hourly\ consumptions_{cemetery} = 14497{,}83\ kWh$$

Then, considering the amount of energy that needs to be bought from the grid, it is possible to retrieve the energy not to be bought as already produced by the photovoltaic plants. Those calculations are reported in the equation 33:

Equation 33: Not bought energy estimation

$$Not\ bought\ energy_{lights} = Annual\ consumptions_{lights} - Energy\ to\ buy_{lights} = 58107{,}37\ kWh$$

$$Not\ bought\ energy_{cemetery} = Annual\ consumptions_{cemetery} - Energy\ to\ buy_{cemetery} = 12391{,}58\ kWh$$

From these values, the annual savings can be retrieved by applying the equation 34:

Equation 34: Savings calculation

$$Savings_{lights} = Not\ bought\ energy_{lights} * 0{,}225 \frac{€}{kWh} = 13074{,}16\ €$$

$$Savings_{cemetery} = Not\ bought\ energy_{cemetery} * 0{,}225 \frac{€}{kWh} = 2788{,}10\ €$$

10.3. Economic benefits for Energy Communities

As done for the entire plants and the unique storage system, also in this case the estimation of the revenues expected for the creation of an Energy Community must be carried out.

Starting with the calculation of the feed-in-tariffs ensured for 20 years after the plants' installation, the first value to be retrieved is the annual shared energy by the two photovoltaic plants. To obtain that value the equation 35 must be applied:

Equation 35: Daily shared energy

$$Daily\ shared\ energy_{lights} = Daily\ surplus_{lights} - Surplus_{\min lights} = Daily\ surplus_{lights} - \ 155{,}57\ [kWh]$$

$$Daily\ shared\ energy_{cemetery} = Daily\ surplus_{cemetery} - Surplus_{\min cemetery} = Daily\ surplus_{cemetery} - \ 27{,}95\ [kWh]$$

In Figure 71 is reported the plot of the two curves representing the daily shared energy by the two plants.

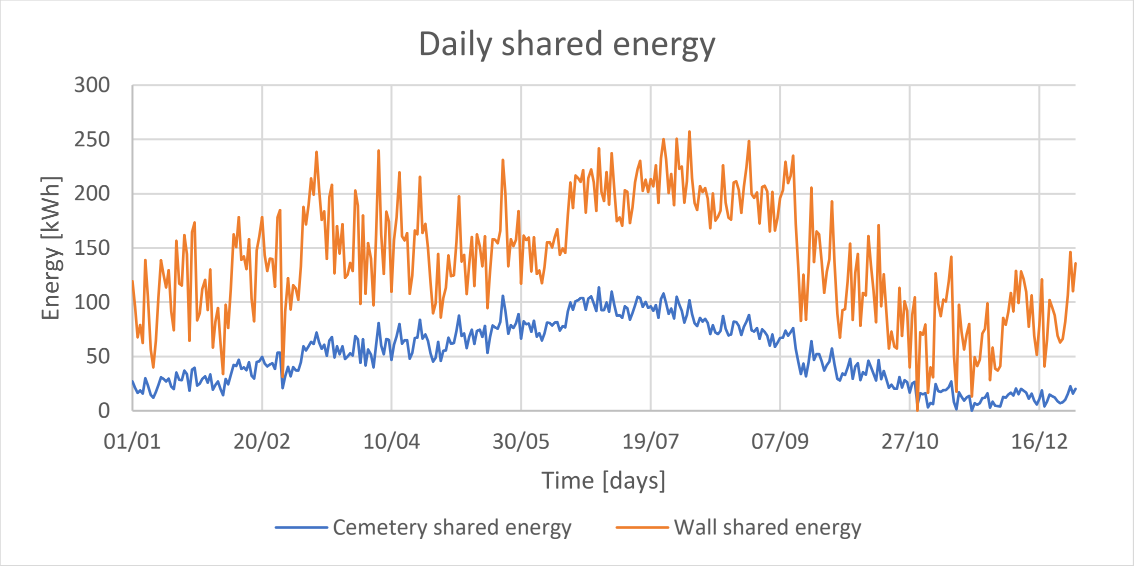


Figure 71: Daily shared energy by the two plants

From these curves, the annual total sharable energy by the two plants can be obtained with the equation 36:

Equation 36: Yearly shared energy

$$Yearly\ shared\ energy = \frac{\sum Daily\ shared\ energy}{1000} = 70{,}24\ MWh$$

By observing the Table 9 and 10, which summarize which are the incentives expected basing on the MWh shared each year, it is possible to calculate the annual feed-in tariff for this case study [26]. In those tables it is also important to select the correct size of the plants, that is 103,3 kW, to retrieve the fixed part and the variable part of the incentive. In the equation 37 it is reported the calculation of the annual revenues taking into consideration also the geographic correction factor.

Equation 37: Feed-in-tariff estimation [26]

$$\begin{aligned} Feed - In - Tarfiff &= (Fixed\ part + Variable\ part + Correction\ factor\ ) * \ MWh_{shared} \\ &= (80 + 20 + 10) * 284{,}21 = 7726{,}67\ \frac{€}{year} \end{aligned}$$

Regarding the non-repayable grant, the calculation is reported in equation 38. In this case, being the size of the plant 103,3 kW, the maximum capex is 1200 $\frac{€}{kW}$ as shown in Table 11 [26].

Equation 38: Non-repayable grant estimation [26]

$$grant_{non-repaybale} = size * max\ CAPEX * 0{,}40 = 103{,}3 * 1200 * 0{,}40 = 49572\ €$$

10.3. Cashflow analysis

In this Chapter all the previously calculated costs and revenues are considered to plot the cumulated cashflow in order to obtain the payback time and the net present value of the considered plants. All the contributions are:

- Capex = -238514,75 €
- 40% non-repayable grant = 49572 €

The initial investment becomes:

$$Investment = CAPEX + 40\%\ non\ repayable\ grant = -188942{,}75\ €$$

- Inverters replacement (every 12 years) = -41750 €
- Batteries replacement (every 16 years) = -112140 €
- Maintenance = 1,5% of CAPEX = -3578 €
- Energy bought from the grid = -1384 €
- Savings = 15862 €
- Feed-In-Tariff = 7726,67 €

From these values the total incomes and the total costs can be estimated as follows:

$$Total\ incomes = Savings + Feed\ In\ Tariff\ [\frac{€}{year}]$$

$$\begin{aligned} Total\ costs = {} & Investment\ (only\ the\ first\ year) + Inverters\ replacements \\ & + Batteries\ replacements + Maintainance \\ & + Energy\ bought\ from\ the\ grid\ \left[\frac{€}{year}\right] \end{aligned}$$

With these two values, the cashflow has been calculated each year, from year = 0 (plant installation) to year = 30 (end of life)

$$Cashflow = Total\ incomes - Total\ costs$$

Lastly, to obtain the cumulated cashflow, the cumulative sum of the yearly cashflow has been performed and is reported in Figure 72.

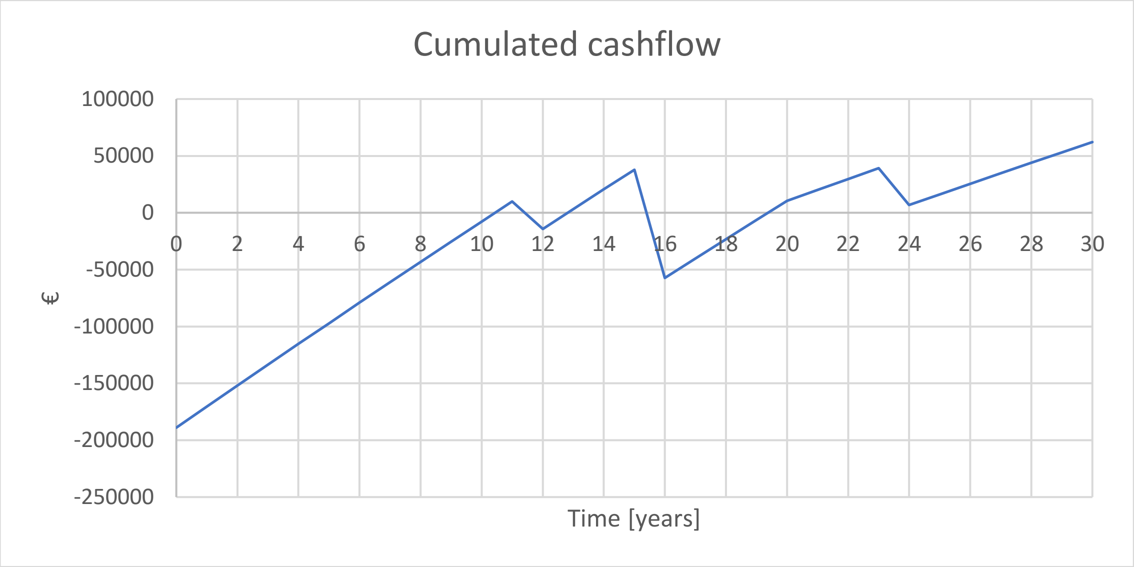


Figure 72: Cumulated cashflow

As done for the previously obtained cashflow, the payback time can be calculated as shown in equation 39:

Equation 39: Payback time calculation [27]

$$PBT = 1 + n_y - \frac{n}{p} = 11{,}4\ years$$

The net present value instead, results to be:

$$NPV = 62143$$

In this scenario the payback time is higher mainly due to the lower amount of yearly shared energy with the virtual consumers and to the different allocation of the storage devices. Indeed, being the accumulation systems placed separately in each plant, accounting only for the local consumptions, an increase of the investment costs because of a bigger storage requirement is expected, and through this analysis it has been confirmed.

11. Conclusions

The aim of this thesis was to study the concept of an Energy Community developed in the small town of Frassinetto in Piedmont region. As the mountainous areas are among the most affected by climate change, it is necessary to take action by adopting more sustainable energy production strategies. At this purpose, it was precisely decided to design an Energy Community that brings not only environmental but also economic benefits. In this context, as the photovoltaic production is almost always above the electrical consumption of Frassinetto, the designed community has the potential to expand its reach to another Municipality by accounting for a portion of its consumptions as virtual. This approach aligns the curves of production and consumption, allowing the Energy Community to qualify for the additional economic incentives presented in Chapter 9.

Another important consideration is that to develop this analysis, particularly with regard to the electrical consumptions' estimation, the hourly values were derived from the monthly ones by factoring in the percentage within each consumption band (F1, F2, F3) as a weight. A more precise evaluation could be achieved with access to consumptions every quarter of an hour.

A final remark regards the sizing of the storage systems which involved pinpointing the day of the year with the lowest disparity between production and consumption to ensure optimal use of installed batteries without waste. This decision was based on economic considerations as batteries are the most expensive component of the plant. In cases where the storage capacity is insufficient to meet the demand, the remaining power will be drawn from the grid. Incorporating advanced tools like co-simulation, allows for a more efficient and optimized calculation of storage requirements.

In conclusion, the design project for the Frassinetto Energy Community can be effectively implemented in reality. As shown in Chapter 9, the payback time is reasonable and it is important to consider that, without any transition to renewable energy production, Frassinetto would continue to be entirely dependent on the national power grid not receiving any economic incentives.

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