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"Renewable Energy Communities: design and management from the household perspective"

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Abstract

[English version]

In this master thesis Renewable Energy Communities are analysed from the household perspective. In particular, all technical, economic and legislative criteria useful for the simulation and analysis of a renewable energy community were evaluated, starting first from a general overview regarding the electrical systems at world level and the changes taking place, and then moving on to the legislative analysis and other characteristics concerning the REC, and finally identifying a calculation process then used for the simulation of various scenarios related to a REC.

The first objective of the present dissertation is to deepen about all the features related to REC, i.e., making an overview of RECs, followed by a detailed analysis about the current legislation in force both at European and Italian levels. The second one is the creation of a procedure calculation for the simulation of a REC, in such a way to explore the benefits of different scenarios and to discover the best case through a techno-economic analysis of the REC: through the help of a database, created in order to demonstrate the economic benefits of a REC, and the tools called Termolog and ROSE, it will be carried out a simulation of a REC system, regarding three house located in Treviso. There will be also a comparison between different scenarios based on several storage system capacities, and they will be compared to demonstrate if the realization of an energy community can bring or not benefits for the citizen who wants to adhere to this configuration.

This study made it possible to highlight the economic convenience of the construction of the photovoltaic system alone for the case study in question, therefore without energy storage. In addition, it is also concluded that, under the current circumstances, it is not advantageous combining storage with the photovoltaic system nowadays given the high investment costs.

[Italian version]

In questa tesi di laurea vengono analizzate le comunità di energia rinnovabile dal punto di vista degli utenti. In particolare, sono stati valutati tutti i criteri tecnici, economici e legislativi utili alla simulazione e all'analisi di una comunità di energie rinnovabili, partendo prima da una panoramica generale riguardante gli impianti elettrici a livello mondiale e le trasformazioni in atto, per poi passare all’analisi legislativa e altre caratteristiche riguardanti le RECs, ed infine identificare un processo di calcolo utilizzato per la simulazione di vari scenari relativi alla comunità analizzata.

Il primo obiettivo della presente tesi è quello di approfondire tutte le caratteristiche relative alle RECs, ovvero fare una panoramica delle comunità energetiche, seguita da un'analisi dettagliata sulla normativa vigente sia a livello europeo che italiano. La seconda è la creazione di una procedura di calcolo per la simulazione di una REC, in modo tale da esplorare i vantaggi di diversi scenari e scoprire il caso migliore attraverso un'analisi tecnico-economica della REC: attraverso l'ausilio di un database, creato allo scopo di dimostrare i vantaggi economici di una REC, e degli strumenti denominati Termolog e ROSE, verrà effettuata una simulazione di un sistema di comunità energetiche, riguardante tre case ubicate a Treviso. Ci sarà anche un confronto tra diversi scenari basati su più capacità del sistema di accumulo, e verranno confrontati per dimostrare se la realizzazione di una comunità energetica può portare o meno benefici per il cittadino che vuole aderire a questa configurazione.

Tale studio ha consentito di evidenziare la convenienza economica della realizzazione del solo impianto fotovoltaico per il caso studio in esame, quindi senza accumulo di energia. Inoltre, si conclude anche che, nelle attuali circostanze, non è vantaggioso combinare l'accumulo con l'impianto fotovoltaico al giorno d'oggi, dati gli elevati costi di investimento.

Table of symbols and abbreviations

ARERA	Autorità di regolazione per Energia Reti e Ambiente (Italian Regulatory Authority for Energy, Networks and the Environment)
BTAU	Variable component value distribution
CAPEX	Capital expenditure
CEEP	Clean Energy for all Europeans Package
CF	Cash flow
$CU_{Af,m}$	Corrispettivo unitario di autoconsumo forfettario mensile (monthly flat-rate self-consumption fee)
DCF	Discounted cash flow
DPP	Discounted payback period
DSM	Demand Side Management
ESCo	Energy service company
GSE	Gestore dei Servizi Energetici (Italian Energy Service manager)
IRR	Internal rate of return
LV	Low Voltage
MiSE	‘Ministero dello Sviluppo Economico’ (Ministry of Economic Development)
MV	Medium Voltage
NPV	Net present value
OPEX	Operative expenses
P.R.	Prezzo risparmio (saving price)
PCR	Percentage cost reduction
PMG	Prezzo minimo garantito (guaranteed minimum price)
PNIEC	Piano Nazionale Integrato per Energia e Clima (integrated Italian national plan for energy and climate)
PNRR	Piano Nazionale di Ripresa e Resilienza (Italian National Recovery and Resilience Plan)
POD	Point of Delivery
PUN	Prezzo unico nazionale (single national price)
PV	Photovoltaic
PZO	Prezzo zonale orario (hourly zonal price)
REC	Renewable energy community
RES	Renewable energy source
RID	Ritiro Dedicato (Dedicated Withdrawal)
RSE	RSE “Ricerca Sistema Energetico”, Energy System Research
SME	Small-medium enterprise
TERNA	Italian TSO
TP	Tariffa Premio (feed-in-premium rate)
TRASE	Transmission tariff for low voltage user
V2G	Vehicle-to-Grid
VER	Variable energy source

Introduction

One of the key challenges that our society has to face is the energy transition, which essentially consists of two main factors: the first involves the conversion from the classic energy system based on fossil fuels to a new one based on renewable sources, while the second aspect, on the other hand, is the new role that the Citizen is having, who is becoming an active figure within the electricity market. These two factors together form a perfect combination for the creation of renewable energy communities: these new forms of association allow their participants to enjoy not only economic, but also environmental and social benefits. These aspects are particularly affecting the countries of the European Union, which thanks to the energy directives adopted is going to become the first continent in the world with zero climate impact by 2050.

Before getting to the simulation and economic analysis results, a general overview of the energy situation at both European and Italian level is made. The main directives and legislations are analysed at the EU and Italian level. In addition, some definition and characteristics of REC are given, together with examples of them in EU and Italy.

This work is important because it firstly presents the overview of the Renewable Energy Communities, which are going to be a key element within electrical systems globally: in fact, these are based on a new concept of energy use and exchange of electricity, and they will represent one of the ways to pursue the objectives of the energy transition underway. Moreover, this dissertation can be useful to all those users who approach the world of energy communities for the first time, because it makes it easy to understand in which cases it is convenient to adopt them and the legislation in the European and Italian context is well explained, which is not easy to interpret since it is always changing.

Chapter 1 starts from a general overview about climate change, the need for new sustainable models for the energy sector and energy transition. Then various definitions of REC are given, together with the reasons for the creation and some other important aspects. Moreover, the literature on REC regulation is analysed, firstly introducing the historical evolution, and then explaining the current laws in both the European and Italian context. This chapter also presents some EU case studies on RES energy community and the drivers of RES communities and the relation with 3Ds Paradigm (Decarbonization, Digitalization and Decentralization).
Chapter 2 is about the used Methodology, and it starts by explaining the main steps to set up a REC, then the implemented approach, and finally the introduction about the tools used for the implementation (calculation procedure through database, ‘Termolog’, ‘ROSE’, ‘PVGIS’).
Chapter 3 regards the presentation of the base case, and the description of the data that will be used for the simulation.
Chapter 4 concerns the simulation of RES community. It starts with the analysis of the hourly producibility of the photovoltaic system by jointly exploiting the PVGIS and Termolog tools. The data collected were then implemented both in the database and in the Termolog tool which allowed the simulation of the base case of the reference REC. Subsequently, using the ROSE tool it was possible to simulate multiple scenarios with different storage capacities, and finally concluded with the economic analysis relating to all the scenarios taken into consideration, with the aim of identifying the best solution. The results are then presented together with the related considerations.
Chapter 5 concerns the conclusion.

1. Contextualization and Literature review

The most ambitious challenge that our generation must be able to overcome is the achievement of the energy transition's objectives. It is undeniable how much the climate and environment are changing around us due to the actions of man regarding the intensive exploitation of the planet's resources, and especially due to the emissions of greenhouse gases. "According to an ongoing temperature analysis led by scientists at NASA's Goddard Institute for Space Studies (GISS), the average global temperature on Earth has increased by at least 1.1° Celsius since 1880. The majority of the warming has occurred since 1975, at a rate of roughly 0.15 to 0.20°C per decade" [1].
The increase of average global temperature is a change largely driven by the rise in CO2 emissions into the atmosphere, and this phenomenon is the reason why the number of record temperatures in various states around the world is on the rise, while record low-temperature events have declined since 1950. In addition to this, other non-ordinary events are happening, for example, in most countries the number of heavy rains is increasing, the global sea level has risen by 20 centimetres in the last century all over the world, and its growth rate in the last two decades has roughly doubled compared to that of the last century and is accelerating more and more every year.

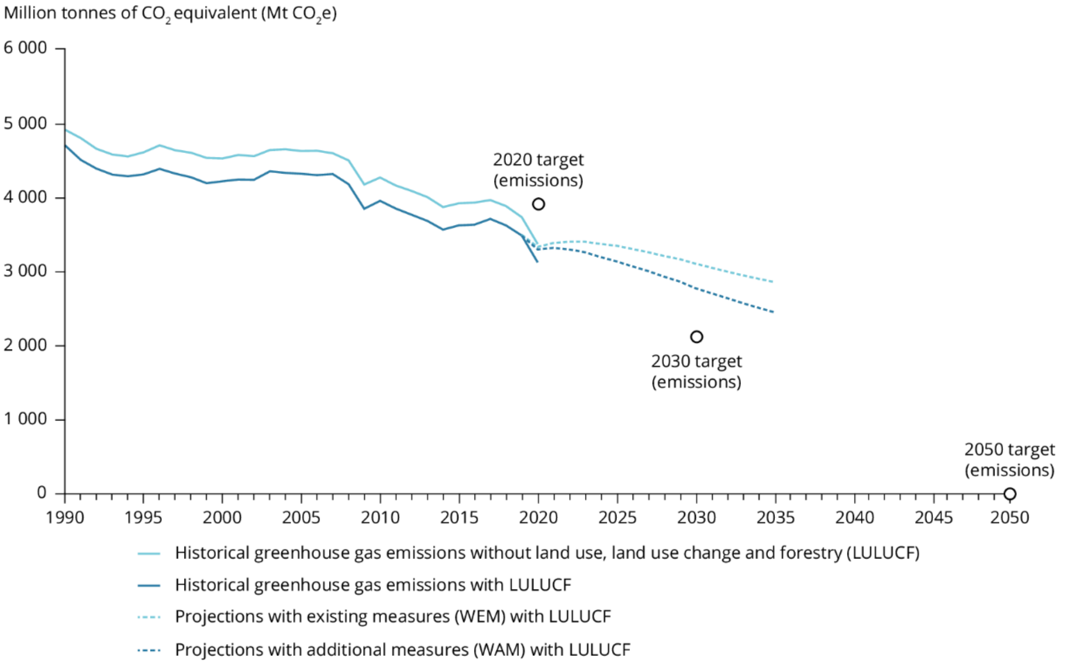

Fig. 1.1 - "Greenhouse gas emissions, projections, and targets for the European Union" [https://www.eea.europa.eu/data-and-maps/figures/figure-1-historical-trends-and, 20 January 2022]

One of the objectives in the "Climate and Energy Package", adopted in 2008 by EU member states, was a 20% cut in greenhouse gas emissions by 2020 compared to 1990 levels, as it can be seen in Fig 1.1, which represents the GHG historical trends, targets and future projections for EU countries. Analysts have estimated that EU GHG emissions in 2020 were 31% lower than in 1990, and this means that the target was exceeded by 11%. In addition, confirmed data shows that emissions decreased 24% by 2019 compared to 1990. It is important to notice that between 2019 and 2020 there was a large drop in EU greenhouse gas emissions, and this is mainly related to the Covid-19 pandemic. However, according to the latest projections based on existing measures, the net emission reduction would only be about 41% by 2030 [2].
This is a huge problem because the new EU climate law will set that the EU emissions level for 2030

has to be reduced at least by 55% compared to 1990 levels. In fact, the EU will emanate in 2022 a package of new and revised laws known as ‘Fit for 55 package’, which sets that “the new 55% GHG target will require a 38-40% RES share in final energy consumption by 2030” [3]. This new package was proposed in July 2021 by the European Commission, and it aims to reach the European Green Deal new objectives through some key area of action as can be seen in the Fig. 1.2, for example the inclusion of additional support for renewables, clean transport, and a new tax on emissions for high-carbon imports, which is called “Carbon Border Adjustment Mechanism”.
The final target is to make Europe a climate-neutral continent by 2050, and this is possible only by implementing innovations and changes in the management model of the energy systems, which has also contributed to security of supply and universal access to energy.

Besides to reduce greenhouse gas emissions (GHG), the EU energy transition is occurring to reduce imported fossil fuels, to utilise local resources and create local jobs and to reduce the costs of energy towards 2050.

Fig. 1.2 - “How the EU delivers the green transition - key areas of action” [https://www.consilium.europa.eu/en/infographics/fit-for-55-how-the-eu-delivers-the-green-transition/, 10 November 2021]

"The effects of human-caused global warming are happening now, are irreversible on the timescale of people alive today, and will worsen in the decades to come. The potential future effects of global climate change include more frequent wildfires, longer periods of drought in some regions, and an increase in the number, duration, and intensity of tropical storms" [4].
The effects of climate change have been perceived mainly in the last century, since in this period, more than any other era, the technological evolution has exploited natural resources to improve human living conditions. For all these reasons, therefore, the main objective of the world community should be the creation of new sustainable management models in all sectors, which can contribute to the reduction of emissions.

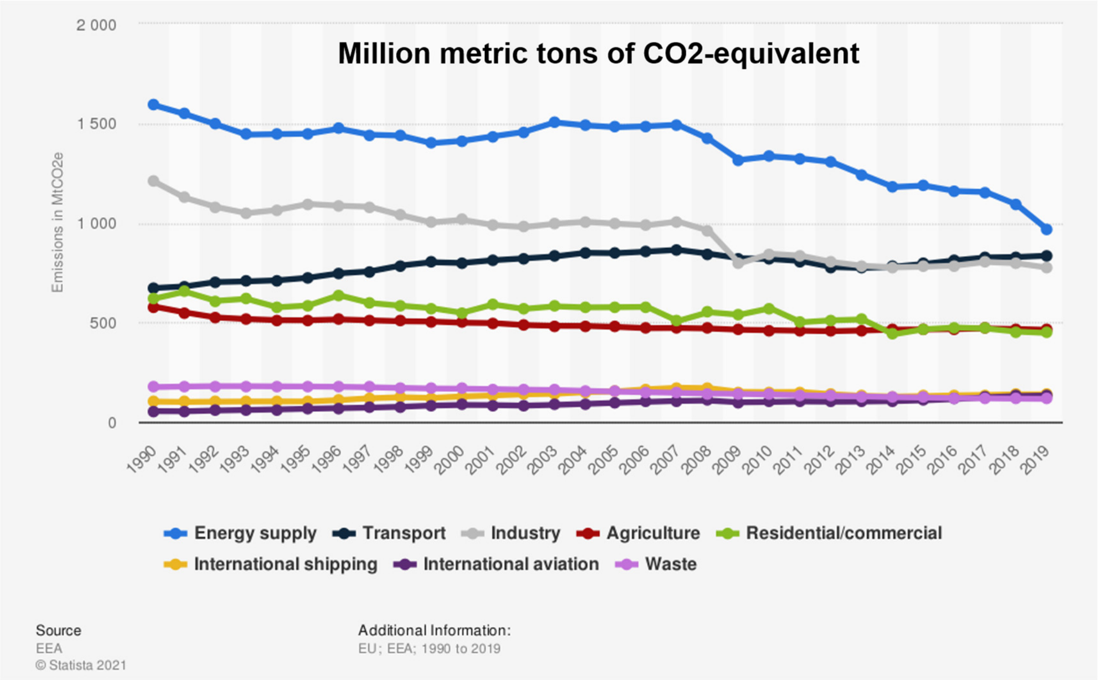

Fig. 1.3 - "Annual greenhouse gas emissions in EU from 1990 to 2019 by sector" [https://www.statista.com/statistics/1171183/ghg-emissions-sector-european-union-eu/, June 2021]

It can be seen from Fig. 1.3 that the main sector which needs to be reformed is the energy sector, which includes the energy industries and fugitives' emissions[1], followed by the transport and industry sectors, which includes manufacturing industries and construction. The reason behind those emissions levels is that fossil fuels are the most used source to produce electrical and thermal energy, as well as combustible for means of transport. Consequently, the element that plays the most strategic role nowadays and allows us to reach the Green Deal objectives is the Energy Transition. This term refers to "the global energy sector's shift from fossil-based systems of energy production and consumption (including oil, natural gas, and coal) to renewable energy sources like wind and solar" [5].
This is part of the wider transition to sustainable economies, which includes the utilization of renewable energies, as well as the adoption of energy-saving strategies, sustainable development techniques, and the utilization of energy storage as a complement to the new intermittent resources.
To foster the EU energy transition, four priorities are crucial:
"i) adopt transformative policies to decarbonize the transport sector;
ii) prepare the electricity system for a substantial increase in renewables, at acceptable cost and

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[1] Fugitive emissions: unintentional and undesirable emission, leakage, or discharge of gases or vapors from pressure-containing equipment or facilities, and from components inside an industrial plant such as valves, piping flanges, pumps, storage tanks, compressors, etc.

without compromising security;
iii) strengthen the EU's comparative advantage in low-carbon technologies;
iv) foster the decarbonization of industry and buildings” [6].

Worldwide, the most important accordance between nations is The Paris Agreement [7]. This document was signed in December 2016 and ratified by the United Nations in 2017, and it is a milestone in achieving the energy sustainability goals since it has involved a total of 195 nations, both developed and developing countries. Italy signed the agreement on 22 April 2016 and ratified it on 11 November 2016. The declared long-term goal is to keep the temperature rise well below 2°C and, indeed, to strive to contain it at 1.5°C compared to pre-industrial levels. Consequently, the mitigation objective is to reach the peak of polluting emissions as soon as possible and to carry out rapid reductions in emissions in the second half of the century. Article 4 then specifies how each country must communicate national mitigation contributions every 5 years. A market mechanism is established in Article 6 and there are also transparency obligations, obviously necessary to measure the real impact of national government decisions on emissions in Article 13.

Instead, at the EU level, there is a European Commission document dated 11.12.2019 which says “This Communication sets out a European Green Deal for the European Union (EU) and its citizens. It resets the Commission’s commitment to tackling climate and environmental-related challenges that is this generation’s defining task. The atmosphere is warming, and the climate is changing with each passing year. One million of the eight million species on the planet are at risk of being lost. Forests and oceans are being polluted and destroyed. The European Green Deal is the answer to energy transition challenges. This is a new growth strategy aimed at transforming the EU into a just and prosperous society with a modern, resource-efficient, and competitive economy that will not generate net greenhouse gas emissions in 2050 and economic growth will be dissociated from resource use” [8].

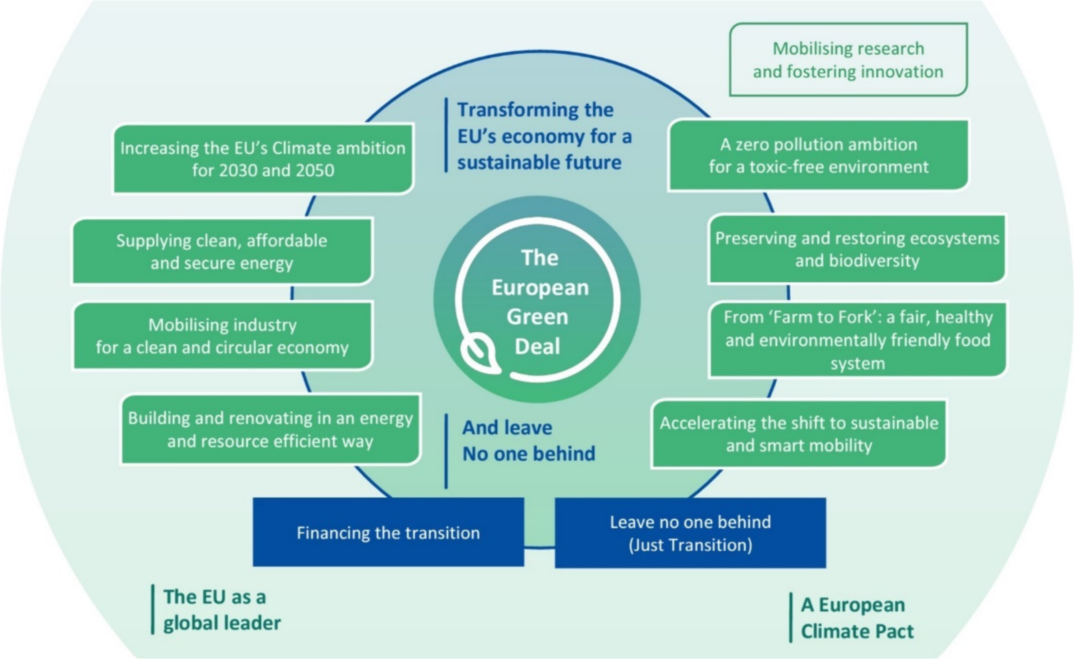

Fig. 1.4 - “European Green Deal Objectives” [https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52019DC0640&from=ET/, 11 December 2019]

In the Fig. 1.4 it can be seen the main objectives of the European Green Deal, which are therefore the establishment of a new sustainable management model, the decarbonization of the energy sector and the fight against energy poverty, and to make Europe the first climate-neutral continent. This document is therefore intended to open a new phase toward climate neutrality, and also to set pressing objectives for member countries. To achieve this ambitious goal, and to become like Europe a world leader in transition, various investment tools, and plans were introduced by the European Commission.

The European Green Deal also represents the lifeline out of the COVID-19 pandemic: one-third of the 1.8 trillion-euro investments from the NextGenerationEU, which is investment plan that will be anchored in the European budget for the next seven years with the aim of making the EU green, digital and resilient, together with Recovery Plans, will help to financing the European Green Deal.

Moreover, at Italian level, the reference document is "Piano Nazionale Integrato per l'Energia e il Clima", also known as PNIEC[2]. This instrument has acknowledged the need to accelerate the energy transition, and so it has set challenging objectives to be reached by 2030. The plan, sent to the European Commission in January 2021, moves along 5 main lines: energy efficiency, decarbonization, energy security, development of the internal market, and R&D. The main goal is to bring the share of gross final consumption of energy derived from renewable sources to 30% by 2030 [9]**.**

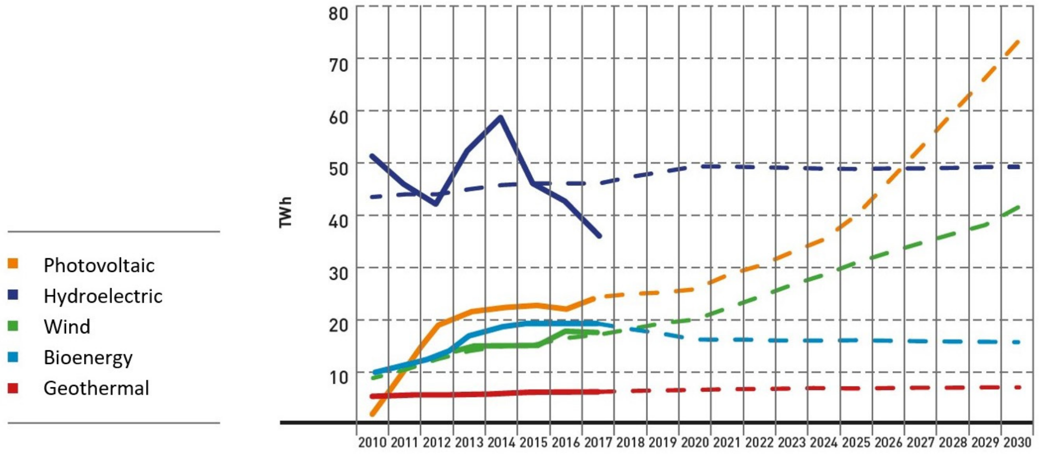

Fig. 1.5 - "PNIEC trajectory for the production of electricity from renewable sources" [Italian National Energy Situation, Ministry of Economic Development - https://dgsaie.mise.gov.it/situazione-energetica-nazionale]

Fig. 1.5 represents the expected trajectory for the production of electricity from renewable sources in Italy until 2030. It predicts a major growth in the photovoltaic and wind sectors, while the hydroelectric, bioenergy and geothermal sectors stand at current values.

If we analyse the actual Italian electrical energy sector, it can be seen that "as for 2020, based on the preliminary data currently available, it is estimated that consumption from renewable sources may have been around 21.5 Mtoe, which, combined with the first estimates on gross final consumption, lead to evaluate a percentage of satisfied consumption through renewable energies, as a first approximation, around 20%" [10]. It can be observed that this value is well above the set target placed for 2020, which was equal to 17%, but it is important to underline that Italy has been above this value since 2014.

From the data given by Terna[3], it is also possible to estimate that, in 2020, there was an increase in

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[2] PNIEC is introduced here for a matter of contextualization. This program is discussed in detail in Chapter 2.

[3] The Italian transmission system operator is Terna S.p.A. It is managed by Terna Rete Italia, which is in charge of the Italian transmission system. Terna is the world's sixth largest electricity transmission grid operator based on the size of its electrical system, with 66,652 kilometres of power lines, almost 98 percent of the Italian high-voltage power transmission infrastructure.

installed electrical power from renewable sources equal to 1134.6 MW. If we focus only on the electricity sector, we can observe from the statistics that the net production from renewables currently stands at around 37.6%, the non-renewable one at 51.7% and the foreign balance at 10.7%. As for consumption, on the other hand, the most impacting sector is the industrial one (44.2%), followed by the one linked to services (30.2%), domestic (23.3%) and finally the agricultural one (2.3%) [11].

The renewable power currently installed in Italy is equal to 10.9 GW of wind power, 21.6 GW of photovoltaics, 23 GW of hydroelectric, 4 GW of bioenergy, and 1 GW of geothermal. From the data contained in the PNIEC, it is possible to observe that for bringing the share of gross final consumption of energy derived from renewable sources to 30% by 2030, it is necessary to set "an annual average installed from 2019 to 2030 equal to 3200 MW of wind power and 3800 MW of photovoltaics, compared to an average installed in recent years of a total of 700 MW. This diffusion of wind and photovoltaics will also require many infrastructural works and the massive use of distributed and centralized storage systems, both for system safety needs and to avoid having to stop renewable plants in periods of lower consumption than production" [12].

It can be noticed that this is a very demanding objective that will require considerable economic and technical efforts, other than the fact that it will be necessary to streamline the bureaucracy in order to approve projects more quickly. This objective will also entail, in the electricity sector the safeguarding and strengthening of the installed park.

As a result of the previous reasoning, there has not been a strong increase on the gross final consumption through renewable energies in recent years. For that reason, it is necessary to accelerate policies and incentives more decisively, given that the goals are increasingly ambitious in a time horizon that has remained unchanged.

Renewable energy sources' introduction: the point about technology

The next step in the analysis of renewable sources is to understand how they can be integrated into the electricity grid and how we can maximize their contribution. In fact, among RES there is a certain subset called VER (Variable Energy Resources) which includes wind, photovoltaic and small hydroelectric among all. The characteristics of these sources are precisely:

- variability (the power produced depends primarily on the renewable resources available at that time;
- uncertainty (which does not allow to plan its use);
- the specificity of the place (the areas that allow natural resources to be converted into energy are fixed, they cannot be transported);
- modularity (the size of photovoltaic systems or wind turbines is smaller than that of conventional ones, this allows for more widespread distribution on the territory);
- low start-up costs (once the plants are built, running them requires low costs).

The characteristic of modularity makes the exploitation of economies of scale less indispensable, and therefore allows the deployment of widespread small-medium scale initiatives. Thanks to this, electric systems have been changing over the past years, giving an increasingly important role to initiatives that individual citizens or groups of consumers can implement, such as REC. In fact, the cost of producing electrical energy through these plants is reaching ever lower values, to the point of making renewable sources competitive with traditional ones, thus making a new approach to the problem of energy supply possible.

Instead, the first three of the features listed (variability, uncertainty, specificity of a place) raise a whole series of problems that hinder the implementation of renewable sources on a large scale, so it is important to find several solutions for each problem.

One of the problems raised with the massive introduction of RES can be seen in Fig 1.6, where it is possible to see a "duck curve", which represents the intraday power consumption of the sample constituted by households, and where each line represent a different year.
The data was collected by the California Independent System Operator (CAISO), and the survey was carried out on a specific day in March, in such a way that there is low consumption of electrical energy from heating/refrigeration of houses.

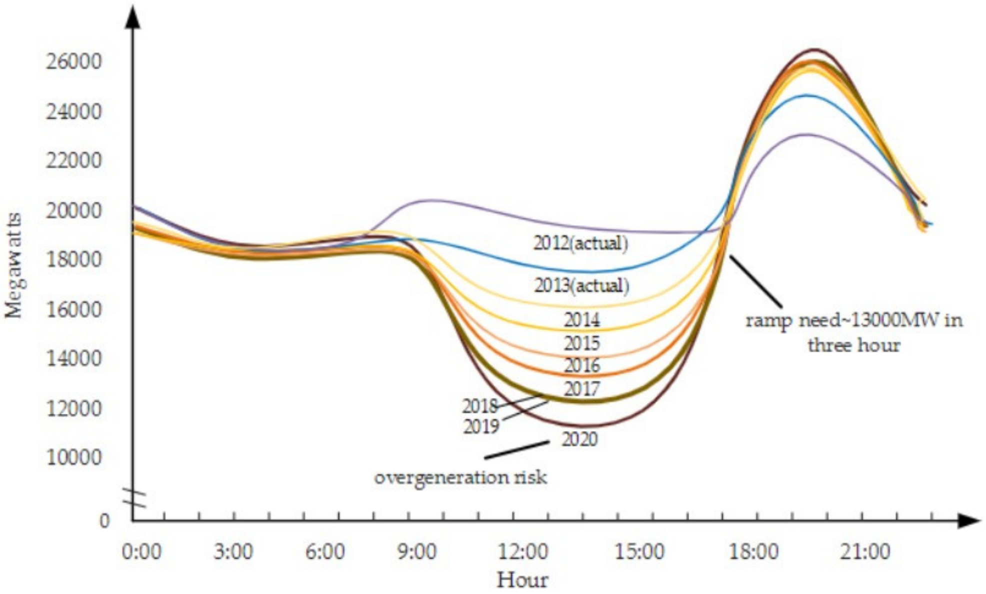

Figure 1.6 - "The CAISO predicted duck curve" [Q. Wang et al., "Mitigation strategy for duck curve in high photovoltaic penetration power system using concentrating solar power station," Energies, vol. 12, no. 18, Sep. 2019]

"The fluctuation of the duck curve should be met by the active power of other power supplies in the power system immediately. During the decreasing segment of the duck abdomen, the traditional power supplies need to reduce their output promptly to cope with the stage of abundant PV generation at noon, avoiding the risk of over-generation. During the increasing segment of the duck neck, traditional power supplies inversely need to increase output rapidly at sunset to make up for the fast loss of PV power, meeting the demand of evening peak load. However, it is difficult for the regulation capability of the conventional power system to support the demand of fast ramping down and up during the segment of the duck abdomen and duck neck" [13].
The last quote explains the challenge of integrating intermittent resources such as wind and photovoltaic energy in the existing infrastructure and consumption habits: as these renewable energy resources reach greater market penetration, they present a new problem for TSOs and DSOs due to their intermittency. In fact, the amount of energy that must be generated by conventional plants (gas-powered above all) will become more and more variable on an hourly basis, and this implies the fact of having many gas plants used for the "capacity market[4]", which means they are only used and getting remunerated for ensuring the necessary reserve margin and to face peak demand.
This situation is at the root of the problem shown in the so-called "duck curve". As variable generation resources significantly reduce the load on conventional generators during the day but not in the evening, a surge in conventional generation demand can occur in this period.

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[4] In some wholesale energy markets, capacity markets are utilized to compensate resources for being ready to meet peak electricity demand. Capacity refers to the ability to generate power in the future, rather than the ability to produce it now.

For all the reasons above, Hirth believed that there was "an implicit limit of 20% maximum VER penetration into the electricity system, and a higher percentage would have involved more costs than benefits" [14]. Although some authors still believe in this limit, some promising facts have been observed: in 2020, about 48% of Denmark's total electricity consumption was covered by wind power, as it can be seen in the Fig. 1.7. The data of Terna (Italian TSO) outlines the current situation in which VER contribute by 12.8% to the final energy consumption in 2020.

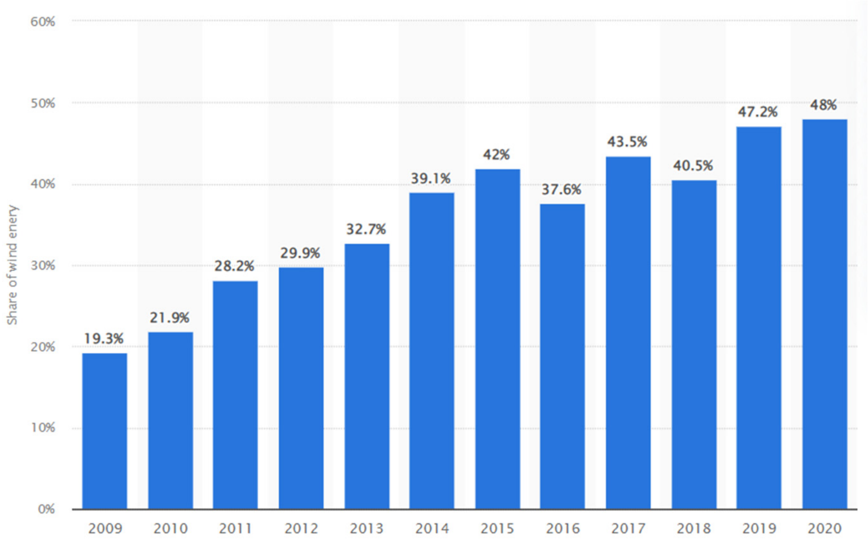

Fig. 1.7 - "Share of wind power coverage in Denmark from 2009 to 2020" [https://www.statista.com/statistics/991055/share-of-wind-energy-coverage-in-denmark/, 09 September 2021]

Other problems related to the implementation of RES on a large scale in the existing infrastructure are:

- Distributed generation might imply the inversion of power flows along with the network and through the transformers, and the consequence of that is a reduction of Power Quality. In this regard, there is more and more talk of managing the network in a meshed way, which implies more complexity but also better management and no need to build new lines
- The number of traditional power plants will decrease because of the increase of RES, and this can cause fewer powerplants connected to the grid which can provide network regulation, and so less governing energy; less regulating power available to the grid, so less inertia; and less short-circuit power, therefore mains disturbances affect more the grid, especially in the LV network.

There are some possible solutions that are under investigation, for example, the so-called "synthetic inertia" (provided by batteries or RES), or generators that can provide ancillary services to the grid, which means they produce active and reactive power mainly for voltage/frequency regulation.

In addition to these, Renewable Energy Communities are expected to provide a meaningful contribution to boost the implementation of renewable energy sources on a large scale despite these problems.

1.1 Renewable Energy Communities in the EU

1.1.1 Definitions of REC

One of the most efficient ways to improve the installation of renewable energy sources is through the creation of Renewable Energy Communities.
In the last years, the concept of renewable energy community has increased its popularity in the European landscape, due to the new socio-economic politics implemented regarding the sustainability of the energy sector.
In particular, the REC are the new actors in the energy market, and they can be described as:

1. "REC are market entities focused on *prosumers aggregation*, which can:
   - facilitate the local optimization of power flows;
   - improve the Power Quality with the reduction of energy losses;
   - postpone or reduce network investments, by increasing hosting capacity and improving flexibility through ancillary services offers for more efficient system operation" [15].

2. "Renewable Energy communities (RECs) represent a significant novelty in the landscape of the liberalized electricity market: these are collective actors with specific organizational and governance features, not primarily driven by commercial purposes. Contrary to collective self-consumption and other traditional market actors, a REC is necessarily constituted as a legal entity (for example as a cooperative, public-private partnership, or an association) and has to comply with sector-specific governance rules on openness to new shareholders and members, effective control over decision-making and management, and ownership of organizational assets" [16, 17].

3. "RES communities come in many different forms, as they often carry out multiple activities, have multiple objectives, their members are driven by different motivations, they can be limited to a more or less wide geographical area, they use different technologies, have different legal forms (and hence different forms of governance), etc. As a result, interpretations can differ as to what exactly constitutes a RES community. In this regard, the element on which consensus appears to be broadest is that the members of a RES community are not only the recipients of potential benefits generated by a CRE (Clean and Renewable Energy) projects but are also co-owners of the project and so can, and ideally would, participate in the decisions about it" [17].

4. "REC can be self-responsible for balancing their portfolio and are responsible to ensure quality and security in energy supply to all members with reduced network and electricity tariffs due to the aggregation effect. Local energy allocation can result in a reduction of peak demand and a decrease in power flows from the main grid. It has to be emphasized that the main difference between energy communities and microgrids is that energy communities are not designated to operate in an island mode" [15].

5. "The Newcomers Project understands energy communities as any collaboration of citizens and other entities, such as municipalities, companies, energy providers, network operators, NGOs, etc., with the joint aim to contribute to energy system transformation by involving

> multiple actors in a participatory manner, and by aiming to create benefits for all involved parties (and potentially for society at large)" [18].

In summary, we can say that renewable energy communities are citizen-centered entities in form of democratic and free aggregations of people, whose objective is the creation of sustainable development through an innovative energy management model and to promote the energy transition through the expansion of distributed energy generation from renewable sources throughout society. They are new emerging modes of transacting energy that challenge the traditional hierarchies based on vertical agreements between consumers and energy providers at the retail level, which can also contribute to the market integration of existing decentralized renewables generation, which currently belongs to civil society and final customers.

REC may become a pillar for balancing the system at the local level, by showing the potential for a decrease in grid dependencies and, ultimately, the avoidance of network costs.

An example of real Renewable Energy Community is a system made up of small/medium scale energy production units, energy storage, intelligent distribution networks (smart grids), and demand management systems.

1.1.2 Reasons for the creation of REC and purposes

Consumers are prone to create a Renewable Energy Community for several reasons including: "to provide environmental, economic or social benefits at the community level, rather than financial profits" [19, 20]**.**

End customers and producers can jointly generate and share electricity from renewable sources. Thanks to this collaboration, the subjects adhering to these configurations can obtain the following benefits at the level of community:

- economic, obtaining incentives and the return of the tariff components provided, to obtain a reduction in the weight of the electricity bill;
- environmental, thanks to the reduction of CO2 emissions;
- social, being able to act on situations of energy poverty and increasing the energy autonomy of a given territory.

  Furthermore, to collect the full potential of distributed generation from renewable energy sources, the contribution of individual citizens appears strategic and can contribute to the success of climate and environmental policies: for this reason, the new relationship between the citizen and energy is fundamental.

The possible purposes to create a REC are the possibility to produce, self-consume, share and accumulate energy, and this involves a whole series of key purposes including efficient use of renewable sources, energy-saving and reduction of current costs of energy carriers, valorisation of sources present in the area, reduction of the carbon footprint in the area in which it is installed, contribution to the achievement of production targets from RES, favouring the fight against energy poverty, spreading the culture of sustainability by stimulating the involvement of citizens.

1.1.3 Differences between REC and Collective Self-Consumption groups

The main difference between a Renewable Energy Community and Auto Consumer of renewable energy that acts collectively is that the users of a REC are necessarily connected to the same primary/secondary electrical substation, while a collective self-consumption group refers to a condominium/building. Also, the REC is a legal entity with members, shareholders, final customers, and/or producers who are therefore constituted in an association, cooperative, or consortium; while the collective self-consumption group is a simple set of final customers and/or producers. The perimeter of a REC includes POD[5] and plants under the same portion of the LV network, while that one of a group of self-consumers includes POD and only the plants in the same building/condominium. As regards the aspects in common, both REC and the collective self-consumption group aim at more efficient management of renewable energy production. They both enjoy the same social, environmental, and economic benefits. As for the economic ones, both receive incentives, tariff reimbursement per MWh of shared energy, and remuneration of the electricity fed into the grid.

1.1.4 The importance of local authorities' role

In this context, local authority plays a key role: for example, a municipality can promote the REC by assigning economic resources for planning/design, proposing itself as an aggregator, removing any obstacles (administrative simplification), informing its citizens on the opportunities and benefits deriving from the REC, aggregating, and managing. For example, given the cost structure of production from renewables (high investment costs compared to negligible operating costs), a public intervention aimed at covering the initial costs of energy communities in areas of specific economic difficulty can be an ideal solution to cope with situations of energy poverty, contributing at the same time to the decarbonization of the system.
In addition, a citizen can join a REC directly, becoming a member of the same in the form of producer (producing energy from its own plant placed in the "availability" of the energy community), the consumer (taking electricity from the grid for a user inserted in the configuration and being the owner of the relative electricity bill) or prosumer (drawing and producing energy at the same time, even for different POD). The municipal body can also contribute to the establishment of a REC both to enhance its assets in favor of the community, and as a response to situations of energy poverty. To do this, it makes available its assets, such as spaces (from the roof of a building to an area to be recovered in its own territory) and its own plants as external producers (to encourage the sharing of energy, and possibly obtaining the proceeds from the concession of such systems and delegating their maintenance).

The energy community must therefore be understood as a cultural, economic, and social reality that locally self-produces the energy necessary for its needs, properly using the resources of the territory, thus protecting its territorial, landscape, environmental and common assets, and addressing the reduction of its ecological footprint. But the benefits that can be drawn from community initiatives go far beyond the electric dimension, starting from the energetic sphere: it is possible to imagine that sharing also extends to the thermal vector.

It is important to underline those experiments in REC, at present time, are made according to a "virtual scheme", thanks to the early transposition of the European Directives: this type of

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[5] POD: Point of Delivery

experimentation allows rapid deployment of the projects as it exploits the infrastructures such as network and meters already in place, thus avoiding duplication concerning the existing distribution network. In addition to this, the possibility of targeting consumption by the so-called "demand response[6]" is being studied to instantly exploit the energy produced on-site. Finally, bringing production and consumption closer together means reducing network losses and, in general, reducing environmental impact and system costs. According to Community guidelines, the quantification of network and system charges will have to consider the guaranteed benefits for prosumers, given that self-consumed renewable energy is not transported on the national transmission grid. However, these benefits have yet to be precisely determined (the Italian Regulatory Authority for Energy, Networks, and Environment is currently working on them).

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[6] Demand response is the adaptation of energy usage to accomplish particular results on the electrical grid at different levels. This could involve reducing net system load in reaction to a power plant failure or reducing load on a local distribution transformer avoiding high marginal prices. Shuttering machines, altering the temperature, turning on a generator, or turning on a battery could all provide load relief. To summarize, it entails directing energy users to change their behaviour.

1.2 Analysing the literature on REC regulation

1.2.1 Historical evolution

Before delving into the laws regarding energy communities, it is necessary to take a step back and analyse the historical evolution of these.
Energy communities, despite their recent resurgence, are far from new, at least on a European scale. As a matter of fact, “the first energy cooperatives date back to the end of the 19th century when they were founded to support the electrification of establishments in rural areas due to an overall prioritization of urban areas by commercial actors and the lack of national grids in those territories” [21]. It's no coincidence that energy communities have always had strong linkages to renewables, owing to the compatibility of the community model with energy sources that are rooted throughout the region by their very nature. In reality, the first energy communities in continental Europe were strongly linked to the use of water resources, particularly in the mountain regions. Hydroelectric energy was the first renewable energy source to be exploited, together with the creation of coal-fired thermoelectric facilities. The Electric Company of Morbegno [22], which was created in 1897, is one example of hydroelectric community from Italy: this is legally formed as cooperative and has been able to continue operating up to the present day while diversifying its fields of action.
Initially, therefore, the first energy communities were born with the aim of electrifying the most remote rural areas, and they did not count on active community involvement and equal distribution of economic benefits as today.

After the Second World War, all European states witnessed the centralization and nationalization of the electrical system, in order to complete the electrification of all territories as quickly as possible: the companies operating in the electricity sector were all merged and nationalized, in such a way that each state could thus control the development of that strategic sector for the national economy. Energy communities entered therefore in a stalemate, given that they are based on distributed generation, that is a model competing with the centralized one, which at the time was based on the use of fossil fuels such as coal and oil.
Over the years, the world entered a phase of profound changes: some of these concerned the inevitable technological evolution, wars such as that of Yom Kippur (1973) which caused a rise in the price of oil, and nuclear accidents such as that of Three Mile Island (1979) and Chernobyl (1986). All these elements together contributed to questioning the centralized model that had established itself all over the World, generating uncertainty and scepticism towards it, and so renewable energy communities started experiencing a phase of revival.

The first emblematic case of the new REC is represented by Denmark, where after the 1980s, within the popular opposition movement to the government plan, the “Organization for Vedvarende Energi (OVE) was born as an organism that offers an energy development scenario alternative to nuclear and based on renewable sources, in particular on wind energy” [23]. Between the 80s and 90s, therefore, there was a peak of new wind energy community experiences in Denmark, in terms of individual properties and partnerships.
Finally, starting from the early 2000s, the development of decentralized energy systems and also the progressive liberalization of energy markets allowed renewable energy communities to confirm themselves as new main actors in the energy markets. In fact, after Denmark, also in other countries such as the Netherlands, the United Kingdom and above all in Germany there was an important relaunch of energy community projects.

However, in some countries, the spread of energy communities' experiences has created fundamental problems concerning the cohabitation of centralized and distributed generation, whose resolution extends beyond the technology realm to include both the social and political spheres. As regards the technological point of view, according to many researchers, the two models could coexist in the German energy transition process: local energy communities on the one hand, and utility-scale plants on the other, both related to seasonal storage systems and connected to integrated and cross-border networks [24]. The contrast is more social and political in nature. Indeed, while it is impossible to believe that communities made up of individuals and local governments can effectively manage huge production plants, it is reasonable to believe that energy utilities do not wish to give up a portion of the market and thus to disappear. Large factories and operators often profit from economies of scale. The two models appear to be much more incompatible from a regulatory standpoint. In fact, the rules and governance structure designed to allow the affirmation of a highly centralized system (which occurred more or less throughout Europe in the post-war period) are not aligned with a decentralized system based on local community initiatives.

1.2.2 Literature on Law

In recent years, the need to introduce legislation to regulate and help the spread of distributed renewable resources and energy communities has thus arisen. The European federation of renewable energy cooperatives, REScoop, was created in 2011 to address the demands of the numerous expanding realities (at least in Northern Europe) and to organize them at the European level. REScoop defines a Renewable Energy Community (REC) as "a legal entity where citizens, SME[7] and local authorities come together, as final users of energy, to cooperate in the generation, consumption distribution, storage, supply, aggregation of energy from renewable sources, or offer energy efficiency and demand side management services" [25].

The establishment of a unified European legislative framework for energy communities is still relatively new, which explains the wide range of legal organizational structures associated with energy community efforts, as it can be seen in the Tab 2.1 below. Cooperatives are one of the most common used structures, whose members are stakeholders directly tied to the territory, such as individual citizens, governmental administrations, or small-medium enterprises. This legal form is characterized by a "one head one vote" decision-making process and encompass both the economic and social dimension in its scope.

Table 1.1 - "Energy communities: an overview of energy and social innovation [A. Caramizaru et al., European Commission, "Energy communities: an overview of energy and social innovation", Joint Research Centre, p. 14, 2020]" [26]

Legal structure	Description
Energy cooperatives	This is the most common and fast-growing form of energy communities. This type of ownership primarily benefits its members. It is popular in countries where renewables and community energy are relatively advanced.
Limited partnerships	A partnership may allow individuals to distribute responsibilities and generate profits

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[7] SME: small-medium enterprise

	by participating in community energy. Governance is usually based on the value of each partner’s share, meaning they do not always provide for a one member - one vote.
Community trusts and foundations	Their objective is to generate social value and local development rather than benefits for individual members. Profits are used for the community as a whole, even when citizens do not have the means to invest in projects (for-the-public-good companies).
Housing associations	Non-profit associations that can offer benefits to tenants in social housing, although they may not be directly involved in decision-making. These forms are ideal for addressing energy poverty.
Non-profit customer owned enterprises	Legal structures used by communities that deal with the management of independent grid networks. Ideal for community district heating networks common in countries like Denmark.
Public-private partnerships	Local authorities can decide to enter into agreements with citizen groups and businesses in order to ensure energy provision and other benefits for a community
Public utility company	Public utility companies are run by municipalities, who invest in and manage the utility on behalf of taxpayers and citizens. These forms are less common but are particularly suited for rural or isolated areas.

In 2016, the EU launched a process of reviewing and upgrading its energy policy framework through the ‘Clean Energy for all European Package’, in order to create a conducive environment for reaching the climate targets agreed with the Paris Agreement. The Package consists of eight legislative acts, divided into directives and regulations, and aims to provide all European citizens with access to clean energy, that is energy as carbon-free as possible, through significant changes to the electricity market, the European Union's energy governance, and the role of the final consumer. At the same time, the energy community is recognized and regulated as a separate entity for the first time at the European level, with a great potential for sustainability and future development, according to the lawmaker. In particular, the contents of the package are the following ones:

1. “Increase the number of renewable sources: the Renewable Energy Directive 2018/2001 sets a target of 32% of gross final energy consumption for the EU by 2030.
2. More consumer rights: the new rules aim to strengthen the rights of the consumer, who transforms himself from a passive to an active subject, allowing him to produce, accumulate, and sell self-produced energy in complete autonomy, inducing to benefit from greater participation in the production process and, as a result, to demand greater transparency in the items on the bill, and possibly to save money.
3. Principle of energy efficiency first: the shift to total decarbonization must start with a sensible and optimal use of energy. The buildings sector is given special attention, including an amendment to the energy efficiency guideline [27]. The EU has therefore set binding targets of increasing energy efficiency over current levels by at least 32.5% by 2030.

4. A smarter and more efficient energy market: the rising percentage of renewables necessitates significant efforts for grid integration and supply security, without sacrificing service quality or the end consumer.
5. Better governance at the level of the Energy Union: each member state must develop a National Energy and Climate Plan outlining how it expects to meet the community's goals. The Commission will then review these proposals and make any necessary revisions or additions" [27].

Two basic directives of the 'Clean Energy for all European Package', notably 2018/2001 and 2019/944, define the European legislative framework. In particular, the CEEP[8] recognises two formal definitions for energy communities in European legislation.

The first one is included in the Renewable Energy Directive (EU) 2018/2001, and explains that "Renewable Energy Community means a legal entity:

(a) which, in accordance with the applicable national law, based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;

(b) the shareholders or members of which are persons, SMEs or local authorities, including municipalities;

(c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits." [28, 29].

Moreover, the Article 22 of the same directive contains essential information for the establishment and identification of RECs. "Members of the European Union must:

1) Ensure that all final customers, especially household customers, are allowed to participate in a renewable energy community while upholding their rights and obligations as final customers, and without being subjected to unreasonable or discriminatory conditions or procedures that would prevent their participation, provided that for private undertakings their participation does not constitute their primary commercial or professional activity [30].
2) Ensure that renewable energy communities have the legal right to produce, consume, store, and sell renewable energy (including through renewables power purchase agreements); share within the renewable energy community renewable energy produced by production units owned by that renewable energy community; and have non-discriminatory access to all appropriate energy marketplaces directly or through aggregation.
3) Conduct an evaluation of the potential for the establishment of renewable energy communities in their territory and the current impediments [31].
4) Establish a supportive environment to encourage and ease the growth of communities using renewable energy sources. This framework will, among other things, make sure that:
    - Renewable energy communities that supply energy, provide aggregation, or other commercial energy services are subject to the provisions relevant for such activities;
    - The relevant distribution system operator works with renewable energy communities to facilitate energy transfers within renewable energy communities;
    - The registration and licensing processes, cost-reflective network charges, and other pertinent fees, levies, and taxes are all subject to fair, proportionate, and transparent procedures, ensuring that renewable energy communities contribute appropriately, fairly, and evenly to the system's overall cost-sharing.
5) When creating assistance programs, take into account the unique characteristics of renewable energy communities to provide them a chance to compete for funding on an equal footing with

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[8] CEEP: Clean Energy for all European Package

other market players" [32, 31].

The second one is included in the Internal Electricity Market Directive (EU) 2019/944, and discloses that "Citizen Energy Community means a legal entity that:
(a) is founded on voluntary and open participation and is in fact governed by members or shareholders who are private individuals, local government entities, including municipalities, or small businesses.
(b) having as its major goal the provision of economic, social, or environmental community benefits to its members, shareholders, or the local communities in which it works rather than the generation of financial gains.
(c) may provide other energy services to its shareholders or members, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, and services related to energy efficiency" [33].

In addition, this directive's article 16 provides useful information for the development and recognition of CECs. "Members of the European Union must:

1) Provide an enabling regulatory framework for citizen energy communities ensuring that:
    - membership in a citizen energy community is free and available to anyone;
    - in a citizen energy community, shareholders or members have the freedom to quit at any time and will not forfeit their rights or duties as household or active consumers.
    - to promote power transfers within citizen energy communities, pertinent distribution system operators work together with them.
    - citizen energy communities are subject to non-discriminatory, fair, proportionate, and transparent processes and fees, including those for registration and licensing, as well as transparent, non-discriminatory, and cost-reflective network fees, ensuring that they contribute adequately and fairly to the system's overall cost-sharing.
    - have the right to own, build, buy, rent, or lease distribution networks;
    - are open to cross-border involvement participation in a citizen energy community is open and voluntary;
2) Ensure that citizen energy communities:
    - are capable of non-discriminatory access to all electrical markets, whether directly or via aggregation;
    - are given non-discriminatory and equitable treatment with respect to their actions, rights, and responsibilities as producers, suppliers, distributors, or market players who aggregate;
    - are financially liable for the inequalities they bring about in the electricity system; to that degree, they must take responsibility for balancing the system themselves or assign that obligation to others;
    - citizen energy communities are considered like active consumers when it comes to using self-generated power;
    - are allowed to organize the distribution of electricity generated by the community's production units inside the citizen energy community, provided that they comply with all other provisions of this Article and that the community's members maintain their duties as ultimate consumers [34].
3) Without affecting other laws and regulations that apply to distribution system operators, decide to provide citizen energy communities the power to administer distribution networks in their area of operation and implement the necessary processes. Member States must make sure that citizen energy communities are protected if such a right is given:
    - are permitted to reach an agreement with the appropriate transmission system operator or distribution system operator with whom their network is interconnected about the operation of such system;

- are subject to appropriate network fees at the places where their network connects to the distribution network outside the citizen energy community, and that these fees separately account for the power supplied to the distribution network and the electricity drawn from it;
- customers who are still a part of the distribution system should not be subject to discrimination or injury" [35].

These two EU directives provide for the first time "an enabling EU legal framework for collective citizen participation in the energy system, as they offer new opportunities for end customers to collaborate and associate for become protagonists of the energy transition" [26].
These European Commission's documents confirm "the prominent role of prosumers, and their collective forms will play in the future energy system, and it is useful to ensure transparency and authenticity to the members of the communities" [26].

Previously, national legislation influenced the fate of communities: certain countries fostered and promoted new shared energy projects, while others hampered their development due to regulatory and bureaucratic impediments. This diversity of models is explained by taking into consideration the heterogeneity of shared energy aggregations that currently exist in each European country, many of which have evolved distinct features over time. Member nations will have to make a variety of decisions when transposing the directives, for example the implementation of virtual or physical scheme, if the incentives will be explicit or implicit, the perimeter of self-consumption, the eligible technologies. On the other hand, some of the directives are purposefully left unanswered in order to allow them to be translated and successfully incorporated into all national legislation.
Accordingly, it is important to point out that the directives are applicable throughout the EU, but it is up to each member state to develop its own legislation considering the uniqueness of each State Member [36].

As we can see, the European legislator envisions two alternative variants of the energy community idea, the REC and the CEC. The nature of participation (open and voluntary), local roots, the purpose (economic, environmental, and social advantages rather than financial gains), and a portion of the activities that these subjects can take out are all shared features of the two models (production, accumulation, sharing and sale of the energy produced.
Instead, the differences between these two distinct energy community configurations are summarized in the following table:

Table 1.2 - Main differences between Citizen Energy Communities (CEC) and Renewable Energy Communities (REC)

Feature	**CEC**	**CER**
Primary energy source	Any	Renewable
Type of energy produced	Electric	Electric and thermal
Community participation	Individuals, institutions and local authorities, companies (no limits on size and main activity)	Individuals, institutions and local authorities, small and medium-sized enterprises (whose participation cannot constitute the main economic and industrial activity)
Effective community control	Exercised by all members or partners, excluding medium-large enterprises.	Exercised by all members or associates
Community extension	No constraints	Proximity to production plants

DSO involvement in the community	Granted in accordance with national legislation	Not included
Sale of energy	Allowed within or outside the community	Allowed within the community
Grid Services	Flexibility, aggregation, EV charging	Flexibility, aggregation

1.2.3 Literature on Italian law

In Italy, the most important document concerning the energy transition is undoubtedly the “Piano Nazionale per L’Energia e il Clima” (PNIEC), in which the involvement of final consumers is a key issue. In fact, this document highlights that: "Italy is aware of the potential benefits inherent in the vast diffusion of renewables and energy efficiency, and intends to continue along this path, with an approach that puts the citizen increasingly at the centre, even in role of prosumer, and businesses" [37]. In particular, in the section relating to the general objectives it is specified that Italy intends to "put the citizen and businesses (in particular small and medium-sized ones) at the centre, so that they are protagonists and beneficiaries of the energy transformation and not just policy makers: this means promoting self-consumption and renewable energy communities" [37].

In this regard, 2020 was a pivotal year, given that collective self-consumption and energy communities finally entered the Italian energy system for the first time. In that year, in fact, the experimentation for the early transposition of the EU Directive 2018/2001 (specifically of Article 21 and 22) was started with the enactment of Law n. 8 of 28 February 2020. This law was published in the Official Gazette on 1 March 2020, and allows, with a series of constraints and limitations, the activation of collective self-consumption schemes and the establishment of Renewable Energy Communities (RECs). To make the law operational, in 2020, a legislative process was launched thanks to which it is now possible to implement initiatives of Renewable Energy Communities in Italy. This process began with article 42 bis of Decree-Law 162/19 (Milleproroghe decree, converted into Law 8/2020), which is then followed by the acts of the regulatory authority (ARERA, resolution 318/2020/R/eel) concerning the ‘Regulation of economic items relating to electricity shared by a group of renewable energy self-consumers who act collectively in buildings and condominiums or shared in a renewable energy community’, the decree of the Ministry of Economic Development (Ministerial Decree 16/09/2020), relating to “Identification of the incentive tariff for the remuneration of renewable source plants included in the experimental configurations of collective self-consumption and renewable energy communities, and finally the one of the GSE, relating to the ‘Technical rules for access to the shared electricity enhancement and incentive service’” [37, 38].
In particular, in the MiSE Decree of 16/09/2020 (published in the Official Gazette n.285 of 16 November 2020), article 1 identifies the incentive rate for the remuneration of renewable source plants included in the configurations for collective self-consumption by renewable sources and in renewable energy communities. “The electricity produced by each of the renewable source plants that are part of the configurations of collective self-consumption or of renewable energy communities and which shared is entitled, for a period of 20 years, to an incentive rate in the form of a premium rate equal to:
a) € 100/MWh in the event that the production plant is part of a collective self-consumption configuration;
b) 110 €/MWh if the plant is part of a renewable energy community” [39].

It is important to highlight that in Italy the electricity market price was about 40€/MWh in 2020. In 2021/2022 it is above 220€/MWh. The remuneration of 100€/MWh would be interesting in 2020. At the present time, the remuneration seems less attractive than when this remuneration scheme was conceived. In fact, in 2020 no one would predict the price escalation of gas and petrol, the Ukrainian war, the geopolitical instability, etc. If the situation persists, it would be advisable to update the REC remuneration.

The entire energy produced and fed into the grid remains in the availability of the configuration referent, with the right to transfer it to the GSE in the manner referred to in Article 13, paragraph 3, of Legislative Decree 387/2003, without prejudice to the obligation to transfer provided for electricity that is not self-consumed or not shared, underlying the share of power that accesses the Superbonus.

The European Commission has launched, after the start of the Covid-19 pandemic, the extraordinary recovery package (Next Generation EU), specifying that more than a third of the funding must be allocated to the objectives of the European Green Deal.

The elaboration of the Italian National Recovery and Resilience Plan (PNRR), which has been launched in 2022, has been included in this framework, in the wake of the decarbonisation trajectories identified by the PNIEC. And in this context, parallel to the legal definition of the new framework of European objectives for 2030, will be inserted the process of updating the scenarios, analyses, objectives, and measures of the PNIEC, to consider this greater European ambition.

Italy strongly believes in the different models of sharing energy, so it allocates a share of the PNRR to energy communities. The investment focuses on supporting energy communities and collective self-production structures and will allow to extend the experimentation already started with the early transposition of the EU 2018/2011 Directive to a more significant dimension and to focus on the areas where the greatest impact is expected, for example socio-territorial one. In particular, "this investment aims to guarantee the resources necessary to install approximately 2000 MW of new electricity generation capacity in a distributed configuration by renewable energy communities and self-consumers of renewable energy acting jointly. The realization of these interventions, assuming that they concern photovoltaic systems with an annual production of 1250 kWh per kW, would produce about 2500 GWh per year, will contribute to a reduction in greenhouse gas emissions estimated at about 1.5 million tons of CO2 per year. To achieve higher self-consumption rates, these configurations can also be combined with energy storage systems" [40].

Finally, the Italian decree-law 199/21, which has become effective the 15 December 2021, acknowledges in a definitive way the EU directives 2018/2001 and 2019/944, and defines the final methods and conditions for the activation of collective self-consumption from renewable sources and the creation of renewable energy communities.

For example, Article 5 of that decree-law indicates the general conditions of incentive tariff mechanism:

"1. The production of electricity from plants powered by renewable sources can access tariff incentive tools, with the following general characteristics:

a) the incentive is assigned through a rate paid by the Italian Energy Services Manager (GSE)[9] on the electricity produced by the plant, or on the portion of this production that is fed into the grid or self-consumed;

b) the period of entitlement to the incentive starts from the date of entry into operation of the plant and is equal to the conventional average useful life of the type of plant in which it falls;

c) the incentive is proportionate to the cost of the intervention to ensure fair remuneration, and is applicable to the construction of new plants, reactivation of disused plants, complete reconstructions, upgrades and renovations of existing plants, also taking into account the various costs specific and peculiar characteristics of the different applications and technologies;

d) the incentive can be diversified on the basis of the size and site of the plant to take account of the scale effect;

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9 GSE: Gestore dei Servizi Energetici

2. For large plants, with power exceeding a threshold equal to at least 1 MW, the incentive is attributed through competitive tendering procedures made with reference to power quotas.

3. For small plants, with power below the 1 MW threshold, the incentive is attributed, according to the following mechanisms:
a) for plants with environmental generation costs closest to market competitiveness, through a request to be made directly on the date of entry into, without prejudice to compliance with technical and protection requirements;
b) for innovative plants and for plants with higher generation costs, for the purpose of controlling expenditure, the incentive is attributed through tenders in which power quotas are made available and selection criteria are set on the technical and protection requirements environmental and territorial and cost efficiency.
4. For plants with a power equal to or less than 1 MW belonging to the energy community or collective self-consumption configurations, it is possible to access a direct incentive, alternative to that referred to in paragraphs 2 and 3, which rewards, through specific tariff, which can also be graduated on the basis of the power of the plants, the energy self-consumed instantly. The incentive is awarded directly, with a request to be made on the date of entry into operation" [41].

Moreover, Article 8 introduces the Incentives' regulation for energy sharing:
"The incentive mechanisms for renewable energy plants are updated inserted in configurations of collective or community self-consumption renewable energy with a power not exceeding 1 MW, on the basis of the following guiding criteria:
a) renewable energy plants can access the incentive which individually have a power not exceeding 1 MW and that they come into operation after the date of entry into force of this decree [20];
b) for active renewable energy self-consumers collectively and renewable energy communities the incentive is supplied only in reference to the share of energy shared by consumer systems and utilities connected under the same primary substation;
c) the incentive is paid in the form of an assigned incentive rate to the sole share of energy produced by the plant and shared within the configuration;
d) in the cases in which sharing is carried out using the public distribution network, it is a single adjustment is envisaged, consisting of the return of the members referred to in article 32, paragraph 3, letter a), included the share of shared energy, and by the incentive referred to herein item;
e) the application for access to the incentives is presented on the date of entry into operation and prior registration is not required a notices or registers" [42].

In addition, Article 15 defines the Use of the proceeds from CO2 auctions to cover the costs of incentives for renewable sources and energy efficiency:
"1) Starting from the year 2022, a share of the annual proceeds deriving from the auctioning of the CO2 emission quotas referred to in article 23 of the legislative decree 9 June 2020, n. 47, under the

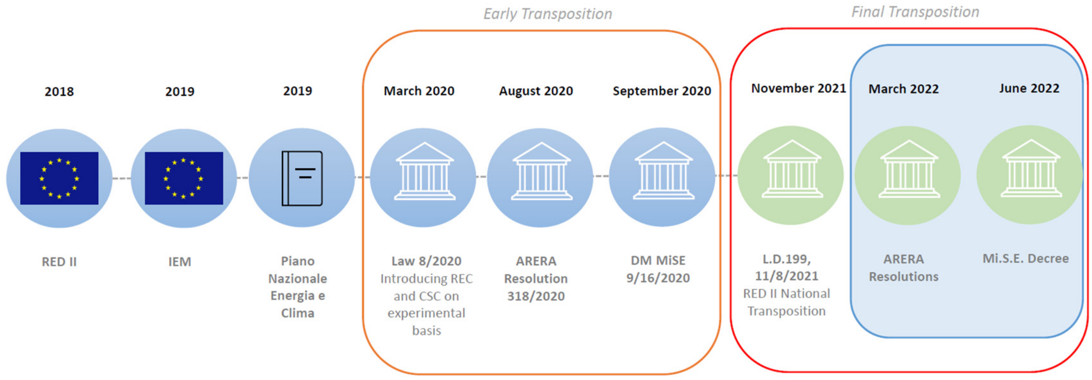

Fig. 1.8 - Summary of the transposition of RECs' laws in Italy

responsibility of the Ministry of Ecological Transition, is intended to cover the costs of incentives for renewable sources and energy efficiency through measures that are covered by energy tariffs" [43].

In the Fig. 1.8 it is shown the summary of the transposition of the law regarding the RECs in Italy.

Redefinition of roles in the Italian Electricity Market

Regarding the structure of the Italian electricity market, with the passage of Legislative Decree No. 79/1999, which implements European Directive 96/92/EC, "the activities of electrical energy production, import, export, purchase, and sale are now free to operate in competition while adhering to the legal obligations imposed on a public service. Dispatching and transmission operations, on the other hand, are reserved for the state, which is provided in concession to Terna under a national monopoly regime; lastly, distribution is expected to be carried out by some corporations under a concession system in form of local monopoly" [44].

As a result, it is critical to rebuild Italy's present legislative framework on self-consumption of power, which means "the consumption of electrical energy in the same location where it is produced, both immediately or through storage systems, regardless of the subjects who cover the roles of producer and final customer (even if they are different from one another), as long as they operate in the same site that is properly defined and confined, and regardless of the source that feeds the production plant" [20].

Self-consumption structures

In a situation where transmission and distribution operations are in fact allocated under concession, national legislation has outlined a number of scenarios in which private configurations might be created, allowing for self-consumption. From ARERA resolution 578/2013, self-consumption structures are divided into Closed Distribution Systems (CDS) and Simple Production and Consumption Systems (SPCS):

1. CDS**:** "Private power grids that distribute energy inside a geographically confined industrial, commercial, or shared service location but do not serve residential consumers in general. These systems, which are owned and managed by entities other than Terna and concessionary distribution companies, are distinguished by the fact that, for technical or safety reasons, the operations or production processes of the users of the systems in question are integrated, or by the fact that electricity is distributed primarily to system owners or operators or their related businesses. As a result, the CDSs are mostly related to systems that have a large number of end consumers and potentially producers" [45].

2. SPCS: "The collection of electrical systems connected directly or indirectly to the public network, within which the transport of electrical energy for delivery to the consumption units that make up the system is designed as an energy self-sufficiency activity rather than a transmission and/or distribution activity" [45]. SSPC are subdivided in:

Self-Generation Systems (SGS) "are systems in which a natural or legal person produces electricity and utilizes at least 70% of it on an annual basis through private connections" [45]. This category is further subdivided into two sub-categories: "historical cooperatives / consortia" with its own network, in which several producers and end consumers may exist; and "Other Self-Production Systems (OSPS)" with a single producer and end customer.

On-Site Exchange Systems (OES): "are certain types of on-site self-consumption that allow for the offset of power generated and supplied into the grid at one time with electricity removed and consumed at a subsequent time, effectively employing the electrical grid as a virtual store. Two types of users can now access the OES: end users who are part of an Other Simple Production and Consumption System, excluding cooperatives and historical consortia from the OSPS operators of one or more production plants from renewable sources or High Efficiency Cogeneration (CAR), whose point of injection into the grid coincides with the point of withdrawal from the same; and end customers (coinciding with Municipalities with less than 20,000 inhabitants) who manage one or more production plants from renewable sources, whose points of injection into the network may possibly not coincide with those of withdrawal (Exchange On Site Elsewhere OESE)" [46].

Efficient User Systems (EUS): "systems in which one or more plants for the production of electricity, powered by renewable sources or in high-efficiency cogeneration, managed by the same producer, possibly different from the final customer, are directly connected , through a private connection without the obligation of third party connection, to the consumption unit of a single final customer (natural or legal person) and are made within an area, without solution of continuity, net of roads, railways, waterways and lakes, owned or fully available by the same customer and by these, in part, made available to the manufacturer or the owners of the related production plants" [45].

Other Existing Systems (ASE): systems existing before resolution 578/2013 and not comparable to the other categories listed above.

Incentives

It is necessary to define all the incentives and mechanisms that can be used to obtain the benefits. "With reference to the tariff conditions to be applied to REC configurations, it is established that the general system charges apply to the electricity drawn from the public network by end customers, including the shared one and that ARERA is required to identify the value of the tariff components connected to the cost of the raw energy material, which are not technically applicable to shared energy, as energy instantly self-consumed on the same portion of the network and, for this reason, comparable to physical self-consumption in site" [47, 20, 31].
This paragraph explains that the current laws define that the general system tariffs are applied to the RECs for the withdrawal of electricity (including the one shared virtually which obviously passes through the LV network). However, ARERA must identify the cost component of the energy that has to be deducted from RECs, since the cost tariffs are not applicable to the energy shared by the REC as it is self-consumed.

The incentives for RECs are paid both on energy fed into the network and on shared energy.
In particular, the energy shared is defined as: "the minimum, in each hourly period, between the electricity produced and fed into the grid by plants powered by renewable sources and the electricity taken from all the associated end customers" [48, 20].
Regarding the method of disbursement of the incentive, the legislation says that the incentives are paid out once the GSE has acquired the hourly measures of shared energy from the distributor.

"The economic contributions due to the group of self-consumers and REC are recognized for each production plant whose electricity is relevant for the configuration, for a duration of 20 years starting from the commercial effective date of the production plant" [49].

For each MWh of shared electricity, the GSE recognizes for a period of 20 years:

- A unit fee $CU_{\mathrm{Af,m}}$[10] (sum of the transmission tariff for low voltage users (TRASE), equal to 7.78€/MWh for the year 2022, and the higher value of the variable distribution component

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[10] $CU_{\mathrm{Af,m}}$: corrispettivo unitario di autoconsumo forfettario mensile, which means monthly flat-rate self-consumption fee

for users other low voltage uses (BTAU), equal to 0.59 €/MWh for the year 2022). In the case of groups of renewable energy self-consumers who act collectively, an additional contribution is envisaged due to the avoided grid losses (variable depending on the voltage level and the Hourly Zone Price) of the electricity. However, the latter element does not apply to RECs. Therefore, for the RECs the following formula is the only valid $CU_{Af,m} = T\text{RASE} + MAX(BTAU_m)$;

- A feed-in-premium rate (TP) equal to 100 €/MWh for groups of self-consumers and 110 €/MWh for RECs. At the end of the 20-year period, the unit fee may be subject to an extension on a tacitly renewable annual basis. This rate is not due to the shared electricity attributable to power share of photovoltaic systems that have access to the Superbonus 110% deduction; the share of obligation power P_o; photovoltaic systems for which access to state incentives are prohibited;
- It is also possible to request to the GSE, together with access to the shared electricity enhancement and incentive service, also the withdrawal service of the energy fed into the grid, i.e. the sale of the energy produced and fed into the grid by the plants to conditions of the mechanism called 'Ritiro Dedicato – RID': this procedure valorises every kWh at PMG[11] price, or alternatively valorises it through the free market in the case that the PZO[12] is greater than the PMG. In addition, in the case of 'Ritiro Dedicato' the withdrawal of the electricity fed into the grid by the GSE is activated for all production plants or production units whose electricity is relevant for the configuration [47].

Therefore, all the energy produced and not self-consumed will be fed into the grid, and this will benefit from the GSE mechanism 'Ritiro Dedicato' or from the sale to the market, which price will be the PZO, that as an indication it usually stood at around 40 €/MWh. Given the large price changes in the last two years, it is possible to approximate the PZO to the PUN and use this in the calculations.

In addition to the three incentives explained above, if the photovoltaic systems belonging to a group of self-consumers or a renewable energy community are connected to a consumer user, for example to a house or an office, self-consumption of the electricity produced on site happens.
Self-consumption of the electricity produced by photovoltaic system allows users to reduce the outlays related to your energy bill: this mechanism goes under the heading "savings from direct self-consumption". In fact, the consumer connected to a photovoltaic system will continue to pay the fixed components (fixed portion and power portion) of the bill, but will see a reduction in the cost of the variable components (energy portion, network charges and related taxes such as excise and VAT), to a greater extent the amount of self-consumed energy.
On the other hand, the other participants of the group of self-consumers or of the REC, not directly connected to the photovoltaic system (but virtually), will continue to pay all the energy taken from the grid in their bills (therefore they will not receive a direct reduction in the bill), but will be able to use of the benefits related to the enhancement and incentive of shared energy explained above.

It is important to emphasize that, obviously, with the adoption of more conscious behaviours in electricity consumption, savings can also significantly increase. It is possible, in fact, to reduce the cost of the bill simply by shifting the electricity consumption during the day, i.e., those of the PV plant production.

In addition to the contributions that has been illustrated, the participants in the schemes have also the possibility of accessing a number of different system of tax deductions, which increase the obtainable

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[11] PMG: prezzo minimo garantito, which means guaranteed minimum price. Every year ARERA establishes this proce of all the renewable technologies.

[12] PZO: prezzo zonale orario, hourly zonal price that is established by the electricity market

benefits. It is therefore important to evaluate the different system tax deduction's possibilities. The main ones are:

- '50% deductions': this incentive provides the tax deduction of 50% on ordinary and extraordinary maintenance works, on condominiums or single buildings, up to a maximum limit of 96000€. Energy requalification (for example the installation of photovoltaic systems), recovery or restoration of facades and the recovery of the building stock are the works to which the incentive can be applied. This mechanism was confirmed by the 2021 Budget Law;
- 'Superbonus 110': in order to apply this incentive, it is necessary to carry out at least one of the "driving" interventions; after which, the beneficiary can decide to install the photovoltaic system. All of these interventions must lead to an improvement of at least two energy classes of the building or real estate unit. This incentive mechanism was introduced by the DL "Relaunch" May 19, 2020, n.34, with the aim of making homes more efficient and safer [50];
- 'Scambio sul posto': it is a mechanism that allows to valorise all the energy injected by the user into the electricity grid, in the case of the energy produced by photovoltaic system is greater than the needs, and therefore not immediately self-consumed. The energy injected is accounted by meters and the GSE determines a cash credit, the so-called 'Contributo di scambio sul posto', which is composed by a remuneration for the energy exchanged, which is valued through a "contribution on exchange account" (about 6-7c€/kWh), and the remaining part of energy neither self-consumed nor exchanged, which is valued by GSE at market price (PZO, hourly zonal price). This mechanism is an alternative to that of 'Ritiro Dedicato'.

It is important to underline the fact that, by the end of 2022, the mechanism 'Scambio sul posto' will no longer be an option accessible to new renewable plants, and by the end of 2024 the renewable plants in operation will lose this mechanism: in fact, the incentives dedicated to renewable energy communities explained above will definitively replace it. For this reason, in the treatment of my thesis I only consider the 'Ritiro dedicato'. Moreover, the 'feed-in-premium' incentive (TP) was also introduced with the aim of replacing the mechanism of 'Scambio sul posto' and, as indicated in the Decree, "taking into account the overall balance of the charges in the bill and the need not to increase trend costs compared to those of the existing mechanisms" [39, 31].

Compatibility of the different systems of tax deductions

Referring to the construction of a photovoltaic system, the 'Superbonus 110' and the '50% deductions' are alternative on the same kW, i.e., up to 20 kW of power can be incentivized with the Superbonus, from 20 kW onwards one can instead access the deduction of 50%, but clearly the two forms of incentives on the same kW cannot be combined.
Also 'Superbonus 110' and 'Scambio sul posto' cannot be combined (as reported in the 'Decreto Legislativo Rilancio', art.119, comma7), because the Superbonus has a constraint, which is the fact that it does not provide for the transfer to GSE of the electricity fed into the network.
'Scambio sul posto' cannot even be combined with collective self-consumption, because these two forms are alternatives: when the configuration of collective self-consumption is requested, it is not possible in the same way to access the exchange incentives on the same plant on site.
However, collective self-consumption and REC can be combined with the '50% deduction': it is then possible to access the 50% deduction of expenses for the construction of the photovoltaic system and at the same time, be configured as collective self-consumption or REC.
Collective self-consumption and REC can also be combined with the 'Superbonus 110', but only partially, in the sense that if this mechanism is accessed for tax deductions, the "feed-in-premium" incentive can no longer be considered valid.

Therefore, depending on the cases, it is necessary to consider all the elements and then chose the best group of compatibles incentives to find the most profitable situation.

In this thesis, for the whole series of reasons highlighted, the tax deduction at 50% is used, which is compatible with all the other mechanisms, especially with that of the 'Ritiro Dedicato'.
In fact, as mentioned on the 'GSE – Guida all'autoconsumo fotovoltaico', in chapter 2.4 'Tax deductions', it is said that: "According to paragraph 16-bis, article 119 of the law decree of 19 May 2020, n.34 ('Decreto Rilancio'), converted, with modification, by the law of 17 July 2020 n.77, for renewable source plants, managed by subjects who adhere to groups of self-consumers acting collectively or to renewable energy communities, the deduction provided for by the article 16-bis, paragraph 1, letter h), of the TUIR, currently equal to 50% of the expenses incurred, is applied up to the threshold of 200kW, up to a total amount of the same not exceeding 96000€, in 10 equal annual instalments amount" [51].

Furthermore, it is established that, according to what is reported in Resolution no. 18/E of 12 March 2021 of the Revenue Agency: "the deduction in question is currently applied to the extent of 50% to the expenses incurred for interventions relating to the construction, on individual real estate units and common parts, of works aimed at achieving energy savings with particular regard to the installation of systems based on the use of renewable energy sources; this deduction can be used, therefore, also with reference to the expenses incurred for the plants managed by subjects that adhere to the configurations referred to in the aforementioned article 42-bis of Decree Law 162 of 2019, regardless of the legal nature of the same, expected the provisions referred to in paragraph 16-bis of article 119 of the Relaunch decree; the deduction is in any case subject to the condition that the system is installed to meet the energy needs of the components of the configuration itself, whose activity does not constitute the conduct of usual commercial activity" [52].

1.3 EU case studies on RES energy communities

1.3.1 REC examples in Europe

As for the European situation, the countries located in the North and in the centre of the EU are the largest holders of renewable energy communities. The main countries are Denmark, Germany, the Netherlands, Belgium, the United Kingdom and Sweden. As for the countries located in the South (those bordering the Mediterranean Sea), the amount of energy communities is decidedly less in comparison, even if in recent years there seems to have been a growing trend.

In the Fig. 1.9 it is shown the ranking of European countries with the highest number of active REC and the related number of them.

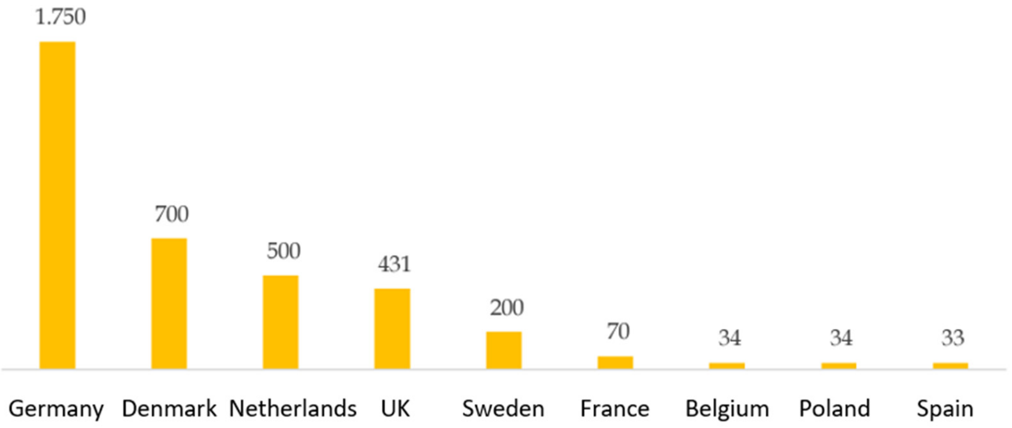


Fig. 1.9 – "Number of active RECs in 9 European countries" [Caramizaru, A. and Uihlein, A., Energy communities: an overview of energy and social innovation] [53]

The technologies most used within the major energy communities in Europe are the wind and the solar, which is combined with the former through the use of photovoltaic panels distributed and located mostly over the roofs of domestic and industrial users, and much more rarely located in large solar parks. A third type of photovoltaic technology concerns small hydroelectric power plants.

The following table lists some peculiar renewable energy communities in Europe:

Table 1.3 - Example of famous RECs in EU

REC name	**Technology used and rated power**	**Location and scale**	**Legal Structure**	**Nationality and foundation year**
Courant d'Air	Two PV plants and three wind turbines (7.04 MW total)	Rural, sub-regional scale	Cooperative	Belgium, 2009
Middlegrunden Wind Farm	Twenty wind turbine (40 MW total)	Urban, large-scale	50% Public Company and 50% Cooperative	Denmark, 2001

Hvide Sande Wind Farm	Three wind turbine (9MW total)	Rural, small-scale	80% Foundation and 20% Cooperative	Denmark, 2012
Bioenergy Village Jühnde	Woody biomass power plant (550kW) and biogas co-generator (700kW)	Rural, small scale	Cooperative	Germany, 2005
Wiltshire Wildlife Community Energy	Two solar parks and three PV plants (10.1 MW)	Rural, regional scale	Cooperative	United Kingdom, 2012
Brixton Energy	Three PV plant on domestic roofs (132kW)	Urban, small-scale	Cooperative	United Kingdom, 2012

Courant d'Air

"Courant d'Air was founded in 2009 in an attempt to give citizens the opportunity to participate in the wind energy plant at Waismes (Belgium). Three partners are involved in this wind energy plant, which currently comprises five turbines. Each partner is an independent owner of its wind turbines and thus directly involved in the sale of the electricity produced. This energy community is open to everyone and currently counts some 1750 members. By share subscription (€250), these members were able to bring in a capital of just over €3.5 million [53]. The cooperative pursues projects in the field of renewable energy and energy efficiency measures. Moreover, Courant d'Air enjoys the juridical and fiscal statute of an enterprise "with social objective"; this means that members seek only limited personal profit, and the company pursues specific social objectives set out in the statutes. Beyond the distribution of a moderate dividend, Courant d'Air seeks to initiate and support social, environmental, and sustainable projects for the benefit of citizens and the common good. This community has an electricity production of around 30000 MWh/year" [54].

Middelgrunden off-shore Wind Farm

"The Middelgrunden wind farm is built in 2000 with a rated power capacity of 40 MW. It consists of 20 wind turbines at 2 MW each. The wind farm is situated just 2 km outside the Copenhagen harbor on shallow water (4 - 5 meter depth). The use of the area is restricted due to its former use as a dump site for harbor sludge. The site is close to an industrial area, and 10 wind turbines (half the project) are owned by the wind cooperative who has 8300 members. Annual production is approximately 44 GWh, covering approximately 4% of the energy needs of the city of Copenhagen. 50% of the Middelgrundens wind farm is owned by the local utility owned by the city of Copenhagen, and the remaining 50% is owned by Middelgundens cooperative members" [55].

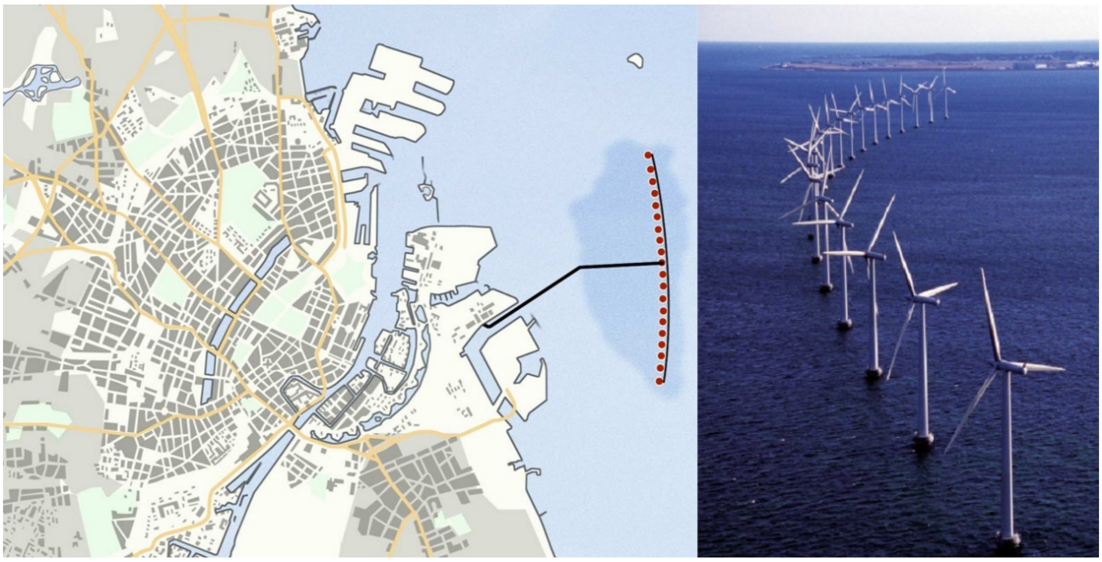


Fig. 1.10 - Middelgrunden off-shore Wind Farm, Copenhagen, Denmark [http://web.mit.edu/nature/archive/student_projects/2007/cherryj/urban-nature/copenhagen/index.html]

Hvide Sande Wind Farm

"In 2010, the Holmsland Tourism Association initiated a Trust Fund 'Hvide Sande Business Development' with the aim to install three wind turbines each of 3 MW on the site owned by the Hvide Sande harbor.

In December 2011, three 3 MW Vestas V-112 wind turbines were installed in the area near the port. The turbines went into operation in January 2012. They each produce 15 million kWh annually (with a capacity factor of 0.50, which is in line with offshore wind turbines where the investment per MW can be more than double).

The Hvide Sande wind power trust fund was founded by four parties: the local Federation of labor unions, the local Confederation of Danish Industry, the local utilities and the tourist association.

The Hvide Sande Trust Fund owns 80% of the wind energy project. As per the guidelines set by the Danish Renewable Energy Act the remaining 20% of a wind project must be offered to local individual residents living within a 4.5 km radius from the wind turbines. The local individuals that own 20% are organized in the North Harbour Windmill Cooperative with approximately 400 shareholders from Hvide Sande and the nearest region" [56].

Wiltshire Wildlife Community Energy

"Wiltshire Wildlife Community Energy was created in 2013. It owns two community solar farms, Chelworth and Braydon Manor, and three rooftop solar arrays on Wildshire Wildlife Trust buildings.

The community structure is a non-profit benefit society, and it is owned by our '1 member 1 vote' shareholders, governed by local volunteer directors and run for the benefit of Wiltshire communities. Surplus funds generated by solar arrays go into a community grant fund to support community-led initiatives that help reduce carbon emissions and create more wildlife in Wiltshire.

WWCE has three rooftop projects: Clattinger, Fisheries and Langford. All three projects were purchased from Wiltshire Wildlife Trust (WWT) in December 2013. The Clattinger Farm House installation is 4kW and is situated on a garage roof at WWT's Clattinger Farm Nature Reserve. The Fisheries Cottage installation also is 4kW and is on the roof of a cottage at Langford Lakes Nature Reserve. The Langford Visitor Centre installation is the largest at 10kW and is on the roof of the Lakeside Building at Langford Lakes Nature Reserve.The Braydon Manor Solar Array is a 9,1MW that project produces around 4,900 MWh of zero carbon electricity per year. The project has significant ecological benefits and acts as a biodiversity bank. Chelworth is WWCE's first community-owned solar installation: a 1MW ground mounted solar PV array at Chelworth Industrial Estate. Work began in the spring of 2014, with the arrays plugged in by June the same year. The average amount of electricity generated is equivalent to that needed to supply 450+ homes" [57].

Bioenergy Village Jühnde

"The system contains a 700kW CHP generator that runs on biogas to produce electricity that is supplied to the public grid. A 550kW woodchip boiler is used in the winter to supply heating which circulates around the local district network. During summertime, the excess heat of the CHP-plant is used for drying of woodchips or logwood for the heating boiler to use in wintertime. The original aim of the project was for the village to be self-sufficient in terms of energy consumption, and the plants now produce 70% of the villages heating demand and double its electricity demand. The bioenergy facility is owned locally and collectively by the people of Jühnde. Residents are able to buy shares in the co-operative company that owns the facility. At present, nearly 75% of Jühnde's inhabitants are members of this company.

Once they have bought shares and become a member, they are then able to purchase heating and electricity from the company– importantly, this means that the consumers of energy are also the producers of that energy.
The development of this REC has resulted in a 60% reduction in the villages CO2 emissions because of a switch away from oil heating, and members are now provided with a comfortable, reliable and relatively cheap source of local energy. Villagers also believe that the development has contributed to the community spirit of the village" [58].

Fig. 1.11 - Aerial shooting of the "Braydon Manor" community-owned solar park [https://www.wwce.org/]

Brixton Energy

“Brixton Energy is a not-for-profit cooperative initiative to produce renewable energy through solar PV panels in the South London area of Brixton. It is an example of a so-called REScoop (Renewable Energy Sources Cooperative). The program has allowed the creation of cooperatively owned renewable energy projects, called Brixton Energy Solar 1 (rated power 37kW), Solar 2 (rated power 45kW) and Solar 3 (rated power 50kW). For each of them, a cooperative limited society, owned by the (citizen) investors, is created” [59].

1.3.2 Examples of REC in Italy

As for the energy communities in Italy, they are mainly located in the northern regions, including Piedmont, Lombardy, Trentino Alto-Adige, Friuli Venezia-Giulia and Valle d'Aosta.

Most of the energy communities derive from energy cooperatives that have already existed for decades, originally equipped with hydroelectric plants only, and currently flanked by photovoltaic or biomass plants. Usually, this type of energy community is of medium-small size and is able to meet the electricity and thermal energy needs of municipalities located in mountain areas. The particular thing about these communities is that they own the ownership of the electricity distribution network.

There are also new projects for the construction of energy communities, however the number of REC in the Italian territory is low when compared with other European countries.

Among the main historical Italian communities there are:

Table 1.4 - Main historical Italian REC

REC name	Technology used and rated power	Location and scale	Legal Structure	General data
SECAB	Hydroelectric (10.6MW) cogeneration (2MW)	Rural, medium scale	Cooperative	Friuli Venezia Giulia, 1911
Energy Company Funes	Three hydroelectric plants (3.71 MW total)	Rural, small scale	Cooperative	Trentino Alto Adige, 1921
E_WerkPRAD cooperative	Photovoltaic (103kW), hydroelectric (4 MW) and biogas (380kW)	Rural, small scale	Cooperative	Trentino Alto Adige, 1926
Electric Cooperative Gignod	Hydroelectric (22.5 GWh/year)	Rural, medium scale	Cooperative	Valle d’Aosta, 1929

Energy cooperative of the municipalities of Carnia - SECAB

“Founded in 1911, it was the first Friulian company set up as a cooperative for the production and distribution of hydroelectric energy. SECAB carries out the distribution and distribution of electricity in the northern part of Friuli for all utilities, civil, commercial, artisanal and industrial.
The distribution service is carried out with its own medium and low voltage distribution network, which covers an area of over 170 square kilometers.
As of December 31, 2021, the total population served was 5221 users and 2552 cooperative members. The production of energy takes place through 5 hydroelectric plants, the total installed power of these hydroelectric plants is 10.8 MW, capable of generating approximately 44000 MWh of energy per year, with 75 kilometers of medium voltage lines, 120 kilometers of low voltage lines and 86 transformers” [60].

Energy company Funes

“Over the years, the Funes Energy Company, whose shareholders are the same inhabitants of the valley, has taken steps to increase the production of electricity from renewable sources in order to do without diesel to cover the peak of electricity consumption. The first modern 255 kW hydroelectric plant in Funes was the one of Santa Maddalena, in operation since 1966 and renovated in 2010, over the years that of San Pietro (active since 1987 from 482 kW and that of Meles from 2, 4 MW, inaugurated in 2004. Today, the valley produces more renewable and clean electricity than it consumes, the rest it sells to the national grid, with significant profits thanks to state incentives. The revenues of the electricity cooperative are reinvested in the territory both by using them in discounts on the electricity bill, and by designing and building new plants. The electricity grid, owned by the Cooperative, extends for 34 km at medium voltage and 79 km at low voltage, supplying 722 member users and 253 non-member users. The last project of the Cooperative was the construction of the 12 km district heating network, able to involve the whole valley and powered thanks to 2 biogas boilers located in San Pietro di Funes and Santa Maddalena di Funes, respectively 1100 and 700 kW. Furthermore, since 2009, thanks to a collaboration between the Cooperative and the local telecommunications manager Brennercom, the fiber optic network has spread. Overall, 98% of the energy supplied to local users comes from the Cooperative's mix of plants” [61, 62].

E-Werk PRAD Cooperative

“In 1926 the EWerk Prad cooperative (Azienda Elettrica Prato) was founded: this is made up of 1472 members (of which 80% of these are families and companies in the country) and is committed to supplying electricity and hot water based on of renewable sources to households and businesses in the Municipality of ‘Prato allo Stelvio’. In particular, by 2021 this cooperative manages 17 renewable energy plants (4000 kW of hydroelectricity, 103 kW of PV, 1600 kW of biomass). In the same year the electricity production was 17224 MWh (totally from renewable sources) while the heat production was 19873 MWh. Electricity is produced in 4 hydroelectric plants and with 4 cogenerators. An MV / LV network with a length of 120 km is used for distribution. Hot water is supplied to members and customers with a 28km long district heating network. It can be seen that the characteristic of this community is to satisfy the demand for energy by mixing different sources of renewable energy” [62, 63].

Gignod Electric Cooperative

"The Gignod cooperative is located in Saint Christophe, in the Aosta Valley. It was established in 1929 and uses hydroelectric power plants to produce electricity through five municipalities in the Aosta Valley (namely Gignod, San Christophe, Valperin, Alain and Douai). The energy produced by the cooperative is sold to the members. In this way the centrality of the mutualistic purpose is manifested in the qualification of the cooperative society and in the objectives set by the statute. In compliance with the regulations of the ARERA authority and the integrated text for historic electricity cooperatives (TICOOP), the C.E.G. sells to a trader the energy exceeding the consumption of the members and purchases, from the same, the energy necessary for the members if the production is not sufficient. The cooperative manages to guarantee its self-sufficiency calculated over a period of one year" [62].

In addition to these historic communities, to date there are more than 20 energy communities in the Italian territory that are consistent with the 8/2020 law, which are listed below:

Table 1.5 - Database of RECs consistent with law 8/2020 "https://www.rse-web.it/wp-content/uploads/2022/02/OrangeBook-22-Le-Comunita-Energetiche-in-Italia-DEF.pdf"

Name of the REC	Location	Stakeholder Promotors	Activity and Goals	Technology
Riccomassimo REC	Storo (TN)	CEDIS, Municipality of Storo	RSE pilot project, contribution of a historic electricity consortium to the creation of RECs in the area	Photovoltaic – 18kW
Napoli Est REC	Napoli	Legambiente Campania, Fondazione Famiglia di Maria, Fondazione con il Sud	Fight against energy poverty	Photovoltaic – 53kW
Borutta REC	Borutta (SS)	Municipality of Borutta	Self-consumption and reduction of energy expenditure	Photovoltaic
Area Vasta, Valle Grana e Valle Maira REC	22 municipality around Valle Maira e Valle Grana	ANCI (22 municipality participating)	studying and promoting energy efficiency in the Maira and Grana Valleys by increasing renewable sources	Under definition
Energy City Hall – Magliano Alpi REC	Magliano Alpi (CN)	Municipality of Magliano Alpi, Energy Center of Politecnico di Torino	Self-consumption and reduction of energy costs	Photovoltaic – 20+20 kW
Turano Lodigiano REC	Turano Lodigiano e Bertonico (LO)	Municipality of Turano Lodigiano and Bertonico - Sorgenia	Self-consumption and reduction of energy costs	Photovoltaic – 34+13 kW
Villanovaforru REC	Villanovaferru (SU)	Municipality	Self-consumption and reduction of energy costs	Photovoltaic – 53 kW

Ussaramanna REC	Ussaramanna (SU)	Municipality	Self-consumption and reduction of energy costs	Photovoltaic – 11+40+20 kW
Synoikeo Messina	Messina	Legambiente, Homers (Politecnico di Torino)	Development of energy communities in cohousing contexts	Under definition
CommOn Light	Ferla (SR)	Municipality	Participate in the energy transition project, favoring the in situ production and consumption of energy from renewable sources. Promote public-private collaboration	Photovoltaic – 20kW
Ventotene REC	Ventotene island (LT)	Lega Navale di Ventotene	Maximization of self-consumption through electrical storage	Photovoltaic – 58kW
Macerata Feltria REC	Macerata Feltria (PU)	ILM S.r.l., Gruppo Professione Energia, Energy People Alliance	Reduce costs of energy supply and related services; the goal is to group all municipal users within the REC	Photovoltaic
Università G. d'Annunzio REC	Chieti	University G. D'Annunzio of Chieti and Pescara	Self-production of thermal and electrical energy	Photovoltaic
Tito REC	Tito (PZ)	Friendly Power s.r.l, Municipality of Tito	Fight against energy poverty	Photovoltaic – 20kW
Angitola REC	Filadelfia (VV)	Municipality	Energy saving, self-production and energy self-sufficiency of the member citizens	Photovoltaic
La Magdaleine – Chamois REC	Chamois e La Magdaleine (AO)	Municipality	Self-consumption and reduction of energy costs	Photovoltaic
Villar Pellice REC	Villar Pellice (TO)	Consortio Pinerolo Energia	Self-consumption and reduction of energy costs	Photovoltaic
Gallese REC	Gallese (VT)	Municipality , BioDistretto della Via Amerina e delle Forre, Kyoto Club	Self-consumption and reduction of energy costs; goal of extending the CER to the entire BioDistrict of Via Amerina and the Forre	Under definition

Sferro REC	Paternò (CT)	Paternò Municipality, Consorzio di Bonifica	Self-consumption and reduction of energy costs	Under definition
Ragusa REC	Ragusa	Municipality	Self-consumption and reduction of energy costs	Under definition
Zona Industriale di Imola REC	Four factories in Imola	Bryo Spa (consortium of 23 Municipalities and some local cooperatives)	Rreduction of energy costs of the factories	Photovoltaic
Recocer Project	33 Municipality around Pordenone and Comunità collinare del Friuli	Energy Center of Politecnico di Torino	Self-consumption and reduction of energy costs	Photovoltaic
Fondo Saccà REC	Fonda Sacca (ME)	Fondazione di Comunità di Messina	Fight against energy poverty and social reintegration	Under definition
Parco delle Madonie – Blufi REC	Municipality of Blufi and of Parco delle Madonie	Blufi Municipality, Parco delle Madonie, Enel-x	Self-consumption and reduction of energy costs	Under definition
Biccari REC	Municipality of Biccari (FG)	Municipality	Self-consumption and reduction of energy costs: fight against energy poverty	Photovoltaic
LELAT REC	Rione Mangialupi (ME)	Messina Municipality, Lega Lotta Aids e Tossicodipendenza, Enel-x	Self-consumption and reduction of energy costs	Photovoltaic – 20kW

1.4 Drivers of RES communities

In the coming decades, the energy sector will undergo major changes worldwide. These changes will lead to challenges that the energy sector will be forced to face, which are summarized in the so-called "Energy Trilemma": this is an index that has been prepared annually since 2010 by the World Energy Council [64] in partnership with global consultancy Oliver Wyman. It consists of an annual measurement of national energy system performances across each of the three trilemma dimensions, which are the ones listed below:

- "Energy Security measures a nation's capacity to meet current and future energy demand reliably, withstand and bounce back swiftly from system shocks with minimal disruption to supplies. The dimension covers the effectiveness of management of domestic and external energy sources, as well as the reliability and resilience of energy infrastructure.
- Energy Equity assesses a country's ability to provide universal access to reliable, affordable, and abundant energy for domestic and commercial use. The dimension captures basic access to electricity and clean cooking fuels and technologies, access to prosperity-enabling levels of energy consumption, and affordability of electricity, gas, and fuel.
- Environmental Sustainability of energy systems represents the transition of a country's energy system towards mitigating and avoiding potential environmental harm and climate change impacts. The dimension focuses on productivity and efficiency of generation, transmission and distribution, decarbonisation, and air quality" [64].

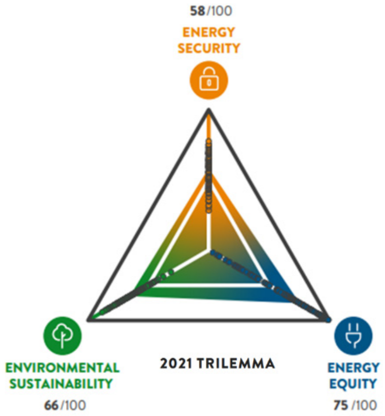


Fig. 1.12 – "Energy Trilemma scheme" [https://www.worldenergy.org/transition-toolkit/world-energy-trilemma-index]

In particular, the Energy Trilemma refers to maintaining the optimum equilibrium between the three dimensions already explained. "An energy system that has a managed balanced Trilemma between the three dimensions is a healthy energy system, and this can be described as equitable, secure, and environmentally sustainable. Maintaining this balance in context of rapid transition to decentralised, decarbonised and digital systems is challenging with the risk of passive trade-offs between equally critical priorities" [65].

Energy leaders need to manage the competing demands of the Energy Trilemma through careful national and international policies, given that it is possible that the aforementioned aspects conflict with each other.

As mentioned, "the energy sector is undergoing a deep and rapid transformation worldwide: for some years the trend towards electrification of final consumption has been underway, which can be analysed as an attempt to decarbonise some sectors, especially the most dependent ones. from fossil fuels. The most important push for changes in our society is represented by the so-called '3Ds Paradigm', which consists exactly of the set of three main actions to be taken to bring about significant transformations of the energy system: digitization, decarbonization and decentralization" [66].

Energy communities are in fact one of those key elements useful for the transformation of systems due to the wave of changes taking place. In fact, the RECs perfectly reflect the needs of environmental sustainability and above all of energy justice.

1.4.1 Digitalization

The development and application of digital technologies is the most important component in today's society. This element must be analysed from the point of view of the use of digital technologies as a support for changing the usual business model, in such a way as to help provide new opportunities and value creation. The key point of this element is that it allows existing models to go digital. The World Economic Forum expressed that "the most revolutionary technologies are Mobile, IoT and Cloud" [66].

As regards the application of this element to the world of energy, reference is made to the now well-known structure called "smart grid", which is based on a whole series of innovative elements, including microgeneration from renewable sources, the management of energy flows, prosumers and above all decentralized electricity system: to allow all this, the application of ICT technologies that support this model is necessary, which could then serve as a basis for future energy communities.

From centralized systems to smart grids

At this point it is good to investigate the main differences between the centralized and distributed electricity system.

The centralized system is also called 'traditional' and consists of three distinct elements:

- Electricity grid: the task of the grid is to put the generation and consumption nodes in communication, guaranteeing an instant balance between power drawn and power injected. The electrical network is made up of different voltage levels;
- Generation nodes: these are represented by the production plants, which inject electricity into the grid. Traditionally, these are plants fuelled by fossil sources, which guarantee a stable and programmable supply;
- Consumption nodes: represented by end customers, who can only draw electricity from the grid.

Fig. 1.13 – "Diagram of the traditional electrical system" [https://www.edsoforsmartgrids.eu/home/why-smart-grids/]

In this configuration the power flows are unidirectional, which start from the generation nodes and arrive at the consumption ones, as it can be seen from the Fig. 1.13. The only two sources of system uncertainty concern on the one hand component failures, while on the other consumer behaviour which varies over time, while at the spatial level the system is well defined.

This type of system does not adapt effectively to renewable energy sources, whose temporal intermittence introduces a greater degree of uncertainty at the level of the production nodes, and which may also be close to the consumption nodes, limiting the effectiveness of the centralized control. In summary, this type of configuration is equipped with large power stations connected to the transmission grid, where consumption is located far from the generation point.

The Fig. 1.14 instead shows a typical configuration for a smart grid: it can be seen that the clear distinction between production and consumption nodes disappears. In fact, the consumer becomes a prosumer, i.e., a consumer but also a seller and producer at the same time. Furthermore, the electricity grid is intelligent, in the sense that it integrates the behaviour and actions of all users who are connected through digital technologies, for example allowing bidirectional power flows. Conventional plants, on the other hand, continue to behave like production nodes.

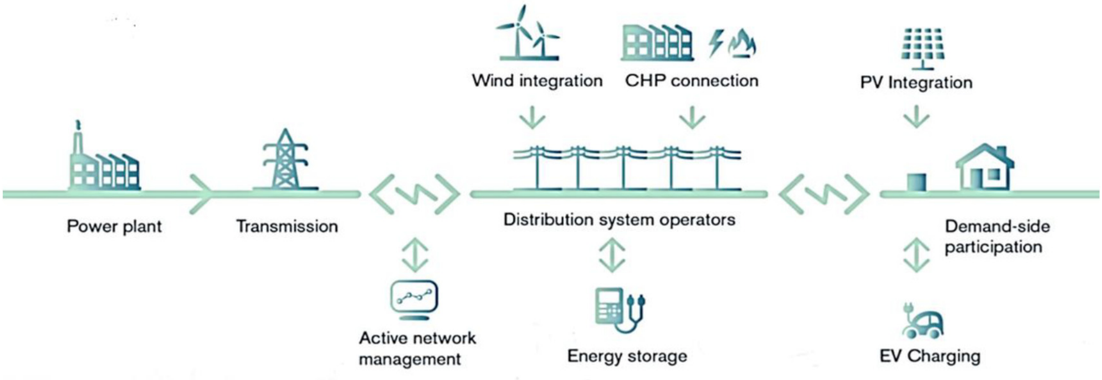


Fig. 1.14 – "Smart Electrical System Scheme" [https://www.edsoforsmartgrids.eu/home/why-smart-grids/]

Operating the Smart Grid system safely is complex since the balance between production and loads must be guaranteed at all times. Numerous technologies contribute to the production and management of electricity flows within a smart grid, such as photovoltaic or wind power, which are the most consolidated technologies, others that are still little used due to high upfront costs, such as storage batteries, while others are still in their infancy, such as Vehicle-to-Grid (V2G) and Demand Side Management (DSM). In any case, they all contribute to guaranteeing maximum flexibility to the system, without which the level of complexity and interconnection would be difficult to manage.

One of the main characteristics of smart grids is flexibility: since RES have been integrated into the system, and being intermittent by nature, the intelligent grid requires measures to ensure balancing, even in the event of a temporary unavailability of the supply side. Demand Management Techniques (DSMs) include a broad spectrum of measures designed to change both the amount of electricity consumed and the time profile of final consumption. "The main techniques of DSM are the reduction of the load (Peak shaving & Conservation), the increase of the load (Valley filling & Load growth), and the temporal shift of the load" [67].

At present, the use of these mechanisms is often connected to the price of electricity: a final domestic customer can decide, for example, to move a certain activity, such as a work cycle of an appliance, to an off-peak period, or to reduce their consumption during a peak period, when the price of energy is high. In some cases, the economic savings that can be obtained can motivate the temporary loss of comfort, since it can also be relevant especially if it is possible to maximize self-consumption from renewable sources. Within a smart grid it is reasonable to think that this technology will find greater application than the single prosumer, given that the number of inputs and withdrawals of all subjects connected to the intelligent network is much higher.

"The essential element to promote smart grids is smart metering, i.e., the provision by all end customers of smart meters” [53]. A smart meter is an electronic device that records electricity consumption automatically and communicates the information to the electricity supplier for monitoring and billing. At EU level, the development of these systems has been carried out through various legislative measures, the last of which with the aforementioned Directive 2019/944. In particular, Articles 19, 20 and 21 deal respectively with the provisions to be followed for the support of the new meters, the functionalities of smart metering systems and the rights of consumers [68].

“Italy has played a leading role in smart metering, anticipating the work of the European Commission and creating one of the most efficient systems at European level” [69], according to the recent report by the same Commission.
In particular, “the so-called 2G smart metering phase was launched in 2016, which provides for a strengthening of the provisions of the previous 1G phase: this new phase includes quarter-hour data transmitted to the seller within 24/30 hours and the creation of a separate chain, not present in 1G, which transmits the data directly to the end customer” [70].

Given the recent Italian legislative developments, the so-called Vehicle-to-Grid (V2G) technology is finally analysed, which could play an important role in the future thanks to the development of electric traction [71]. This is a technology capable of intelligently managing the interaction of a battery-equipped vehicle with the electricity grid, both full electric and plug-in hybrid.
There are two main ways. The first is the “V1G”, through which the vehicle's battery can only draw energy from the grid through the recharging point to which it is connected. Charging can take place at a variable power based on the needs of the electricity grid at that precise moment, obviously within the power limits of the column. In this way the vehicle offers to all intents and purposes some ancillary services, such as grid frequency regulation or load balancing.
The second is the so-called “V2G”, where in this case the battery can both withdraw and transfer energy to the grid. This means that the flow of power is bidirectional, from the charging station to the vehicle and vice versa, and therefore compared to the previous case, this solution offers even more flexibility to the electricity grid. For both cases, the most suitable recharge method is the slow one, in the evening or at night.

The tools provided by a smart grid environment could be quite useful in the management of the energy communities.

1.4.2 Decarbonization

According to various scenarios, energy communities will play a fundamental role in combating climate change at the European Union level. The energy transition process in the EU is essentially composed of decarbonisation, circular economy, and biodiversity protection, which are the pillars of the European Green Deal.
In this regard, it may be useful to recall the last years of European energy policy.

The energy sector plays a crucial role in the emissions of carbon dioxide, the main greenhouse gas that contributes to global warming. A climate policy to combat and mitigate climate change cannot ignore the energy sphere, given that the production of energy, both electrical and thermal, largely contributes to $CO2$ emissions on a global scale.

Thus, it was that the European Union, following the entry into force of the Kyoto Protocol, approved the 'Energy and Climate Package 2020'. The structure of this is composed of three main objectives concerning decarbonization, the penetration of renewables and energy efficiency. The member states, following the enactment of these objectives, have the task of translating them into a series of binding rules. In detail:

- "20% improvement in energy efficiency;
- 20% cut in greenhouse gas emissions compared to 1990;
- 20% of the energy requirement covered by renewable sources" [72].

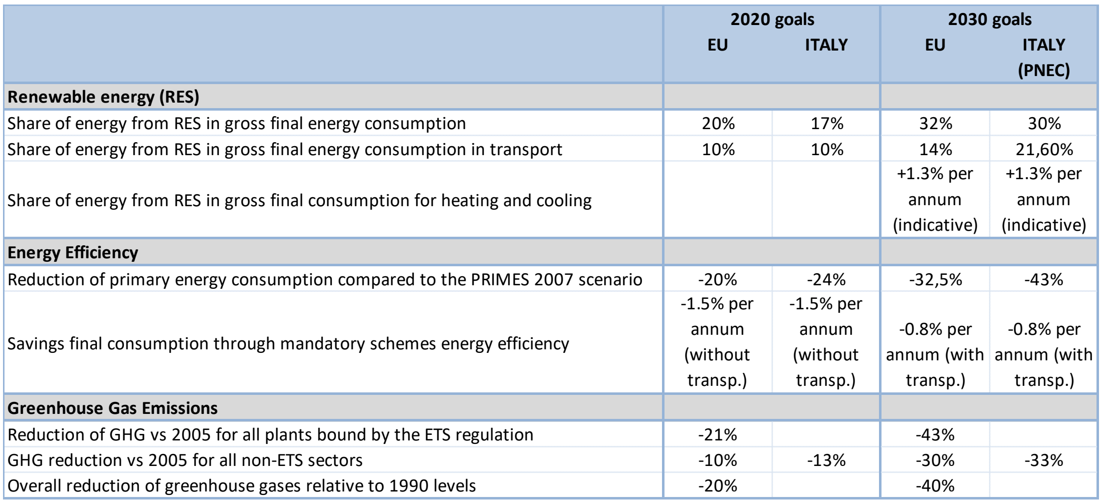
Following this, in 2014 the Council of the European Union adopted the '2030 Climate and Energy Framework', containing the updates of the previous package of laws, and valid for the period 2021-2030.

Again, on 12 December 2015 the Paris Agreement is signed, and the EU decides to further review its targets, and issues the aforementioned 'Clean Energy for all Europeans package': the main objective in this case too is that to foster the energy transition, which can be pursued in particular through a main factor, namely the decarbonisation of the energy sector, which can be achieved by guaranteeing security of supply and fighting energy poverty. The main focus of this package concerns RES: the same directive 2018/2001, referred to several times, aims to promote the use of renewable energy, setting as a binding target for the EU in 2030 the share of 32% of gross final consumption.

As regards the Italian situation, in December 2019 the final version of the Integrated National Plan for Energy and Climate (PNIEC) was published, as required by the 'Clean Energy for all Europeans package' The most important points of the plan concern renewable energies, energy efficiency and electricity infrastructure, and decarbonisation.

According to the PNIEC, 30% penetration of renewables must be reached in Italy by 2030 with the following renewable share mix: 55% in the electricity sector, 33% in the thermal sector and 22% in the transport sector.

In the Fig. 1.15 there is a scheme with the main objectives on energy and climate of the EU and Italy for 2020 and 2030.



	2020 goals		2030 goals	
	EU	**ITALY**	**EU**	**ITALY (PNEC)**
Renewable energy (RES)				
Share of energy from RES in gross final energy consumption	20%	17%	32%	30%
Share of energy from RES in gross final energy consumption in transport	10%	10%	14%	21,60%
Share of energy from RES in gross final consumption for heating and cooling			+1.3% per annum (indicative)	+1.3% per annum (indicative)
Energy Efficiency				
Reduction of primary energy consumption compared to the PRIMES 2007 scenario	-20%	-24%	-32,5%	-43%
Savings final consumption through mandatory schemes energy efficiency	-1.5% per annum (without transp.)	-1.5% per annum (without transp.)	-0.8% per annum (with transp.)	-0.8% per annum (with transp.)
Greenhouse Gas Emissions				
Reduction of GHG vs 2005 for all plants bound by the ETS regulation	-21%		-43%	
GHG reduction vs 2005 for all non-ETS sectors	-10%	-13%	-30%	-33%
Overall reduction of greenhouse gases relative to 1990 levels	-20%		-40%	

Fig. 1.15 - Main objectives of EU and Italy for 2020 and 2030 regarding energy and climate [Ministry of Economic Development (MiSE), "Integrated National Plan for Energy and Climate," 2019]

The electricity sector therefore needs a rapid and decisive acceleration, marking a strong discontinuity with what has happened in recent years. In 2020, the gross national production was equal to 280.5 TWh, which was covered for 57.6% by non-renewable thermoelectricity, and for the remaining 42.4% by renewable sources including hydroelectricity, wind, geothermal, photovoltaics and bioenergy [73]. The table below compares the PNIEC objectives with the actual renewable production by source in 2020 in Italy.

Table 1.6 - Comparison between production from RES to 2020 and PNIEC objectives to 2030 [Ministry of Economic Development (MiSE), "Integrated National Plan for Energy and Climate," 2019]

Renewable Source	Production in 2020 [TWh]	PNIEC target to 2030 [TWh]
Hydroelectric	47.55	49.3
Photovoltaic	24.94	73.1
Bioenergy	19.63	15.7
Wind Power	18.76	41.5
Geothermal	6.03	7.1
Total	116.91	186.7

It can be observed how photovoltaic and wind sources are far from the objectives of the PNIEC, so these are the two technologies on which we will focus massively in the coming years.
"Hydroelectricity should see a slight increase, due to new low-power installations and the repowering of old Alpine plants. Geothermal is also stable, while the bioenergy sector is expected to decline slightly, due to the end of incentives for bioliquids. The additional renewable production is required for photovoltaics and wind, which must more than triple and more than double their contribution respectively" [9].
As for wind power, the PNIEC plans to promote offshore installations, even on floating platforms where the Mediterranean seabed does not allow the construction of traditional foundations, and the revamping of older onshore plants with modern turbines. According to some estimates, the modernization activity should allow a large gain in producibility.
On the other hand, photovoltaics certainly require the greatest 'effort', since it is necessary to triple the production of energy.
Looking at the figure below, you can see the growth trend of photovoltaics and wind power in recent years in Italy. "The development of renewable sources, in the face of a boom in installations which occurred between 2008 and 2013, has suffered a sharp slowdown in recent years and the rates of increase in installed capacity have fallen to around 800 MW/year. These are extremely contained and insufficient values to achieve the PNIEC objectives (at least 40 GW of new wind and photovoltaic capacity by 2030) and even more so of the objectives that will be defined by the implementation of the EU Green Deal (+60 GW)" [74].

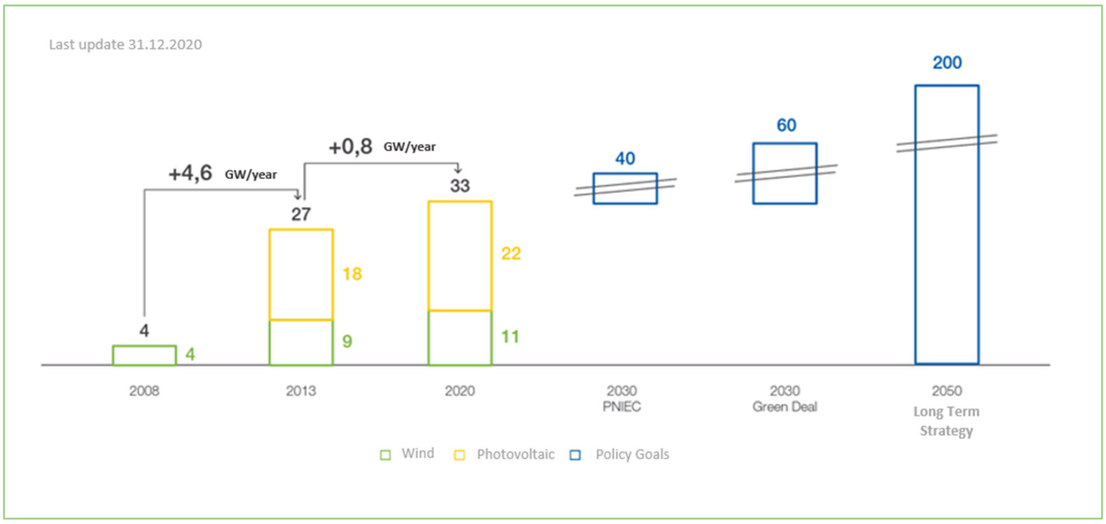


Fig. 1.16 - European energy objectives [https://www.arera.it/allegati/operatori/pds/21/06_EVOLUZIONE%20RINNOVABILE_2021.pdf]

Having said that, a possible help to this problem could come from self-consumption, taking into account that this method allows not to consume agricultural land and can benefit from more streamlined authorization procedures compared to large plants: such a radical and rapid growth in self-consumption could be achievable, as long as the perimeter of self-consumption itself is widened, above all overcoming the barriers of one-to-one. With this in mind, the contextualization of the EU directives 2018/2001 and 2019/944 to Italy is fitting and timely: the configurations of collective self-consumption and renewable energy communities can really relaunch photovoltaics, making it possible to achieve the objectives set by the PNIEC.

An important step change is also required from the thermal sector: the PNIEC recognizes the importance of 'unblocking' RES in the thermal sector, for example in terms of solar thermal in the home environment, while at the same time paying attention to the problem of pollution. air from fine dust in densely populated areas.

1.4.3 Decentralization

As already mentioned, energy communities have the ability to promote renewable sources and therefore to support the energy transition, and it is therefore essential to promote their growth.
One aspect that could favour the development of RECs is the trend towards decentralization of the energy system. However, there is a problem in this regard, namely the fact that the post energy transition society cannot simply be the low carbon version of the current one.

Historically, the electricity sector has always been composed of plants powered by fossil fuels, which have allowed the affirmation of the centralized model, based on large production plants and high or very high voltage transmission lines for the transport of electricity for even for hundreds / thousands of km. This model is inevitable if, for example, a fossil fuel such as coal is used, the transport of which is problematic and not very convenient from an economic point of view. In recent years this model has been called into question thanks to the advent of natural gas and renewable sources: it is possible to create smaller production plants but located near the consumption centres, while still connected to the grid but at a lower voltage level.

The new one is even more markedly decentralized thanks to the development of new digital communication and data sharing technologies, which includes micro-production plants from RES, connected directly to the consumption site through intelligent micro-grids that are managed directly by the end customer.
The process of energy transition, in addition to technological and infrastructural changes, involves profound social changes, attributable to the emerging role of the citizen, who transforms himself from a passive subject to an active subject, and to the recognition of the socio-economic links involved in the energy sector. In this sense, the energy transition can strengthen a model that can be defined as ‘decentralized’.

In fact, the technological evolution that has taken place in the last decade has changed people's habits. As regards the energy context, new technologies allow citizens to overcome their role as simple consumers of goods and services, which was instead rooted during the industrial phase, also becoming active producers, i.e., prosumers, that is the figure who can produce and sell energy, as well as consume it.
However, speaking of decentralization and distributed generation does not imply the existence of prosumers. It is possible, in fact, to distinguish two scenarios: the first concerns a generically

distributed system, which provides that the production plants are small and well distributed on the territory near the points of consumption, while the second is polycentric, which includes a structure in which a plurality of private entities owns such distributed plants and has the possibility to manage them independently. The latter model is certainly more suitable for describing the behaviour of prosumers, as it includes independence and self-governance.

It should be noted that in the literature there are many definitions and characterizations of prosumers: some authors also add the activity of energy storage in addition to that of production, sale and consumption, while for others the figure of the prosumer “is the participant in a smart grid, able to exchange the energy it produces with other users of the smart grid” [75].

Prosumers are now a reality in Europe and are widely recognized and supported. An example is the PV-Prosumers4Grid (PVP4Grid) project, promoted by 12 member countries, including Italy. An important part of the project involved the drafting of guidelines for policy makers and DSOs, who are called upon to guarantee an appropriate regulatory framework that is not hindering. For consumers, on the other hand, an online tool was created that made it possible to carry out an economic simulation of energy projects based on photovoltaic technology. Finally, specific in-depth analysis have been drawn up for each partner country, analysing obstacles, barriers, and best-cases [76].

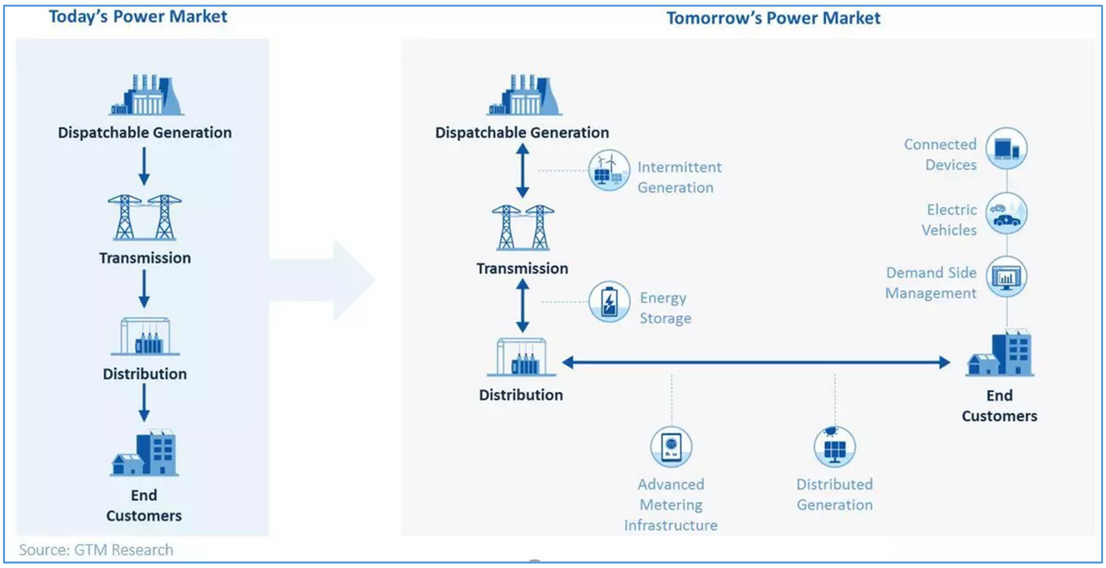
It can be said that there is a close analogy between the activities typically carried out by prosumers and those envisaged for REC. However, at this point it is necessary to underline the fact that the purpose of REC, as aggregations of citizens (be they simple producers, consumers, or prosumers) is also to bring more benefits to the electricity system and its members than the situation of prosumers. individuals operating within a distributed system.

It is possible to analyse the added value of energy communities from two points of view.

The first attributes to the establishment of communities a series of values including:

- practical benefits, mainly attributable to the reduction of investment and management costs, thanks to the use of smart digital systems, micro-economy of scale, optimization of times and methods of organizing self-consumption systems;
- reduction of the investment risk, thanks to the subdivision of the same among several participating subjects;
- the possibility of creating integrated systems and maximizing the use of local resources and self-consumption.

The second focuses instead on the so-called ‘intrinsic’ value of communities, and therefore on the fact that creating energy communities can contribute to building new social bonds, cohesion, and mutual trust on the part of the members. The value of community experiences, whose main core business is still an energy activity, transcends the economic-financial dimension and includes important human, social and psychological components, such as the creation of a local identity in which the members can identify themselves.



Source: GTM Research

Fig. 1.17 - Differences between today and future Power Market [https://blog.se.com/smart-grid/2018/04/04/decentralization-defined-and-what-it-means-for-you/]

The decentralization of the energy system therefore contributes significantly to the dissemination of community energy experiences. At this point, however, it is inevitable to address the issue of energy poverty: this is defined, at European level, as “the impossibility, by an individual or a family, of guaranteeing primary energy services, due to one or more of the following factors:

- low household income;
- high energy prices;
- inefficient energy performance of buildings concerning thermal insulation, heating systems and equipment” [77]

At the same time as the challenge of decarbonisation, the EU is therefore also facing that of energy inclusion, confirming the urgent relevance of the energy trilemma.

The EU response to the problem is again entrusted to the ‘Clean energy package for all Europeans’, and is divided into a framework of interventions, including the promotion of energy efficiency and active monitoring of the problem. One of the most effective structural measures is the bonus for the energy requalification of the existing building stock.

An example from Italy is the ‘Relaunch Decree’, developed to restart the Italian economy after the Covid19 pandemic, which led to the birth of the ‘Superbonus 110%’ and the ‘50% tax deduction’. Both mechanisms have already been explored in the previous chapter.

In a decentralized energy system, energy production plants typically have smaller sizes and are distributed throughout the territory. In this distributed generation configuration, it is not uncommon for a plant to be built near a built-up area, especially when it comes to a densely populated area, causing reactions from the local population. Over the years, the acronym ‘NIMBY’ (Not In My BackYard) has described the protest attitude of a local community towards the construction of a work of public interest in its territory. From this point of view, including citizens in decision-making processes would help promote the establishment of energy communities, thus overcoming some of the disputes that today hinder the spread of renewable sources in Italy.

2. Methodology

2.1 Introduction: main steps to set up a Renewable Energy Community

Any person can gain economically from renewable energy communities. Regardless of financial level, anybody may participate in a renewable energy community and help to lower the cost of the energy transition: in fact, this type of associations really permits all of its members to locally utilize and share the energy generated by their renewable energy plants. As a result, those who belong to a REC enjoy the evident benefit of paying less expenses, due to incentives and less bill components that result from locally usage of the energy supplied by the community which are advantageous to REC members.

The main steps to follow for the creation of an energy community are the following ones:

1. **The plant and user area's identification**

Any public or private organization can take the lead in developing a community powered by renewable energy. This implies that anybody may build an energy community, even common residents in the same area. The group of individuals who are linked at low voltage in the area around the same primary substation are actually identified under the existing legislation as possible members of an energy community.
After establishing this essential concept, it is time to outline the first action to be taken to fund an energy community, which is setting the location of the production facility or the community facilities. In addition, another procedure must also be finished in conjunction with this one: determining which community members can be included inside the plant's perimeter is crucial, because it is important to obtain the supply numbers (POD) and agreement to data processing from each potential member. This is a preliminary operation that also serves to appropriately query the distributor, so that it is feasible to determine which subjects are inside the community's boundary.

2. **Evaluation of the achievable potential and requirements of the installer and the system**

A good criterion for sizing the system and for the choice of the power size in kW to be installed is to choose a size that allows an annual production with the same order of magnitude as the sum of the annual electricity consumption of the users who are part of it.
To choose the right power in kW to be installed, and therefore the right size of the system, it is necessary to bear in mind that the energy produced per kW installed, also called producibility, varies according to the geographical position (i.e. in the south of Italy the irradiation is greater than north) and based on the positioning (i.e. orientation and inclination) of the plant. In Italian's latitudes, the inclination that maximizes production is between 30 and 35 degrees, while the best orientation is obtained by turning the modules towards the South.
Due to the existence of impediments near the system or those on the horizon (such as other buildings, vegetation, etc.) which can greatly affect producibility, it is thus required to minimize or restrict as much as possible the shading over the solar modules.

Generally, for PV plants built on the top of the building, we consider the data above:

- in Northern Italy the annual production is about 1000 and 1100 kWh/kW installed;

- in Central Italy the annual production is about 1110 and 1200 kWh/kW installed;
- in Southern Italy the annual production is around 1200 and 1300 kWh/kW installed.

In addition to this, however, it must be considered that the size of the photovoltaic system that can actually be installed depends on the usable area actually available, bearing in mind some considerations: for example, each kW of photovoltaic modules installed on a pitched roof occupies less area than each kW of photovoltaic modules installed on a flat roof, because this last solution needs a support structures of the modules and this causes some extra spacing between the rows of modules to avoid shading. The size of the system, initially identified on the basis of consumption and producibility, must therefore necessarily be compared and possibly corrected on the basis of the usable area available.

Once the size has been determined, starting from the load profile of one's energy user (consumption profile based on the time of day), it is possible to estimate the percentage of self-consumed energy or that will be shared.

In any case, it is possible and recommended, following the construction of the system, to change one's behaviour in order to use electricity when the system is in production, in order to increase self-consumption and/or sharing. However, this increase can also be achieved through the installation of appropriately sized and programmed energy storage systems to improve self-consumption and sharing of electricity.

In the Fig. 2.1 there is graph representing the typical load profile of a domestic user and the production profile of the associated photovoltaic system.

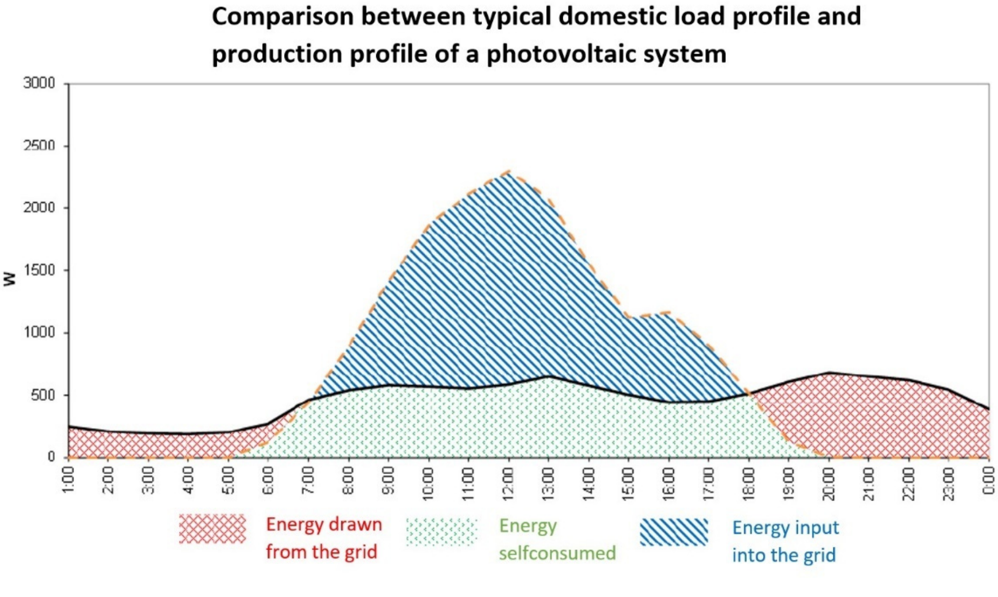


Fig. 2.1 - Comparison between domestic load profile and PV production profile

3. The constitution of the legal entity

The next phase entails creating the legal foundation upon which an energy community is built. At this point, it is important to keep in mind that the community cannot exist for the sole goal of making money; as a result, the legal entities that make up a REC are essentially unrecognized associations. In reality, this kind of partnership may be formed with a straightforward financially registered contract. Additionally, the organizational needs and associated administration expenses are quite straightforward and affordable. It is also feasible to establish a cooperative, obviously given that the group must not be organized for profit. The association's status must be approved after it has been established. This should enable everyone who is interested in joining and meets the requirements to be associated with the community in a non-discriminatory manner. Since open structures are what distinguishes energy communities, financial restrictions or high membership fees cannot serve as an entry barrier to them.

4. Acquisition of plant availability

The acquisition of plants that may be utilized to share energy is the next stage in the creation of an energy community. In fact, the community cannot impose access quotas from which to draw funding, and therefore the energy community has no financial resources to finance itself through direct contributions from members. This means that the REC will need to rely on other sources of funding. In this context, the financing strategies that call for a contract with the Municipality or other territorial bodies through subsidized state financing are the most common. However, there is also the option of using a private party agreement in addition to these strategies.

5. Construction of the plants, request for incentives and concessions

In order to build a working PV system and for sharing energy among a group of self-consumers or REC, the following procedures must be taken:

- requesting for permission from the relevant authority (i.e., the Municipality);
- requesting a connection with the Grid Operator;
- registering plant data on the TSO online portal;
- having the system installed and connected (by the installer firm and local network manager, respectively);

It is feasible to apply to the GSE to activate the shared energy enhancement and incentives services once the REC has been formed and at least one system has been built and linked. The incentives are merely related to the energy that is generated, shared, and used by the community's residents. The production must match the community members' energy usage within a specific time period in order to qualify for the incentive. If production outpaces consumption, the REC have the possibility to feed that energy into the grid and the GSE will compensate the community by paying a sum that is roughly three times the value of the energy sold wholesale, and then the community will be able to distribute these profits to its constituents based on what the legislation of each community specifies on how these profits will be distributed.

Regarding the tax deductions mechanism for RECs, they are also compatible with the already explained incentives. If the plant is owned by the community or by private organizations that support the community, then using these tools may be advantageous. They will gain from the tax deduction in the latter scenario.
It should be made clear that a third party to the REC may also be the owner of the facility. As long as they follow the REC, they may continue to profit from the tax deductions offered; consequently, they can choose to take advantage of the deduction also through a tax credit or reduction on the invoice by financing a lower amount. They will use their facility and whatever energy it produces that is not used by the owner for personal use to benefit the neighbourhood. By lowering their use and consequently their expenses, they will be able to self-consume the energy that their plant generates, giving them a twofold advantage.

6. Plant management and maintenance

The management and maintenance of a PV system requires minimal interventions, especially if compared to other energy production technologies. In order to keep the system functioning properly, it is advisable in any case, at least annually, to monitor the productions and compare them with the previous year to detect any anomalies; clean the panels and remove the causes of shading (foliage, pruning trees, etc.); carry out inspections to verify the good condition of the electrical parts (e.g. switches) and of the inverter (e.g. no lights on), as well as to verify the absence of damage to the PV modules (e.g. cracks, stains) and structures fixing (e.g. bolt layouts)

2.2 Implemented methodology

Renewable energy communities and collective self-consumption groups are presented as an economically more convenient solution than the incentive schemes currently used in Italy '(Conto Energia', 'Scambio sul posto'). In these thesis a simulation of a REC will be made to evaluate the real economic convenience based on different scenarios considered.
It is therefore essential to identify a tool that allows to evaluate the economic and energy convenience of energy communities: the objective of this thesis is therefore the identification of a method that allows to evaluate the feasibility of a REC project from the point of view of users as regards the technical-economic sphere, to demonstrate to all those subjects who are interested in creating an energy community, the economic benefits of the latter.

The methodology used for the research and implementation of the input data necessary for the evaluation of the technical-economic feasibility of a REC is then described in the following paragraphs.

First of all, it is necessary to get all the information related to the buildings and related plants in question. The main information needed in this regard concerns:

- number and type of users who are part of the scheme;
- type of utility supply contract (MV/LV);
- geographical position and size of the various buildings;
- type and characteristics of the systems that make up the consumption of users;

All this information is necessary to identify the behavioural habits of the typical user, in order to estimate a possible amount of energy shared within the scheme useful for choosing the size of the generation plant.

Secondly, the information concerning the electric consumption of the users is a key element in the analysis: in this regard, the optimal evaluation of user consumption can be carried out by having the load and production hourly profiles obtainable from the user's meters. This opportunity is offered through two methods: the first one is requesting the relevant data to the electricity supplier or by consulting the website of the network operator and checking if the data is available for download; the second one is by connecting a measurement device called 'user device' to the communication interface of the new generation meters. As an alternative to these two methods, consumption can be estimated by analysing the electricity bills of households.
Moreover, the next key element to identify is the size of the photovoltaic plant that is going to be installed: after obtaining the annual consumption data of the utilities taken into consideration, it is possible to size the photovoltaic system. The general rule to be respected is that the energy produced must be of the same order of magnitude as that consumed by all users annually.
Through a simulator (e.g., PVGIS[13]), it is possible to enter data relating to the geographical position, orientation, and inclination of the modules, and this allows to identify the annual irradiation on a surface and consequently it is easy to find it on the photovoltaic modules.
To obtain the greatest possible production, the panels must be possibly facing South, and positioned in such a way as to receive the greatest amount of solar radiation possible, and this is possible by positioning the panels with an inclination of 30-35° with respect to the plane of the horizon (assuming to install the modules in Italy). It is also important to avoid shading, which cause a decrease in the production.

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[13] PVGIS: Photovoltaic Geographical Information System, it is a tool that provides information about solar radiation and photovoltaic (PV) system performance for any location in Europe.

Nowadays there are different types of panels on the market. The following table shows the main characteristics.

Table 2.1 - Information about the most common PV technologies in the market – "Impianti di produzione dell'energia elettrica. Criteri di scelta e dimensionamento. Fabio Bignucolo, Roberto Caldon"

Technology	Average rated Power [Wp]	Height [cm]	Length [cm]	Thickness [cm]	Surface [m^2/kWp)	Average Efficiency [%]
Monocrystalline	300-400	130-140	90-100	4-5	5-6	Up to 22%
Polycrystalline	250-300	160-170	90-100	4-5	6-8	15-18%
Thin-Film	100-150	120	60	0.6-0.7	11-13	10-14%

For the simulations, it is assumed to use monocrystalline silicon panels. Once the type of panel has been identified, it is possible to identify from its technical datasheet the efficiency value, i.e., how much each panel produces based on the irradiation value considered. In addition, the other components of the photovoltaic system must be taken into account, and it is necessary to consider the losses attributable to the various electrical devices of the system. To obtain the final value of efficiency of the system, therefore, it is necessary to consider the system losses. The following ones are the values assumed in the scenarios that will be analysed:

- losses due to non-optimal tilt;
- loss of the inverter;
- losses due to temperature deviation;
- reflection losses;
- loss due to battery charging and discharging;
- loss in direct current;
- loss due to dirt accumulated on the modules;

In this case the total losses are assumed to be equal to 31%.

After identifying the production value of each panel net of system losses, knowing the size of each module from the datasheet, it is possible to calculate the virtual surface (i.e. the square meters hypothetically necessary to cover the considered requirement) for the installation of the photovoltaic system and the number of panels to be used. Finally, the size of the system is calculated by multiplying the power of the panel by the number of panels identified to achieve a pre-set rated power value of the system or to cover the total consumption of the building.

In addition, it is useful to identify the most important economic parameters, which are going to be used in the techno-economic analysis to discover the benefits of each scenario.
The average values of CAPEX (capital expenditure) and OPEX (operating expenses) are reported in the Tab 2.2 based on the different types of PV technologies in the market.

Table 2.2 - Relevant economic data for the most common PV technologies in the market

Technology	CAPEX [€/kWp]	OPEX [€/year]
Monocrystalline	1200-1900	50-80
Polycrystalline	800-1500	40-60
Thin-Film	2700-3200	90-120

Considering the prices shown in the previous table and knowing that monocrystalline panels will be used, we assume a CAPEX equal to 1800 €/kWp and an OPEX equal to 60 €/year.
We must then consider the economic benefits, which are explained in the following chapters of the thesis.

2.2.1 Economic Analysis formulas

The various economic elements used for the economic quantification of the various scenarios that will be analysed are introduced here. In particular, the "Discounted Cash Flow" (DCF) technique is used, which allows to calculate a series of economic indicators, including the Net Present Value (NPV), the Internal Rate of Return (IRR) of the investment accomplished and the Percentage Cost Reduction (PCR). In formulas:

- Net Present Value:

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+d)^t}$$

  I_0: initial investment sustained;
  CF_t is the net cashflow of the t-th year; considered in the summation;
  d: discount rate of the investment;
  n :è is the useful life of the plant subject to the investment.

- Discounted Payback Period (DPP) is a mechanism which indicates the period of time required to reach the break-even point based on a net present value (NPV) of the cash flow. Discounted payback period is useful in that it helps determine the profitability of investments in a very specific way: if the discounted payback period is less than its useful life (estimated lifespan) or any predetermined time, the investment is viable. Comparing the DPP of different investments, ones with the relatively shorter DPPs are generally more enticing because they take less time to break-even.

  The formula for discounted payback period is: $DPP = \frac{-\ln\left(1-\frac{I_0 \cdot d}{CF_t}\right)}{\ln(1+d)}$

- CFt (cashflow in period t) refers to an income-based valuation approach that helps determine the fair value or security by discounting future expected cash flows

- Discount rate refers to the interest rate used in discounted cash flow (DCF) analysis to determine the present value of future cash flows.

- Discounted Payback period is a capital budgeting procedure used to determine the profitability of a project. A discounted payback period gives the number of years it takes to break even from undertaking the initial expenditure, by discounting future cash flows and recognizing the time value of money. The metric is used to evaluate the feasibility and profitability of a given project.

- Annualized ROI is a performance measure used to evaluate the efficiency or profitability of an investment or compare the efficiency of a number of different investments. ROI tries to directly measure the amount of return on a particular investment, relative to the investment's cost.

In order to apply the economic indicators just introduced to the case study, it is necessary to define the variables that appear in these parameters:
• The initial investment I_0 is the sum of the expenditure incurred for the PV system and the battery;
• The investment discount rate is d = 7%.
• The net cash flow CF_t is the difference between the total annual benefits and the total annual costs of the plant.

2.3 Tools used for the implementation

2.3.1 Definition of the Calculation Procedure

The first tool used to assess the energy-economic feasibility of a REC is a calculation procedure implemented in Excel, that first of all allows to analyse the system from a qualitative point of view, and then allows to carry out a sensitivity analysis that develops a range of values of the energy quantities (self-consumed energy, energy input and shared energy), instead of a specific data. In this way it is possible to perform an analysis of the results in a more complete and wide way, being able to consider a range of possible scenarios. The purpose of this procedure is to provide, by entering the data reported in the previous chapter (the one relating to the methodology), a preliminary assessment of the feasibility of a REC, which makes it possible to immediately understand the economic benefits to the customer who is approaching this type of system for the first time.

The data to be included in the model is mainly the hourly consumption of households for a specific year, and data relating to the photovoltaic system.
After entering these data, the procedure allows to obtain the quantities of self-consumed energy, shared energy and energy fed into the grid.

At this point the calculation procedure allows to calculate the total benefits of the system in each scenario, and in particular the benefit of each specific user, through a distribution coefficient, which is established in the community statute: this coefficient establishes the portion of the economic benefit destined for each individual user.
The output data that the model returns are of two types:
1. Energy: such as the production of the PV plant, self-consumed energy, shared energy, energy fed into the grid and excess energy sold to the grid;
2. Economic-financial: such as savings from direct self-consumption, revenues from electricity fed into the network, management and maintenance costs, incentives and the return of network charges (which include the MiSE incentive and the feed-in premium tariff on shared energy and the return of tariff components), and some financial indicators such as the payback time.

It is now important to show the parameters used in the calculation procedure and their definitions:

- Energy produced: total energy produced by the PV system in one year [$E_{produced\_PV}$];
- Energy consumed: total energy consumed by all users in one year [$E_{consumed,tot} = \sum_{n=1}^{3} E_{consumed,n}$];
- Energy consumed by User 1: energy consumed in one year by the user who owns the PV system [$E_{consumed,1}$];
- Energy self-consumed: share of energy produced by the PV system that only satisfies the consumption of the user who owns the PV system, in this case User 1. It is obtained as the hourly sum of a year between the minimum of [$E_{produced\_PV}$; $E_{consumed1}$]. The formula used is the following one:
$$E_{selfconsumed} = \sum_{h=1}^{8760} min[E_{produced_{PV},h}, E_{consumed,1,h}]$$
- Energy input: Part of energy produced by the PV plant that is not consumed by User 1, and therefore is fed into the grid [$E_{input} = \sum_{h=1}^{8760} \left[E_{produced,PV,h} - E_{selfconsumed,h}\right]$
- Energy withdrawn: total energy withdrawn by all users from the grid [E_{drawn}];

- Energy withdrawn by User 1: $E_{drawn,1} = \sum_{h=1}^{8760}[E_{consumed,1,h} - E_{selfconsumed,h}]$. For the other users this parameter is equal to the energy consumed
  $[E_{drawn,2} = E_{consumed,2} \quad E_{drawn,3} = E_{consumed,2}]$
- Energy shared: part of energy introduced by User 1 into th grid that goes to other users of the REC. It can be defined as $E_{shared} = \sum_{h=1}^{8760} \min\left[E_{input}, E_{drawn,2} + E_{drawn,3}\right]$
- Selfconsumed energy rate: $E_{selfconsumed,1} / E_{produced\_PV}$
- Shared energy rate: E_{shared} / E_{input}

2.3.2 Termolog

Termolog is one of the tools I have used to calculate some parameters needed for the REC, and in particular to simulate the base case scenario of the renewable energy community.
This is a BIM software that can be used for several uses, for example to calculate the energy efficiency of buildings, applying the mechanism such as ‘Ecobonus’, ‘Superbonus’ and ENEA practices, plant projects, ‘nZEB’ and energy diagnosis. It includes the UNI EN ISO 52016 dynamic hourly calculation. The automatic procedures make data collection, construction of the energy model, drafting of the energy certification, analysis of results and technical reports more efficient.

This software can be employed in two different ways, because it allows either to create the energy model importing the entire BIM model from IFC file or to create it from scratch using the convenient integrated BIM modeler. It can also be used to quickly model any type of electrical system and it will automatically propose energy improvement solutions.
Termolog is a modular energy calculation software too: it can calculate an APE and run the dynamic energy simulation to evaluate comfort and consumption hour by hour and generate evaluations on renewable energy systems.

This software was used first of all to calculate the PV production of the already existing PV system. Then it was used to simulate the energy community base case, and the results obtained from it were then compared with the results obtained from the calculation procedure created.

2.3.3 ROSE – Energy Community Platform

ROSE Energy Community Platform is an intelligent energy management software for the management and optimization of renewable resources. It offers AI-based capabilities for energy community design and management, energy monitoring, energy optimization, flexibility, and predictive maintenance. It can configure the share of redistribution of the incentive and estimate the economic performance of energy communities.
In this thesis it was used for the scenarios in which I added the storage capacity, because it was able to calculate the variation on the shared energy.

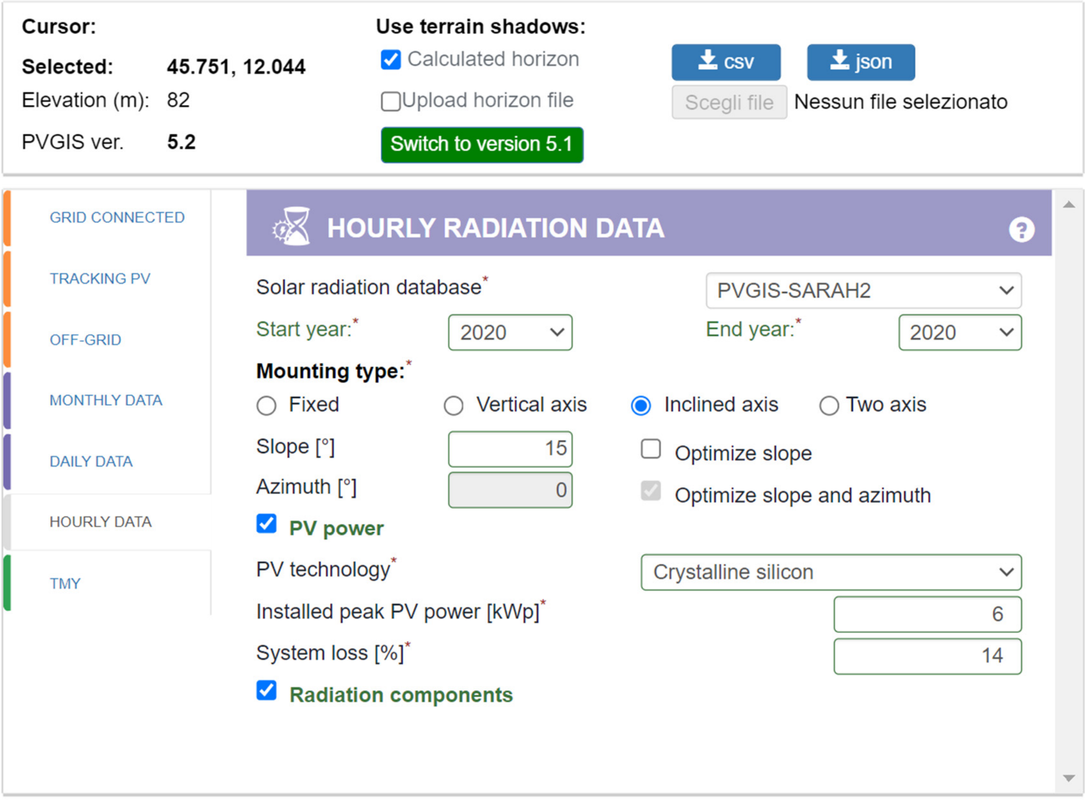
2.4 Photovoltaic design through PVGIS and Termolog

It is possible to evaluate the availability of incident primary energy on the photovoltaic surfaces and subsequently to estimate the unit production of the system (in the absence of systematic or occasional shading) querying a database, in this case the PVGIS portal, which is widely known as reliable tool on a financial level. This web database requires as input:

- "Type of solar radiation database to be used;
- Geographical coordinates of the installation site (the exact address of the site can also be entered);
- Rated power of the plant, and if it is not definitive, by entering the value '1 kWp' it is possible to directly calculate the unit productivity of the plant;
- The photovoltaic technology chosen, whereby through the typical coefficients dependent on this information, the thermal and reflection losses are estimated, to provide the estimate of unitary electrical productivity at the output;
- Arrangement of the photovoltaic panels, in particular as regards orientation and inclination. The database can automatically process the optimal exposure conditions for the indicated site.
- Estimate of plant losses. Thermal and reflection losses are already processed by the portal in relation to the environmental characterization of the site. In this field it is required to indicate an estimate of the other losses that occur downstream of the photovoltaic conversion such as losses due to shading, losses due to mismatching, losses due to the Joule effect, losses on the static converter, etc. A good design of the system, also aimed at containing systematic shading, can limit this parameter to below 10%. However, this value can vary considerably according to the design choices;
- Clinometric profile of the shadows on the horizon, if available and detected on site;
- Anchoring method of photovoltaic panels. During normal operation, in relation to the environmental conditions, the photovoltaic panels can work at very high temperatures (70-80°C). In integrated installations, where the panel is positioned adherent to the roof or even constitutes an integral part of it, the dissipation of heat is limited, so this aspect has a negative impact on the calculation of thermal losses;
- Type of output requested" [78].

In addition to the annual and monthly values, the portal allows for in-depth analysis of the availability of the source month by month and provides the daily irradiation trend for an average day of each month.
Through the PVGIS portal it is also possible to analyse the influence of the non-optimal positioning of the panels, for example due to the binding structural configuration of a roof.

The Fig. 2.2 shows a screenshot of the PVGIS tool interface, where it can be seen some of the input data required by the software.



Cursor:

Selected: **45.751, 12.044**

Elevation (m): 82

PVGIS ver. **5.2**

Use terrain shadows:

☑ Calculated horizon

☐ Upload horizon file

Nessun file selezionato

Solar radiation database*: PVGIS-SARAH2

Start year:* 2020

End year:* 2020

Mounting type:*

○ Fixed ○ Vertical axis ● Inclined axis ○ Two axis

Slope [°] 15

☐ Optimize slope

Azimuth [°] 0

☑ Optimize slope and azimuth

☑ **PV power**

PV technology* Crystalline silicon

Installed peak PV power [kWp]* 6

System loss [%]* 14

☑ **Radiation components**

Fig. 2.2 - PVGIS tool graphic interface

To sum up, in this thesis the technology considered for electricity generation is the photovoltaic one, and the design of the PV plant is obtained using the software Termolog by querying first the PVGIS tool of the JRC (Joint Research Center of the European Commission). From the PVGIS tool it is possible to obtain all the output data needed for the 8760 hours of a year, i.e., the system power; direct, diffuse and reflected irradiance on the inclined plane, the sun height, the air temperature, total wind speed. In the tab. below there are the output data needed obtained by the PVGIS tool.

Table 2.3 - Output data from PVGIS

Month	Average daily diffuse irradiance H_d [kWh/m^2]	Average daily direct irradiance H_{bh} [kWh/m^2]	Average daily total irradiance H_h on horizontal plane [kWh/m^2]	Coefficient R_b [-]	Coefficient R [-]	Average daily irradiation E on inclined oriented plane [kWh/m^2]	Monthly solar radiation E on inclined oriented plane [kWh/m^2]
Jan	0.58	0.56	1.14	2.37	1.65	1.88	58.2
Feb	0.86	1.39	2.25	1.86	1.52	3.42	95.6
Mar	1.22	2.25	3.47	1.45	1.28	4.45	138.0

Apr	1.81	2.39	4.19	1.16	1.07	4.50	135.1
May	2.47	3.03	5.50	0.99	0.98	5.38	166.7
Jun	2.69	3.56	6.25	0.92	0.94	5.88	176.5
Jul	2.47	3.81	6.28	0.95	0.96	6.02	186.5
Aug	2.39	2.86	5.25	1.08	1.03	5.39	167.0
Sep	1.75	2.06	3.81	1.32	1.16	4.40	131.9
Oct	1.11	1.28	2.39	1.71	1.36	3.25	100.7
Nov	0.61	0.69	1.31	2.22	1.63	2.13	63.8
Dec	0.50	0.69	1.19	2.57	1.90	2.27	70.3

Therefore, this data, together with the information about the PV panels form the datasheet, are inserted in the Termolog software, which is able to process the input and then give in output other information needed for example the hourly production curve of the plant as it can be seen from the Fig. 2.3 below, which represents the monthly produced electric energy [kWh] by the PV plant.

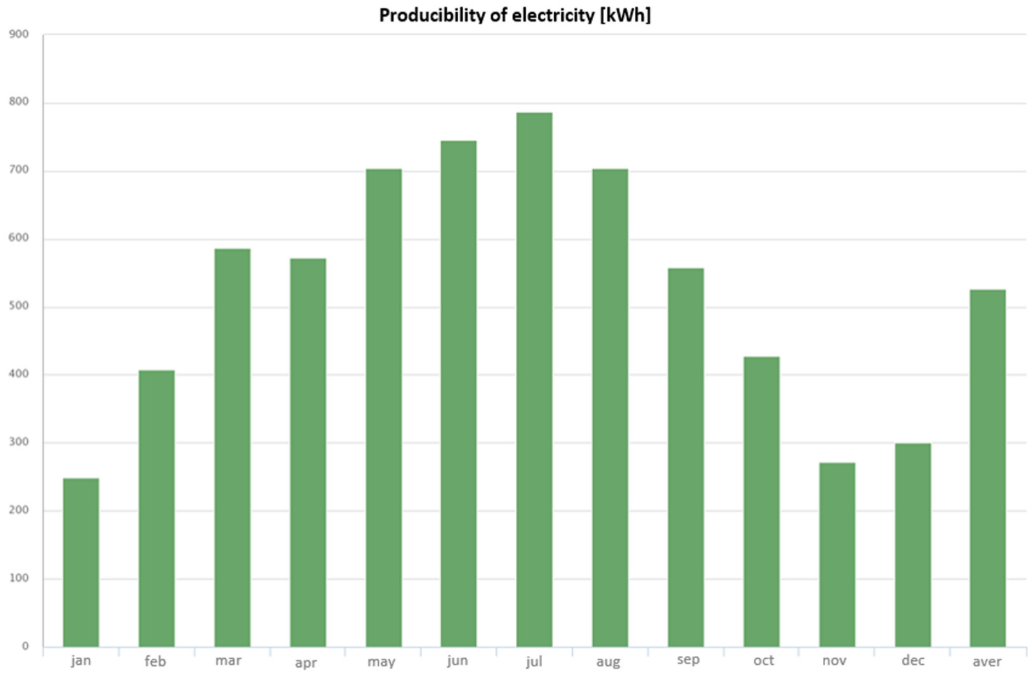
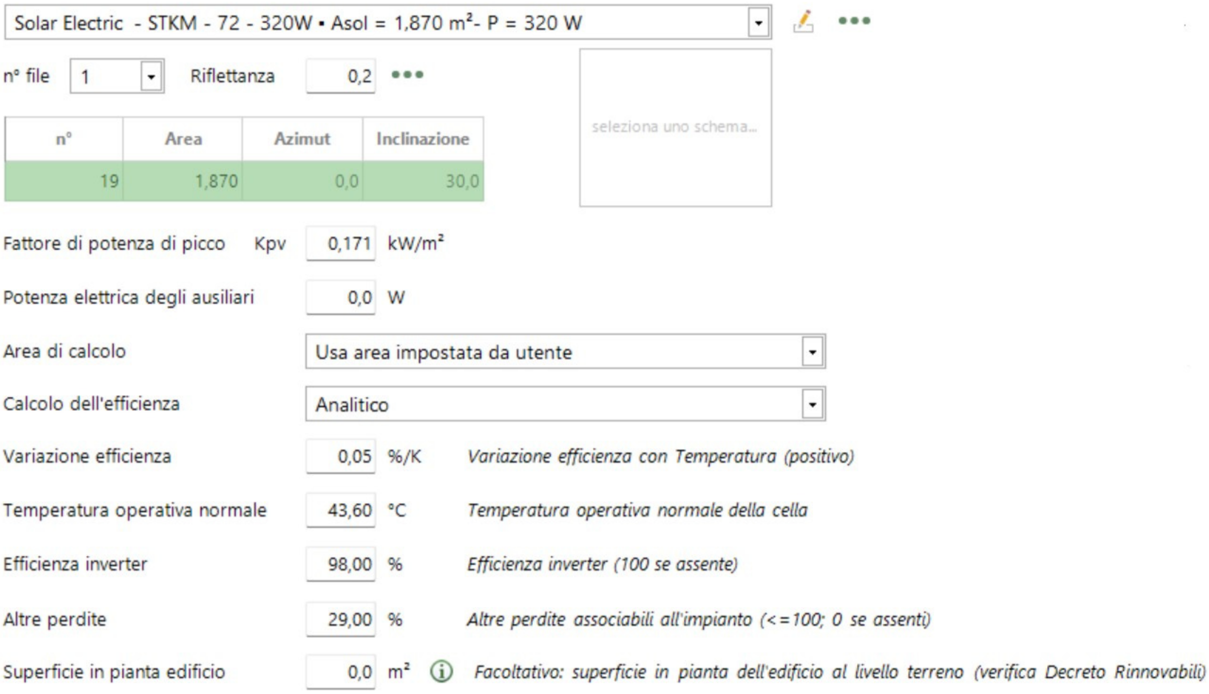


Fig. 2.3 – Monthly Electric Energy produced by PV plant from Termolog

Moreover, the Fig. 2.4 below represents the graphic interface of the Termolog tool, in which it is possible to insert the data related to the PV panels obtained from the datasheet.



Solar Electric - STKM - 72 - 320W • Asol = 1,870 m²- P = 320 W

n° file 1 Riflettanza 0,2

n°	Area	Azimut	Inclinazione
19	1,870	0,0	30,0

seleziona uno schema...

Fattore di potenza di picco Kpv 0,171 kW/m²

Potenza elettrica degli ausiliari 0,0 W

Area di calcolo: Usa area impostata da utente

Calcolo dell'efficienza: Analitico

Variazione efficienza 0,05 %/K *Variazione efficienza con Temperatura (positivo)*

Temperatura operativa normale 43,60 °C *Temperatura operativa normale della cella*

Efficienza inverter 98,00 % *Efficienza inverter (100 se assente)*

Altre perdite 29,00 % *Altre perdite associabili all'impianto (<=100; 0 se assenti)*

Superficie in pianta edificio 0,0 m² *Facoltativo: superficie in pianta dell'edificio al livello terreno (verifica Decreto Rinnovabili)*

Fig. 2.4 - Termolog graphic interface

In addition, in the Fig. 2.5 it is possible to observe the Single-line Diagram of the photovoltaic plant that is going to be used for the analysis of the different scenarios.

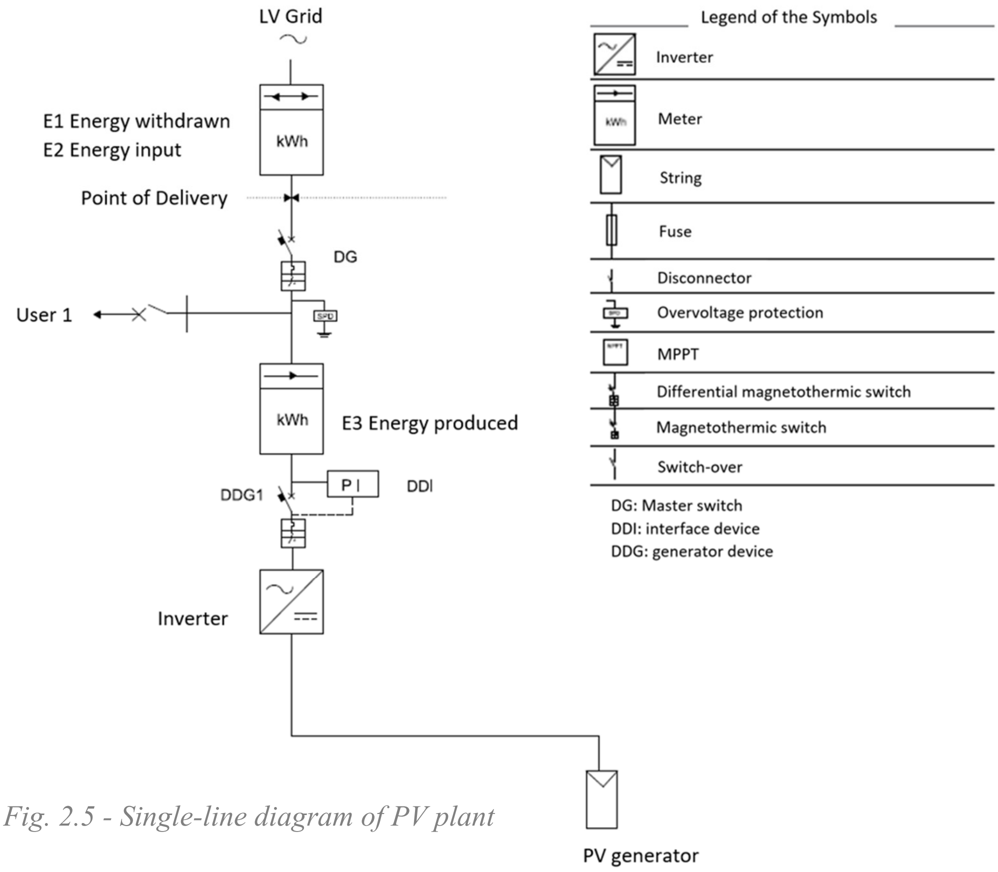


Fig. 2.5 - Single-line diagram of PV plant

In the Fig. below there is the datasheet of the PV panel datasheet of the PV panel.

MECHANICAL PARAMETERS

Cell (mm)	Mono 156x156
Weight (kg)	23 (approx)
Dimensions (L×W×H) (mm)	1990 x 991 x 7,5
Cable Cross Section Size (mm^2) / Plugs	4 / MC4 compatible
No. of Cells in the Line	72 (12 x 6)
Junction Box	Huber+Suhner J-Box
Front / Back Glass (mm)	3 / 3
Packaging Configuration	23 per pallet

WORKING CONDITIONS

Maximum System Voltage	DC 1000V (TÜV)
Operating Temperature	-40 °C~+85°C
Maximum Reverse Current	15A
Maximum Static Load, Front (wind / snow)	2400Pa / 5400Pa
NOCT	43,6°C
Application Class	Class A

ELECTRICAL PARAMETERS

TYPE	STKM-72-320
Rated Maximum Power at STC (Wp)	320
Open Circuit Voltage (Voc/V)	45,48
Maximum Power Voltage (Vmp/V)	37,04
Short Circuit Current (Isc/A)	8,60
Maximum Power Current (Imp/A)	8,10
Module Efficiency [%]	18,20
Power Tolerance	0+3%
Temperature Coefficient of Isc (αIsc)	+0.05%/°C
Temperature Coefficient of Voc (βVoc)	-0.34%/°C
Temperature Coefficient of Pmax (γPmp)	-0.42%/°C
STC	Irradiance 1000W/m^2, Module Temperature 25°C, AM 1.5

I-V CURVE

ENGINEERING DRAWING

The module is certified with Alumero Click 5.0 L-100 clamps.

Approved for:

- 2400 Pa snow load

- 5400 Pa wind load

🟪 clamp area

🟩 clamp mounting area

Fig. 2.6 - Datasheet of the selected PV module - "Solar Electric - STKM 320Wp Monocrystalline 72 cells module"

2.5 Electric Bill components

Before analysing the various scenarios of this thesis, it is necessary to make a description of the economic payments that make up the utility bill: the purpose of this is to highlight, in greater detail, how the incidence of each fee analysed varies according to the different semesters of the year 2021. As for the cases that will be analysed, it must be remembered that "virtual configuration" system will be used in the community, through which the participants in the scheme are able to receive an incentive assessed on shared energy.
The electricity bill depends on the type of user considered and is generally made up of the items listed below, which refer to customers served under the Maggior Tutela[14] mechanism:

1. "Expenses on energy: the price of which is made up of a fixed amount (€/year), and an energy share (€/kWh) with differentiated price for time bands for users with electronic meters. In particular, for domestic customers the price is the same for the trimester, while for non-domestic customers it may vary from month to month.
   The total price applied in the bill is given by the sum of the prices of the following components: energy (PE), dispatching (PD), equalization (PPE), commercialization (PCV), dispatching component (DispBT).
   For customers served with the Maggior Tutela mechanism who receive the bill in electronic format and who have activated a payment method with automatic debit, the item includes the discount for the electronic bill" [79]

2. "Expenses for the transport and management of the meter: the tariff can vary every quarter and is composed of: a fixed quota (€/year), a power quota (€/kW/year) and an energy quota (€/kWh).
   The overall price includes the components of the transport, distribution and metering tariff and the UC3 and UC6 tariff components" [79]

3. "Expenses for general system charges: tariffs may vary in correspondence with the requirements for covering the charges. They are usually reviewed every quarter and consist of an energy share (€/kWh), a power share (€/kW/year) which is not applied to homes, and a fixed share (€/year), which is not applied to homes of registered residence.
   The total price includes components such as Asos (general charges relating to the support of energy from renewable sources and CIP 6/92 cogeneration) and ARIM (remaining general charges). It therefore includes the amounts invoiced to cover costs relating to activities of general interest for the electricity system" [79]

4. "Taxes: it includes excise duties and VAT, in particular the former is applied to the quantity of energy consumed (domestic customers with power up to 3 kW enjoy reduced rates for the supply in the home of registered residence), while VAT it is applied to the total amount of the bill. Currently, for domestic users it is equal to 10%, for non-domestic users it is equal to 22%" [79]

The total price applied in the bill is given by the sum of the prices of the components listed above, plus other components that may be present in certain cases such as recalculations or other items.

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[14] Maggior tutela: it is an option service envisaged in the Italian energy market, which guarantees the consumer the supply of electricity under the economic and contractual conditions established by the Regulatory Authority for Energy, Networks and the Environment (ARERA)

With regard to the various quotas mentioned, it is necessary to make an in-depth analysis of the main items:

- “Fixed fee: it is the part of the price, expressed in €/year, that you pay to have an active delivery point, even in the absence of consumption and whatever the power used. The annual price is applied to the bill in monthly or daily rates.
- Energy quota: includes all amounts to be paid in proportion to consumption. It is expressed in €/kWh.
- Power quota: it is the amount to be paid in proportion to the power used, even in the absence of energy consumption. It is paid in €/KW/month. The annual price is applied to the bill in monthly or daily rates.” [80]

The following figures show the percentage breakdown of the tariff fees for the Maggior Tutela mechanism, assessed in the I and IV quarters of 2021. The fees refer to the consumption of the typical Italian family with average consumption of 2700 kWh/year.

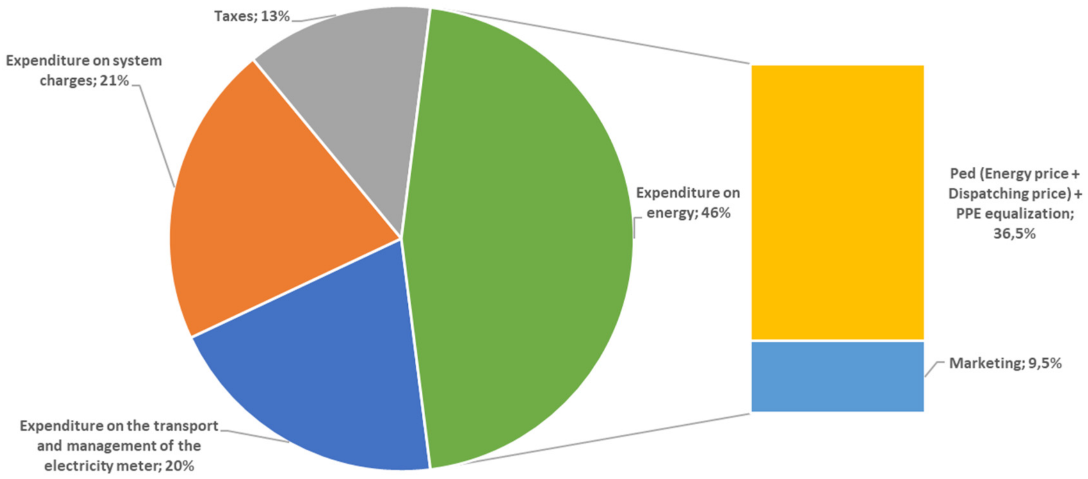


Fig. 2.7 - Percentage composition of the price of electricity for a typical domestic consumer for the first trimester of 2021 [https://www.arera.it/it/dati/ees5.htm]

Instead, as it can be observed from the Fig. 2.8, it is clear how the prices has changed through the 2021: the Energy Component went from 46% to 74.7% of the total percentage composition, meanwhile the System Charges have been cleared by the Italian Government through the Decree-Law 27 September 2021, no. 130, with the aim of reducing the total cost of electricity bills. In fact, even without the latter item, the total gross price went from € 20.06c€/kWh in the first quarter to € 29.70c€/kWh in the fourth quarter of the same year. This price increase is due both to the post Covid19 effects and to the tensions that have arisen between Russia and the European countries for the issue concerning the Nordstream 2 gas pipeline.

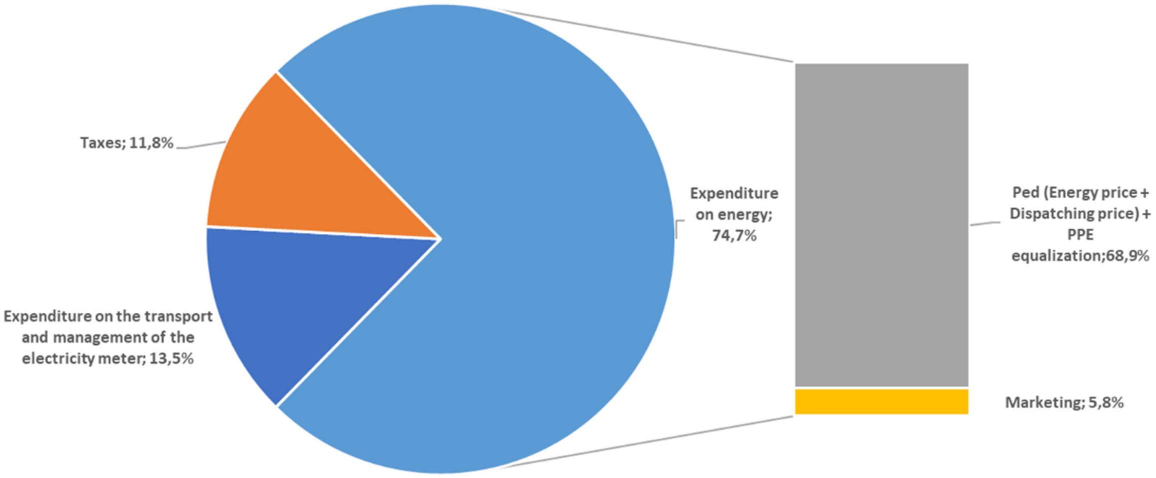


Fig. 2.8 - Percentage composition of the price of electricity for a typical domestic consumer for the fourth trimester of 2021 [https://www.arera.it/it/dati/ees5.htm]

Some of these fees, as already mentioned, are differentiated into variable components (€/kWh/year), fixed components (€/year) and components depending on the contractual power chosen by the user (€/kW): the variable portion refers to energy (the price of which depends on the market in which it is operating) and depends on the type of tariff selected (single time, dual time or band). The fixed fee and the power share can be applied, depending on the reference year, to the fees that they refer to the transport and management of the meter and system charges. In addition to the fees described, each user connected to the public network is subject to the application of excise duties and VAT.

As reference prices for the purchase and sale of energy, reference is made to the "Technique sheet – Aggiornamento delle condizioni di Tutela del IV trimestre 2021 (Milano, 28 settembre 2021)" by ARERA: "From 1 October 2021, the reference price of electricity for the typical customer will be € 29.70 c€/kWh, including taxes, divided as follows:

- Expenditure on energy: 20.47 c€ (68.9% of the total bill) for energy supply costs, up by 73% compared to the third quarter of 2021, and 1.71 c€ (5.8% of the total bill) for retail marketing, unchanged compared to the third quarter of 2021;
- Cost of meter transport and management: 4.01 c€ (13.5% of the total bill) for distribution, metering, transport, transmission and distribution equalization, quality services; unchanged compared to the third quarter of 2021;
- Expenditure for system charges: 0 c€ (0% of the total bill) for the expenditure for system charges, zeroed compared to the third quarter of 2021;
- Taxes: 3.51 c€ (11.8% of the total bill) for taxes that include VAT and excise duties" [81].

3. Test Case

3.1 REC Calculation Model

At this point of the dissertation, it is necessary to identify a calculation procedure that allows to perform the analysis of the system from a qualitative point of view, and that can be also utilized for the evaluation of the techno-economic feasibility of the REC. The model has to allow to carry out an analysis which develops a range of energy quantities (self-consumed energy, energy input and shared energy), instead of a specific data, and this is possible by means of formulas and relationships that the model contains. In this way it is possible to examine the results of the evaluation in a more complete and coordinated way, being able to consider a range of possible scenarios. The purpose of this model is to provide, through the insertion of the data reported in the previous chapter, a preliminary assessment of the feasibility of a REC, which makes it immediately understand the economic benefits to the customer, who is approaching for the first time at this type of system.

To build a reliable calculation model of the REC, it is necessary to insert the following data into it:

a) Consumption of domestic users: for each user it was possible to obtain the data related to the full load diagrams, which contains the 8760 annual hours of electrical energy consumption of each user;

b) Creation of the generation curve of the PV system using the software in the website of the European Union [https://re.jrc.ec.europa.eu/pvg_tools/it/#MR] through which it is possible to download the hourly irradiance, measured in [W/m^2], which affects the solar panels installed on the roofs of the producer. The data obtained was then used to calculate the annual production of the PV plant on an hourly basis for the 8760 hours of the year, taking them as the basis for the subsequent analysis. This step was possible using the software Termolog since it allows the possibility of inserting the characteristics of the photovoltaic module and then all the loss factors related to the base case;

c) Calculation of the Energy self-consumed by the User1, which is the share of energy produced by the PV system that only satisfies the consumption of the user who owns the PV system. This is obtained as the hourly sum of a year between the minimum of [$E_{produced\_PV,h}$; $E_{consumed1,h}$];

d) Calculation of Energy input, which is the portion of energy produced by the PV plant that is not self-consumed by User 1, and therefore is fed into the grid. It can be calculated by doing the hourly summation of yearly values between the subtraction of $[E_{produced,PV,h} - E_{selfconsumed,h}]$;

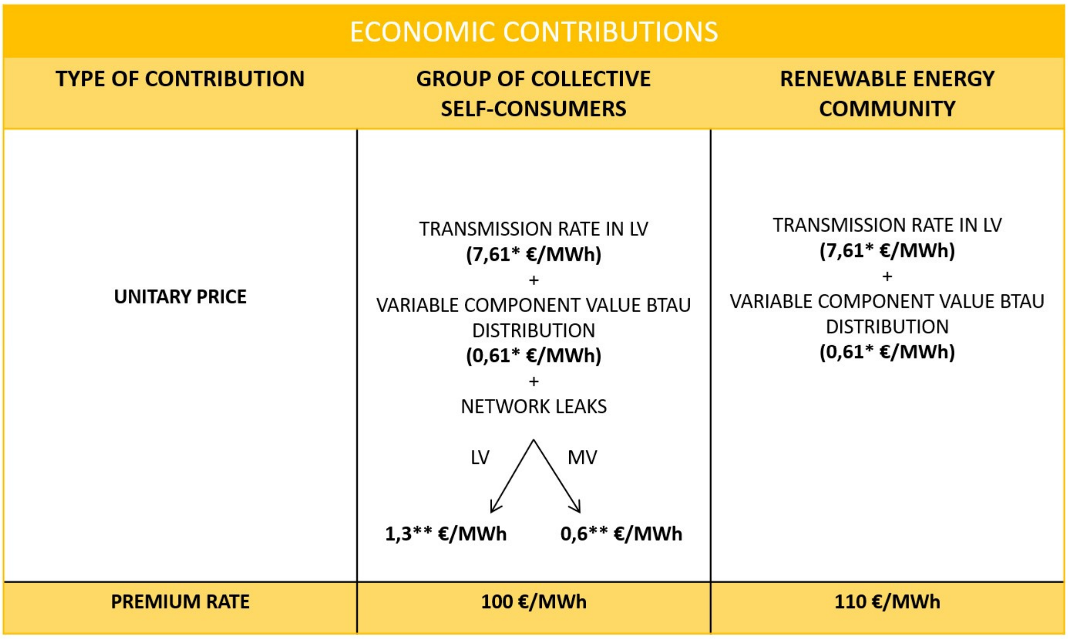
e) Calculation of the energy withdrawn by User 1: $E_{drawn,1} = \sum_{h=1}^{8760}[E_{consumed,1,h} - E_{selfconsumed,h}]$. For the other users this parameter is equal to the energy consumed [$E_{drawn,2} = E_{consumed,2}$; $E_{drawn,3} = E_{consumed,2}$];

f) Creation of the aggregate annual load profile of users 2 and 3, adding the hourly values of these two users. Thanks to this parameter, it is then possible to find the shared hourly energy which is identified by the following equation $E_{shared} = \sum_{h=1}^{8760} min[E_{input}, E_{drawn,2} + E_{drawn,3}]$;

g) Calculation of the self-consumed energy rate = $E_{selfconsumed,1}$ / $E_{produced\_PV}$ and the shared energy rate = E_{shared} /$E_{input.}$

After having characterized all the energy parameters, it is necessary to recall all the incentives and mechanisms that can be used to obtain the benefits, which can be calculated through the previously calculated energy components.

The following Fig. 3.1 summarizes the economic contributions provided by the GSE, which are different based on the type of configuration chosen.



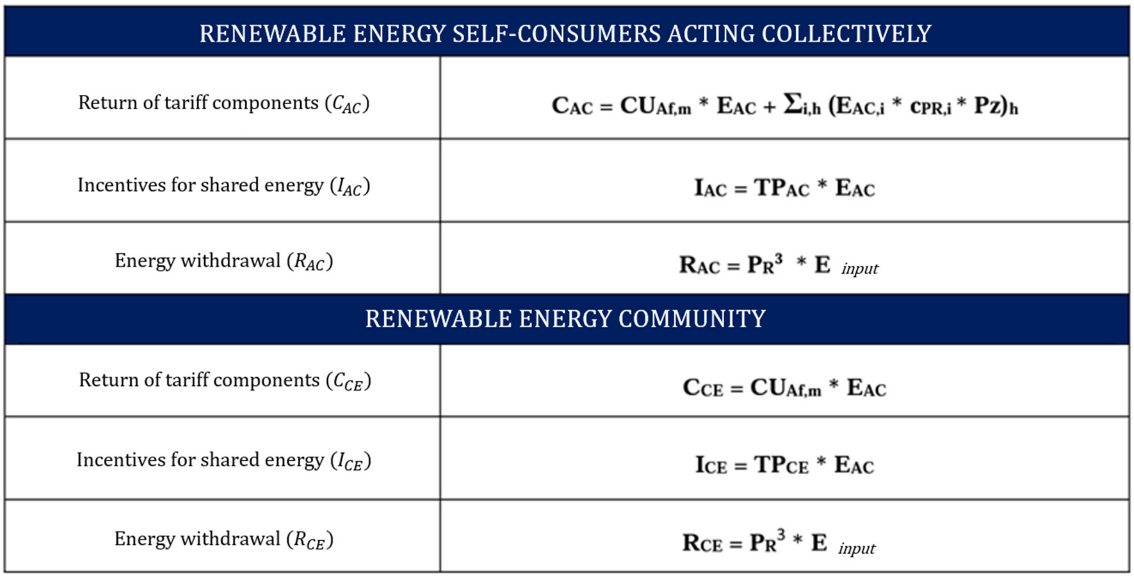
ECONOMIC CONTRIBUTIONS

TYPE OF CONTRIBUTION	GROUP OF COLLECTIVE SELF-CONSUMERS	RENEWABLE ENERGY COMMUNITY
UNITARY PRICE	TRANSMISSION RATE IN LV **(7,61* €/MWh)** + VARIABLE COMPONENT VALUE BTAU DISTRIBUTION **(0,61* €/MWh)** + NETWORK LEAKS LV → **1,3** €/MWh** MV → **0,6** €/MWh**	TRANSMISSION RATE IN LV **(7,61* €/MWh)** + VARIABLE COMPONENT VALUE BTAU DISTRIBUTION **(0,61* €/MWh)**
PREMIUM RATE	**100 €/MWh**	**110 €/MWh**

*for the year 2020
** referring to the average zonal price of 2019. The voltage level refers to the connection point of the system.

Fig. 3.1 - Economic contributions for Italian RECs and self-consumption groups [*GSE document, pag. 10, "Technical rules for the enhancement of access to the shared electricity incentive service" (April 4, 2022)]*

So, the economic contributions due to the REC configurations (and groups of self-consumers) can be of three types: valorisation of shared electricity, by returning the tariff components provided by the Resolution 318/2020/E/EEL ($CU_{Af,m}$); incentives for shared electricity pursuant to the Decree 16/09/2020 (feed-in-premium tariff); withdrawal of electricity fed into the grid by the GSE, where required using the RID mechanism.
The above-mentioned contributions, expressed in €, are recognized by the GSE upon receipt of the electricity measurements from the grid operators and the data necessary for its validation. Below there is a summary Tab relating to the calculation algorithms (defined in Article 7 of Annex A to the Resolution) applied based on the type of configuration and the type of contribution.



RENEWABLE ENERGY SELF-CONSUMERS ACTING COLLECTIVELY	
Return of tariff components (C_{AC})	$C_{AC} = CU_{Af,m} * E_{AC} + \Sigma_{i,h} (E_{AC,i} * c_{PR,i} * P_Z)_h$
Incentives for shared energy (I_{AC})	$I_{AC} = TP_{AC} * E_{AC}$
Energy withdrawal (R_{AC})	$R_{AC} = P_R{}^3 * E_{input}$
RENEWABLE ENERGY COMMUNITY	
Return of tariff components (C_{CE})	$C_{CE} = CU_{Af,m} * E_{AC}$
Incentives for shared energy (I_{CE})	$I_{CE} = TP_{CE} * E_{AC}$
Energy withdrawal (R_{CE})	$R_{CE} = P_R{}^3 * E_{input}$

Fig. 3.2 – Incentives Mechanisms [GSE document, pag. 10, "Technical rules for the enhancement of access to the shared electricity incentive service" (April 4, 2022)]

Savings on the bill (in the case of PV systems connected to users)

In addition to the three incentives explained above, if the photovoltaic systems belonging to a group of self-consumers or a renewable energy community are connected to a consumer user, for example to a house or an office, self-consumption of the electricity produced on site happens.
Self-consumption of the electricity produced by photovoltaic system allows users to reduce the outlays related to your energy bill: this mechanism goes under the heading "savings from direct self-

Moreover, the participants in the schemes also have the possibility of accessing a number of different system of tax deductions, which increase the obtainable benefits. In the treatment of this thesis, it is only considered the "50% deductions", which is an incentive that provides the 50% tax deduction of the expenses related to the construction of the photovoltaic system and at the same time.

Charges to GSE

Table 3.1 - General fees table for RECs [Regole tecniche valorizzazione per l'accesso al servizio di incentivazione dell'energia elettrica condivisa" – cap. 7.1]

General fees table		
Rated Power [kW]	Fixed fee [€/year]	Variable fee [€/kW]
P ≤ 3	0	0
3<P ≤ 20	30	0
20<P ≤ 200	30	1

Each REC is required to pay certain fees to the GSE: for example, the following ones are used to cover administrative costs, which are charged to the configuration for which the GSE is requested and include a binomial rate consisting of a fixed fee and a variable fee with the power of the plant, to be applied for each plant, as shown in the following table.

As already said, in the treatment of this thesis a REC based on real data will be simulated and it will be used the mechanism called 'Ritiro Dedicato'. The law in this regard says that "In the event that the user requests the GSE, for all production plants, to withdraw the electricity injected under the conditions of the Ritiro Dedicato, the GSE also applies the fees provided for the Ministerial Decree of 24 December 2014 for the Ritiro Dedicato”. This annual fee is used to cover the costs of management, verification, and control, and must be paid by the producer to the GSE. This tariff will depend on the power of the system and the power source, and it is described in the text GSE “Ritiro Dedicato dell’energia elettrica - Conguaglio a Prezzi Minimi Garantiti - Tariffa Onnicomprensiva - Modalità e condizioni tecnico-operative - Disposizioni Tecniche di Funzionamento”, which parameters of interest are summarized in the table below.

Table 3.2 - Tariffs for “Ritiro Dedicato mechanism”

Table of RID’s fees		
Rated power of plant [kW]	Variable fee [€/kW]	Maximal [€/year]
$1<P \leq 20$	0.7	10000
$20<P\leq 200$	0.65	
$P>200$	0.6	

An additional contribution of 4 €/year is also applied for each connection point that is part of the configuration.

Also considering the management costs of the system (OPEX), the total cost to subtract will be 106.2€/year.

3.2 Base case – Modelling of the REC

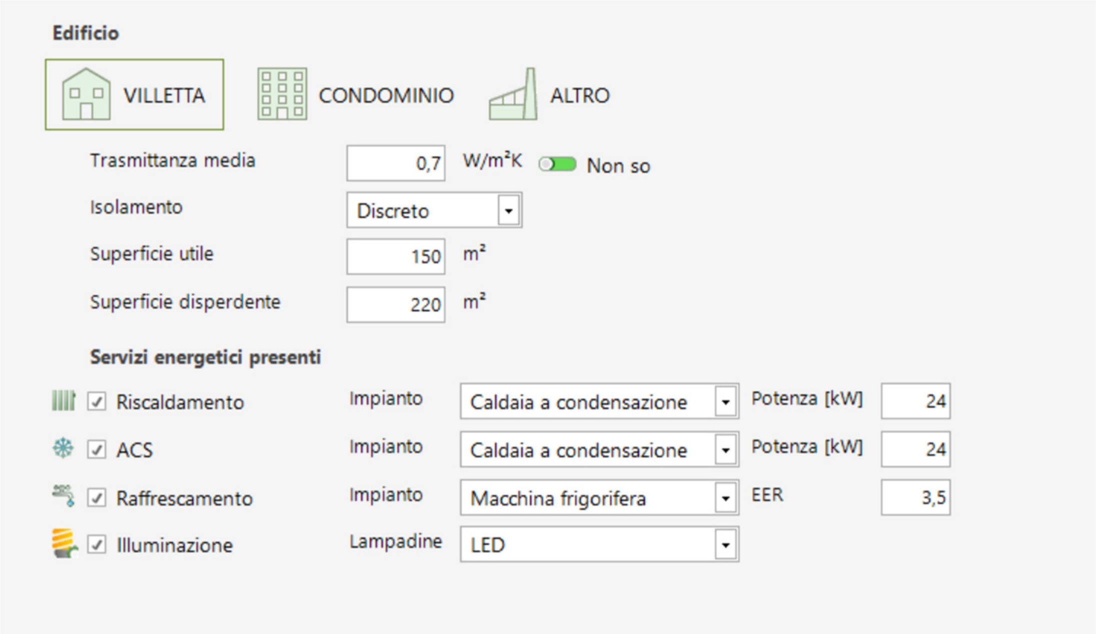
3.2.1 Presentation of the base case

The base case of this dissertation is a simulation of a Renewable Energy Community located in Montebelluna, Italy. In the following table it is present the most important information about the municipality where the REC is placed.

Table 3.3 - General data

General Data	
Area	49.01 km^2
Density	633.07/km^2
Climate Class Zone	zone E, 2404 GG
Seismic Class Zone	Zona 2 (average seismicity)
Geographic Coordinates	
Latitude	45°46′31″N
Longitude	12°02′20″E
Altitude	
Altimetric Zone	Plain
Elevation	109 m

Regarding the structure of the community, three real users were chosen to simulate the REC, and from this users it has been possible to get all the real data needed, i.e., the hourly load data for each user, the hourly production of the PV system, the information about the electrical appliances and habits of the households. It is important to point out that the User 1 has already installed the PV system, and so the REC was created afterwards.



Trasmittanza media 0,7 W/m²K Non so

Isolamento Discreto

Superficie utile 150 m²

Superficie disperdente 220 m²

Servizi energetici presenti

☑ Riscaldamento Impianto Caldaia a condensazione Potenza [kW] 24

☑ ACS Impianto Caldaia a condensazione Potenza [kW] 24

☑ Raffrescamento Impianto Macchina frigorifera EER 3,5

☑ Illuminazione Lampadine LED

Fig. 3.3 - Main information related to User 1 from Termolog

In the Fig. 3.2 there is some important information related to the User 1, which was possible to insert in the 'Termolog' Software for the calculations. These data includes the type of building, average transmittance and insulation of the building, useful and dispersant surface, and the data related to all the energy services present in the house like heating system, water heater, cooling system and lighting.

Regarding the PV system, it is important to remark that the REC is located in Montebelluna (TV), in the North of Italy. The PV system is located on the roof of the User 1, which is oriented at south (azimuth 0°) and has a tilt of 15°. From a visual assessment, there is no shading around the building that reduce the productivity of the system.

For the modelling of the REC, the first step was to create a Calculation Model, in which it was inserted all the information and calculated all the parameters needed to find the results and accomplish with the base case simulation objectives. Then a software called Termolog was used, in which it was added all the data and calculated the same parameters. In particular, it was also possible to obtain the electric bills of each user, and these monthly data was used within Termolog since it was not possible to enter the hourly data. Meanwhile in the calculation method created the complete load curves were utilized, provided with 8760 values. This is why small differences in the results can be seen when comparing the calculation method and software. However, in principle, the results are in agreement and similar to each other.

In the table below there is the data related to the electric bills of the User1 of the 2021:

Table 3.4 - Data from the electric bill of User 1 (2.9kWh/year, 2021)

[€/kWh]	kWh consumed	[€]
0.252	294	74.09
0.252	289	72.83
0.255	263	67.07
0.255	244	62.22
0.265	220	58.30
0.265	198	52.47
0.243	193	46.66
0.243	183	44.47
0.231	216	49.90
0.231	242	55.67
0.341	266	90.71
0.341	294	100.25
Total	2902	774.62

Through the data contained within the User1 bills of 2021, in particular the data relating to the unitary cost [€/kWh], it was possible to obtain the P.R.[15], which is subsequently used to calculate savings from direct self-consumption.

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[15] P.R.= prezzo risparmio, which means the saving price

3.2.2 Data for the simulation

The following table contains the main data of the households of the REC.

Table 3.5 - Users' annual electrical energy consumption and production

REC data		
	kWh/an (consumed)	kWh/an (produced)
User 1	2902	6313
User 2	2505	0
User 3	3301	0

At this point, it is possible to make different sizing choices of the photovoltaic system:

1. Sizing considering that the annual PV production must be similar to the annual consumption of the sum of all users;
2. Sizing based only on consumption in the F1 band, i.e., the band coinciding with the production curve of the PV plant;
3. Just consider the already existing PV panel and make the simulation based on that data

In this case we are going to consider only the 3rd point of the list above, as the PV system was already installed.

It must be noticed that in all the scenarios that are going to be developed there is no problem of space in the roof, because there is an available surface of 60 m^2, and as it can be seen from the table below the PV system occupies less than 36 m^2. More information are available on the Tab below.

Table 3.6 - Main parameters of PV system

Parameters	Value [Unit of Measure]
Rated power of PV plant	6.08 [kWp]
Rated power of each panel	320 [W]
n° of panel	19
Size of each panel	1.87 [m^2]
Size of the system	35.53 [m^2]
Efficiency of each panel	18.2%
Annual energy production	6313 [kWh/year]
Irradiance on the inclined roof	1490 [kWh/m^2]
Raw prod of each panel	276.56 [kWh/m^2]
Net prod of each panel	179.76 [kWh/m^2]

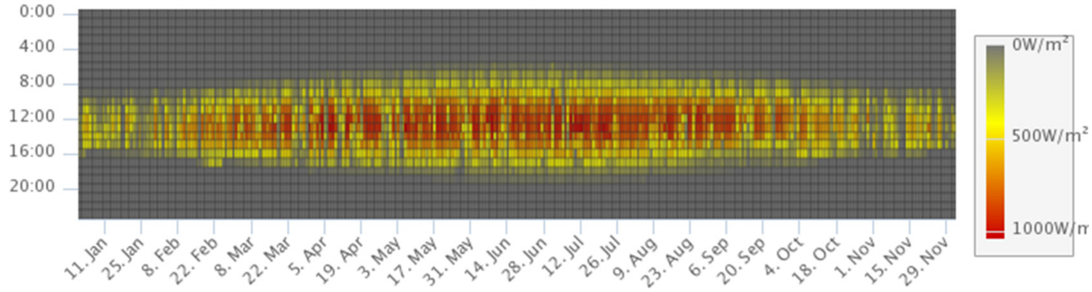

Fig. 3.4 - Results from the probes in W/m2 for each time of all days of the year.

Some parameters are required for the simulation and related calculations. For example, the energy purchase price, the energy sale price, the MiSE incentive rate, the return of charges by Arera, etc. All these parameters are listed in the Table 3.8 below:

Table 3.7 - Definition of Economic Parameters needed

TRASE[16]	0.778 c€/kWh
BTAU[17]	0.059 c€/kWh
$CU_{Af,m}$[18]	0.837 c€/kWh (corrispettivo unitario - MiSE)
TP (feed-in-premium)	110€/MWh (tariffa premio - ARERA)
Energy purchase price	PZO
Energy sale price	P.R.
CAPEX (unitary initial investment)	1800€/kWp
OPEX (managing and maintenance operative costs)	60€/an

Other parameters are related to the remuneration mechanism called "Ritiro dedicato", which can be indicated using the acronym RID. The value of this mechanism is the following one:
$RID = PMG \cdot E_{input}$, but if PZO>PMG then the following formula will be used $RID = PZO \cdot E_{input}$.

In addition, regarding the CAPEX (unitary initial investment), we can calculate the total initial investment cost related to the PV system. Knowing that CAPEX = 1800 €/kWp for monocrystalline silicon modules, since we have 6kWp of installed power, then the initial investment cost will be 10800 €.

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[16] TRASE: Transmission rate on low voltae
[17] BTAU: variable component value of distribution
[18] $CU_{Af,m}$: fixed unitary fee

4. Results

4.1 Simulation of RES community, techno-economic analysis and results

The base case includes the results obtained from the procedure calculation and Termolog, and both show the case in which self-consumption is around 20%, while the shared energy rate is around 40%.

The REC was first simulated through the calculation procedure created. The following Tab 4.1 shows the results obtained for the base case, the one without storage system, for the year 2021.

Table 4.1 - Results of simulation of the base case using the calculation procedure

Energy produced by PV system	6313.53 kWh/year
Total Energy consumption of all users	8709.42 kWh/year
Energy consumed only by User1	2902.56 kWh/year
Energy Shared	2030.16 kWh/year
Energy fed into the grid from User1	5210.07 kWh/year
Energy drawn from the grid by all Users	7605.92 kWh/year
Energy self-consumed by User1	1103.50 kWh/year
Self-consume index	18%
Energy shared index	39%
Feed-in-premium tariff (TP)	223.32 €
Unit fee $CU_{\mathrm{Af,m}}$	16.99 €
RID (valorisation of energy sales)	605.76€

To verify the correctness of the calculation model, the same estimates were entered on the Termolog software. The result of the simulation of the base case of the Energy Community is shown below.

Table 4.2 - Results of simulation of the base case using Termolog

Energy produced by PV system	6313.47 kWh/year
Total Energy consumption of all users	8709.42 kWh/year
Energy consumed only by User1	2975.63 kWh/year
Energy Shared	2148.08 kWh/year
Energy fed into the grid from User1	5032.05 kWh/year
Energy drawn from the grid by all Users	7412.36 kWh/year
Energy self-consumed by User1	1283.53 kWh/year
Self-consume index	20%
Energy shared index	43%
Feed-in-premium tariff (TP)	236.28 €
Unit fee $CU_{\mathrm{Af,m}}$	17.98 €
RID (valorisation of energy sales)	575.66 €

If the two tables are compared, it is possible to notice a great affinity and similarity between the results obtained. It is possible to notice some small differences due to the fact that in the Termolog

software it was possible to enter only the monthly consumptions of the users and not the hourly, which thanks to its algorithm and using standard pre-set load curves, was able to obtain approximately the same results.
For example, the self-consume index is 18% in the first case, and 20% in the second one; the energy shared index is 39% and 43%. About the economic benefits, the sum of all them is 846.97€/year in the first case (calculation procedures through database) and 829.92€/year in the second one (using Termolog tool).

For the other scenarios, on the other hand, it was considered the inclusion of different sizes of collective storage capacities, which will mainly result in a change in the shared energy rate. It was possible to calculate this last factor and its correlation with the amount of storage installed thanks to the 'ROSE' tool. Thanks to these scenarios it was possible to observe how all the other factors, rates and benefits change.
Before entering the data and perform the simulations of the various scenarios it is important to specify some preliminary hypothesis on storages system. In fact, it was decided to manage the battery operation with the aim of maximizing self-consumption within the configuration instead of the economic gain. As a consequence of this decision, there are two important aspects to specify: the first concerns the fact that it would not make sense to allow the battery to be charged by buying energy from the grid, so it is mandatory that the charge is strictly linked to the availability of energy from the PV system (this was decided to facilitate the analysis, because if the price in an hour1 is higher than in the hour2, it could become profitable to charge it even with grid energy at hour1 and sell it at hour2); the second, on the other hand, concerns the fact that if the battery were to be discharged to sell energy to the grid, self-consumption would suffer, and for this reason it is necessary that the sale on the grid has to be possible only in the event of excess production compared to the load.

Having said that, it cannot be excluded that battery management logics referring to the electricity market or the needs of the grid will be useful in the future, once the role that energy communities can actually play has been established. For the moment, the most reasonable strategy is to optimize self-consumption.

Therefore, in the Tab. 4.3 it is given the correlation between energy storage system and shared energy rate. This data was obtained through the ROSE software, and it is valid only for the REC analysed in this thesis.

Table 4.3 - Relation between storage capacity and rate of shared power

Storage capacity installed	Rate of shared energy
0 kWh	43%
2 kWh	57%
4 kWh	69%
6 kWh	79%
8 kWh	88%
10 kWh	94%

The software assume that the rated power is proportional to the capacity of the storage system.

For each scenario it was then possible to calculate different energy parameters as reported in the Tab 4.4 below.

Table 4.4 - Energy output data for each scenario

Energy storage capacity installed [kWh]	0	2	4	6	8	10
Energy Self-consumed [kWh/year]	1283	1283	1283	1283	1283	1283
Energy from the grid [kWh/year]	7412	7412	7412	7412	7412	7412
Energy fed into the grid [kWh/year]	5032	5032	5032	5032	5032	5032
Energy Shared [kWh/year]	2148	2846	3460	3977	4404	4726

Observing the data obtained, it is possible to analyse the data regarding the different results about the energy parameters. For example, energy self-consumed, energy from the grid and energy input remains constant to vary of rate of energy shared. Meanwhile, the only parameter that changes is the energy share, which increase proportionally to the quantity of energy storage installed.

Inserting the storage capacity entails, at first glance, a benefit for the energy communities: in fact it is well known that the non-self-consumed energy that is fed into the grid is bought by GSE at a lower price than the one which is sold to the citizen, and so renewable energy communities are fundamental because are based on the simple concept which is the exploitation of shared energy and related incentives, rather than the energy input to the grid, from which there are fewer benefits. Therefore, to minimize the electricity bill of User1, it is necessary to maximize self-consumption, while to minimize the bills of the other users it is required to maximize the amount of shared energy. However, in this case, the storage system is collective and therefore its costs must be divided among all users, as well as the associated benefits. So, the objective of the analyses will be to find the best scenario which allows to obtain the maximum final benefit.

Continuing with the calculation, it is then possible to achieve results regarding the incentives and return of tariff components. The following formulas were used to obtain the results regarding the savings of energy self-consumed and benefits from energy input into the grid concerning the year 2021.

- Savings from self-consumed energy: $\sum_{m=1}^{12}\left[P.R._{m}\cdot E_{selfconsumed,m}\right]$
  The term P.R. refers to the price saved for each kWh of energy consumed. In fact, self-consuming the electricity produced by the photovoltaic system allows the user to reduce the outlays related to the energy bill: the self-consumer connected to a photovoltaic system will continue to pay the fixed components (fixed portion and power portion) of the bill, but will see a reduction in the cost relating to the variable components (share of energy, network charges and related taxes such as excise duties and VAT), to a greater extent the larger the quantity of self-consumed energy. By analysing the electricity bills of User 1 for each month of 2021, it was decided to adopt a P.R. equal to 85% of the total, given that the sum of the fixed quota and the power quota is equal to 15% on average for each month. Doing the summation of the results of each month, it is possible to obtain the annual value, which in this case is equal to 288.79 €/year.

- Benefits from Energy input into the grid: This benefit is related to the “Ritiro Dedicato” (Dedicated withdrawal), which is a service from the GSE available for producers for the selling of the electricity produced and fed into the grid. It consists in the sale to the GSE of the electricity fed into the grid by the plants that can access it, at the request of the producer

and as an alternative to the free market, according to principles of procedural simplicity and applying economic market conditions.
Accordingly, the GSE pays the producer a certain price for each kWh fed into the grid
The following formula explains the mechanism:
$RID = \sum_{m=1}^{12} \left[PMG_m \cdot E_{input,m} \right]$.
For the year 2022 the PMG is equal to 40.7 €/MWh, and it was determined by ARERA.

However, if the PZO>PMG, then the formula used will be $RID = \sum_{m=1}^{12} \left[PZO_m \cdot E_{input,m} \right]$.
It is important to notice that in this analysis it is assumed that PZO≃PUN[19]. In the Fig. 4.1 above it is present the PUN used for the year 2021.

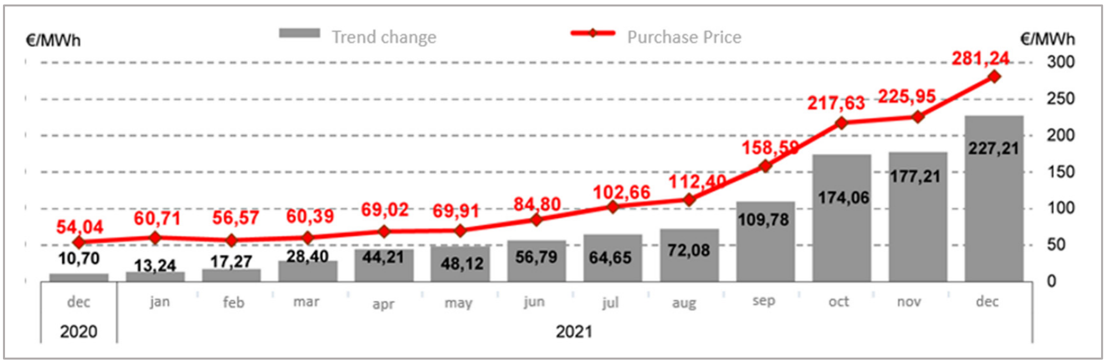

Fig. 4.1 - PUN for electrical energy in Italy in 2021

The total yearly benefit obtained from energy input into the grid is equal to 575.66€/year.
To obtain this last result, it was necessary to use the data related to the from the GSE, which is reported on the Fig. 4.1.

As regards the costs of the REC instead, these have already been identified in the previous chapter of this thesis, and as a result a total cost of 106.2 €/year has been obtained, which must be subtracted from all benefits. The key incentives related to the amount of energy shared within the energy community are then calculated. Both incentives are provided by the GSE: in particular, the first was established by the MiSE Decree of 16 September 2020, while the second by the ARERA Resolution 318/2020. It is important to remember the definition of shared energy "the latter equal to the minimum, in each hourly period, between the electricity produced and emitted into the grid by the photovoltaic system and the electricity taken from all the associated end customers" [48].

Table 4.5 - Final tab of REC simulation results divided for each scenario of 2021

Energy storage capacity installed [kWh]	0	2	4	6	8	10
savings from direct self-consumption [€/year]	288.79					
Benefits from Energy input into the grid [€/year]	575.66					

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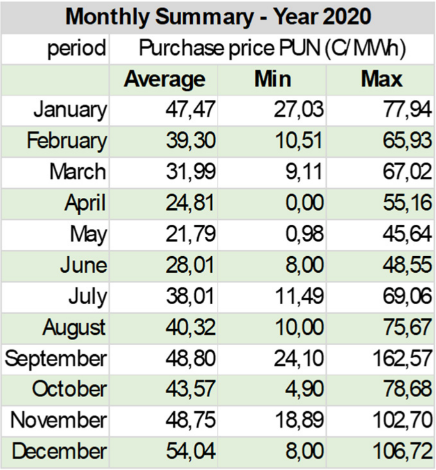
[19] PUN: Prezzo Unico Nazionale, which means Single National Price

Incentive of MiSE on Shared Energy [€/year]	17.98	23.82	28.96	33.29	36.86	39.56
Return of tariff components by ARERA [€/year]	236.28	313.06	380.6	437.47	484.44	519.86
Costs [€/year]	-106.2					
Total [€/year]	1012.51	1095.13	1167.81	1229.01	1279.55	1317.67

From the result it is possible to see how the benefits deriving from energy sharing (feed-in-premium and RID mechanisms) increase as the amount of storage installed by the community increases. This is normal and agrees with the meaning of these tariffs, since they are proportional to the shared energy, on which the sense of an energy community is based. It is also necessary to consider that in this case it is not included the cost of the storage system itself, which will instead be included in the economic analysis.

Before analysing the economic feasibility of each scenario based on the capacity storage installed, it is necessary to compare the results obtained from the data relating to the year 2021 with those relating to the year 2020. Let's see below the results obtained using the data from the P.U.N. of the year 2020.



Monthly Summary - Year 2020			
period	Purchase price PUN (C/MWh)		
	Average	Min	Max
January	47,47	27,03	77,94
February	39,30	10,51	65,93
March	31,99	9,11	67,02
April	24,81	0,00	55,16
May	21,79	0,98	45,64
June	28,01	8,00	48,55
July	38,01	11,49	69,06
August	40,32	10,00	75,67
September	48,80	24,10	162,57
October	43,57	4,90	78,68
November	48,75	18,89	102,70
December	54,04	8,00	106,72

Fig. 4.2 - PUN 2020

It was decided to take this year for comparison since it was in this same year that the ARERA Resolution 318/2020 was first issued in August (indicating the feed-in-premium rate) and then the Ministerial Decree MiSE 16/09/2020 (indicating the rate relating to the Unit Fee) in September. Furthermore, it is necessary to remember that in the year 2020 prices were not yet affected by the post-pandemic effects of Covid19, unlike the following year.

Table 4.6 - Final calculations of REC simulation results divided for each scenario of 2020

Energy storage capacity installed [kWh]	0	2	4	6	8	10
savings from direct self-consumption [€/year]	271.58					

Benefits from Energy input into the grid [€/year]	214.04					
Incentive of MiSE on Shared Energy [€/year]	17.98	23.82	28.96	33.29	36.86	39.56
Return of tariff components by ARERA [€/year]	236.28	313.06	380.6	437.47	484.44	519.86
Costs [€/year]	-106.2					
Total [€/year]	633.68	716.3	788.98	850.18	900.72	938.84

As for the calculations, in the months in which PUN<PMG the 2020 PMG was used, which is equal to 0.04 €/kWh. Taking this last consideration into account, the new RID values were then calculated. As for savings from direct self-consumption, it was possible to obtain the updated value of this item for 2020 by analysing the bills related to User 1 for each month of the year 2020: in this case, from the analysis of the electricity bills, it was decided to adopt a P.R. equal to 80% of the total price of energy bought by the user itself, given that the sum of the fixed quota and the power quota is equal to 20% on average for each month. The new values found have been reported in the table above, together with the results of the other incentives and rates previously obtained, which remain unchanged.

If we compare the results for 2020 with those obtained for the year 2021, it can be seen that the structure of the incentive mechanisms for REC need to be reformed, given that the sudden increase in electricity prices has made them less competitive and not suitable for today's situation. In fact, it can be seen that the total benefits depend for the most part on RID and savings from self-consumption. The main problem of these mechanisms (related to shared energy and created specifically to support the development of REC) is the fact that the incentive rates are fixed and are not proportional to market prices. For example, as already stated, the feed-in-premium tariff has a fixed remuneration of 110 €/MWh for 20 years. As the price of electricity increases, as happened in 2021, these incentives affect the total benefits less and less.
This fact entails a serious problem for communities, which lose their competitive advantage: it would therefore be necessary to reformulate the incentive structure, making them proportional to the price of energy, for example, and perhaps even setting a minimum guaranteed price base.

From these data it is also possible to see that setting up a REC, according to pre-Covid market prices, has always been competitive than installing a system for self-consumption: in fact, pre Covid the PUN has been lower on average than 110 euros/MWh. The problem, however, arises from the fact that if we analyse the situation with post-Covid prices, we can see how things have radically changed, given that, for example, the PUN in December 2021 reached 281 €/MWh.

Result analysis

From the analysis of the results of both tables, it can be seen that the case of the highest total gross remuneration is obviously the one in which there is the greatest accumulation capacity. However, between the two tables of 2020 and 2021 there are substantial differences: in fact, in 2020, before the economic consequences of Covid19, the case of higher total remuneration entails a benefit of 938.84€, while in 2021 the same scenario corresponds to € 1317.67€. Once again it is demonstrated how the current structure of the incentive mechanism makes energy communities less competitive when the price of electricity increases.

Cost-benefit analysis

It is now possible to proceed to interpretation and quantification of the feasibility of the investment from an economic point of view, based on the various scenarios previously identified for the year 2021. The final results to be obtained from the economic analysis are finding the best scenario for the REC taken into consideration, evaluating the quantification in years of the payback time of this investment and the real rate of return of the project (or instead of the latter, evaluate after 10 years which project is the most profitable for the community).
The simplest economic model that can be adopted to describe the various scenarios is based on the fair sharing of any benefits among all members of the community, so that the annual revenues that the configuration allows to generate must be shared between the prosumer and the various users: in particular, the profitability of the investment must be ensured for the former, while for the other users it is suitable to guaranteed to them some economic savings on the cost of the electricity bill.

The production of the systems at each POD could be shared, hour by hour, in a transparent manner and respecting the wishes of the members of the community through the blockchain. In this way, the division of revenues could correspond precisely to the effective distribution of the energy shared between the different end customers.

Costs data

As for the purchase costs of a photovoltaic system, they have been significantly reduced in recent years, thanks to the great development achieved globally by this technology. Analysing the specific costs of a plant (€/kW), it has been observed that the main factor affecting this parameter is the size of the plant itself, i.e., the total power in kWp: in fact, thanks to the economy of scale achieved on the devices that due to the lower incidence of costs relating to accessory services (such as, for example, costs for design, installation), the specific cost decreases as the size increases. Below is a table with examples of indicative average costs:

Table 4.7 - Cost of plants in relation to the size [https://www.gse.it/documenti_site/Documenti%20GSE/Archivio/Guida%20per%20Gruppi%20e%20Comunita.pdf]

Rated power of the system [kW]	Average cost (+VAT) [€]
1÷1.5	3000÷4000
1.5÷3	4000÷6000
3÷5	6000÷9000
20	25000
100	105555
500	450000
1000	850000

The quality of the devices used, the distance between the system and the connection point to the network, and the methods of installation of the system are the main factors that influence the total cost of the system. However, the preponderant part of the variable cost is constituted by the modules, while the inverter represents the second variable cost item. In the case which it is decided to integrate the photovoltaic system with a storage system, an additional cost proportional to its capacity must be considered.

That said, the price per kW of the modules, inverters and per kWh of the storage systems can differ greatly depending on the characteristics that determine their performance, quality and the guarantees offered. There are also mandatory costs related to the design, installation and authorization and connection to the network, and other secondary costs such as those relating to insurance and management of administrative documents, ordinary maintenance service.

It is possible to consider three types of financial solutions for the construction of a photovoltaic system: invest own resources; apply for partial/total funding; make use of a company that offers energy production or plant rental services (Energy Service Company - ESCo), which is responsible for the overall investment against part of the revenues or sharing the savings resulting from the investment.

In the case analysed in this thesis it was decided to build a photovoltaic system without recourse to financing of any type and without relying on an ESCo: this solution allows to obtain the greatest gains over the useful life of the plant (25 years), as there are no additional costs due to interest on the financed capital nor are the sources of income shared with other parties.

Economic analysis results

In order to apply the economic indicators introduced in the chapter 2, it is necessary to define the variables that appear in those parameters:

- The initial investment I_0 is the sum of the expenditure incurred for the PV system and the battery;
- The investment discount rate is d = 7%.
- The net cash flow CF_t is the difference between the total annual benefits and the total annual costs of the plant:

Table 4.8 - Economic Output related to the PV system

CAPEX (PV modules)	1800 €/kWp
Primary investment cost	10800 €
OPEX	60 €/year

The total surface of the PV system is equal to 36 m^2 as previously calculated. This data is in agreement with the fact that in the literature, for 1 kWp of the monocrystalline photovoltaic system, it is said that between 5-9 m^2 are required. As regards the initial investment, a CAPEX of € 1800 was used, which multiplied by the size of the plant leads to an initial investment of 10800€; in this case, however, the tax deduction of 50% is used, resulting in an initial investment of 5400€, to be paid over 10 years.
Regarding the storage system, it is supposed a fix cost of 1000€ and a variable cost depending on the capacity installed. In the Tab. above there is a summary about the final costs of each storage system.

Table 4.9 - Final cost of each storage system

Storage Capacity	CAPEX
2 kWh	2600 €
4 kWh	3800 €
6 kWh	4900 €
8 kWh	5800 €
10 kWh	6600 €

For simplicity, a useful life of PV plant and the storage system is assumed to be 20 years, while the useful life of the storage systems is assumed to be 10 years. Accordingly, in the 11th year of the analysis it is necessary to consider the price of the replacement of the storage system.

The following table reports the final results obtained for each scenario:

Table 4.10 – Economic Analysis 2021

Economic Analysis 2021						
Storage [kWh]	0	2	4	6	8	10
I_0 [€]	10800	13400	14600	15700	16600	17400
CF_t [€/year]	1012.51	1095.13	1167.81	1229.01	1279.55	1317.67
Annual fiscal detraction 50% [€/year]	540	670	730	785	830	870
Discount Rate	7%					
NPV (after 20 years) [€]	4527.36 €	2664.49 €	2172.95 €	1664.53 €	1253.60 €	815.71 €
Discounted Payback Period [years]	9.87	14.89	16.67	18.45	19.91	20.55
CFRR[20] [% per year]	11.69	8.86	8.15	7.51	7.03	6.57
Annualized ROI [%]	1.77	0.77	0.56	0.39	0.27	0.17

The annual fiscal detraction of 50% is only valid for 10 years, and it gives back the 50% of the total investment cost. The investment results always profitable in each scenario using the fiscal detraction of 50%.

The choice of the storage CAPEX was assumed by observing the market values for 2021. It was therefore decided to compose the CAPEX through two factors: the first is a fixed minimum value of 1000 € for all the storage capacities (relative to the costs of design, installation, etc.), while the second is a variable value based on the size, starting from 800 €/kWh for the first 2kWh, then passing first to 600 €/kWh and then to 550 €/kWh for the addition of another 2 kWh, and finally 450 €/kWh for the addition of further kWh when the threshold of total storage 6kWh is exceeded.

It can be seen from the results that the best scenario is the one without the storage system for several reasons: it needs less initial investment, it has higher NPV after 20 years (4527.36€), annualized ROI and CFRR.

The idea of including a storage system for the REC analysed previously is not convenient with current market prices. This fact, in addition to being confirmed by the simulations performed, is justified by a series of elements including the large increase in the prices of raw materials, and consequently of the storage systems.
However, it should be noticed that combining storage and photovoltaic would be advantageous if, for example, one of the following factors or a combination of those would happen: price's reduction of storage, increase in energy price, high difference between peak and valley prices.

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[20] CFRR: cash flow return rate

4.2 Exploitation of future scenarios, opportunities, and prospects

Incentive and benefits

The directions specifically state that the RECs' primary goal is to provide community-level economic, environmental, and social benefits to its members, shareholders, and the area in which they operate, as opposed to making a profit.

For this reason, it seems appropriate to define tools to support the development of REC that consider not only the energy aspects but also, specifically, the economic, social, and environmental benefits, not only for the members of the communities but also for the entire territory in which operate. It may also be appropriate to consider providing additional bonuses for these particular aspects.
Therefore, it would be wise to establish acceptable performance indicators to quantify these benefit categories and serve as the foundation for any extra bonuses, being careful not to duplicate any existing particular assistance programs.

Additionally, it seems desirable to keep certain explicit incentives for the development of REC, such as by connecting them to communal energy sources and perhaps specifying incentives specifically for storage and automation systems that might raise self-consumption limits with a positive net effect. As ARERA has often noted, the explicit incentives enable difference by source, technology, and scale.

Additional features and rewards

RSE[21] identifies that it would be desirable to introduce specific bonuses if the REC, for example:

- " pursue specific objectives of environmental and territorial policies to combat climate change;
- procure local raw materials through a short supply chain, for example by identifying a maximum distance from the generation plant;
- promote policies and interventions to support the electrification of consumption;
- involve a specific number of users in situations of economic hardship to combat phenomena of energy poverty;
- encourage the use of energy storage and management systems aimed at maximizing shared energy as well as enabling active community behaviors for the benefit of the electricity system such as, for example, the reduction of imbalances (of which the communities according to directives are fully responsible) and the provision of services to the transmission and distribution grid;
- promote energy requalification interventions;
- are able to enhance the territorial peculiarities by appropriately diversifying the generation technologies according to the site-specific characteristics." [37]

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[21] RSE "Ricerca Sistema Energetico", meaning Energy System Research

Other elements to be considered

- It is hoped, an acceleration in the plans for the diffusion of the new 2G meters, given that the ARERA Resolution 318/2020 highlights the use of conventional hourly withdrawal profiles, based on historical data and provided by the GSE, to compensate for all those cases where it will not yet be possible to determine the actual withdrawal through 2G meters. These conventional profiles will inevitably provide an hourly estimate of the withdrawals and therefore of the shared energy that is incorrect and statistically the more incorrect the less the aggregation of users will be (the same thing also applies to configurations equipped with energy storage systems);
- To promote investments in RECs configurations, it would be desirable to give stability (in terms of planning and temporal continuity of medium or long duration) to the 50% tax deduction and related assignment of credit for the installation of systems such as photovoltaic ones.
- A collaborative and transparent attitude on the part of the DSOs towards the new actors of the RECs is hoped for, given that the distributor has an important role in allowing and facilitating the RECs, and for this reason he will have to provide data on the PODs relating to the same primary cabin without problems.
- To comply with the need for operational safety and supply of the national electricity system, it would be appropriate to provide for a system for monitoring and communicating the operating data collected by distributors to the transmission network operator;
- It is hoped for the inclusion in the Energy Communities of plants for High Efficiency Cogeneration (CAR), in view of the transposition of the EU Directive 2019/944 on common rules for the internal electricity market, which introduces the Citizen Energy Community . These plants can play a role in promoting primary energy savings through the joint exploitation of thermal and electrical vectors and consequently in the local balancing of energy flows;
- In possibly more extensive territorial contexts where it may be necessary to build new network infrastructures and energy services for the Community, it is hoped that the experimentation of models, including physical models of the energy community, will be opened.

5. Conclusions

The use of renewable sources, prosumers, energy sharing and self-consumption to locally meet energy needs and the adoption of an intelligent infrastructure are all elements that make up the innovative model of a renewable energy community. This form of association provides for the active participation of a whole series of subjects present in the area, including citizens, institutions, distributors and producers of energy, companies.

In Italy, currently, there are just over 20 REC, not counting the new REC projects that are still in the development phase. Their effective diffusion could become particularly relevant with recent regulatory updates: in fact, nowadays there are new opportunities, given by public funds, and great advantages such as incentives and tax breaks, which combined are able to provide a new incentive boost and an acceleration in their development and diffusion.

It has been seen from the simulations made that, from the creation of the energy community under consideration, there is an effective economic return identifiable in the reduction of costs for the electricity supply and the increase in consumption awareness through the possibility of monitoring, as well as environmental and priceless but important social value. In addition to this, the enhancement of properties must also be considered, both for the improvement of energy efficiency and for the perception of the user, who feels from belonging to a community and from being an active part of a sustainable practice.

In any case, there are some aspects that are currently problematic to underline: from a social point of view, it is necessary that these projects are accepted among end customers, in addition to the fact that it is then necessary to assist the members of the REC; from a regulatory point of view, the Italian legislative framework is not yet complete and in some points it may be difficult to interpret, in addition to the fact that the shared energy incentive mechanism does not take into account fluctuations in energy prices, and in the face of a rise in prices (such as the one seen from 2021 onwards) the mechanism loses its effectiveness. It is therefore necessary that the remuneration be proportional to the price of energy; from a technical-economic point of view, the prices of storage systems are still too high, which makes them nowadays inconvenient to adopt, even if installed and shared between users of the energy communities.

In conclusion, regardless of the prices and the state of advancement of the technology, the regulatory completeness, the necessary acceptance of the REC by citizens, the development of these appears to be necessary and inevitable for independence from fossil fuel energy sources. Their diffusion makes it possible to address the environmental issue, due to the possibility of supply and greater use of energy from renewable sources, and the issue of energy poverty.

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