Politecnico di Milano

SCHOOL OF INDUSTRIAL AND INFORMATION ENGINEERING

Master of Science – Energy Engineering

Energy communities and collective self-consumption: regulatory assessment, market overview and techno-economic evaluation of the emerging applications in Italy

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Academic Year 2019 – 2020

Acknowledgements

This thesis was conceived within the context of the Honours Programme "Engineering for Sustainable Development", a parallel training programme of Politecnico di Milano aimed at enhancing the cross-discipline skills of future engineers, helping them to evaluate global challenges, in order to operate in the field of sustainable development.
The training course also included the development of a multidisciplinary master thesis, which in this case was conceived in collaboration with the Department of Management Engineering.

Ringrazio il Professore Simone Franzò per la disponibilità alla collaborazione per questa tesi interdipartimentale e Andrea, Niccolò e Camilla per l'aiuto ed il supporto nel lavoro di ricerca.

Sommario

Ambiziosi obiettivi in ambito energetico ed ambientale sono stati fissati dagli Obiettivi di Sviluppo Sostenibile dell'ONU e dal Green New Deal Europeo per assicurare a tutti l'accesso affidabile ed economico all'energia e per azzerare l'impatto netto della sua produzione; sono perciò necessarie soluzioni innovative per affrontare questa sfida. In questo contesto emergono i progetti di produzione collettiva di energia: sistemi di generazione distribuita di energia rinnovabile gestiti o finanziati direttamente dai consumatori, che assumono perciò un ruolo attivo nel sistema energetico.

Obiettivo di questa tesi è analizzare il contesto normativo, tecnico ed economico di sviluppo dei sistemi di produzione collettiva di energia e generare un modello di rappresentazione degli stessi per individuare gli elementi utili alla loro diffusione e gli interventi necessari a renderli sostenibili e vantaggiosi sia per gli utenti che ne entreranno a fare parte sia per il sistema nel suo complesso.

Il lavoro è cominciato dall'analisi dei progetti nati in Europa prima dello sviluppo del relativo quadro giuridico; sono state individuate strutture ricorrenti, vantaggi e svantaggi di ciascuna di esse. Altro aspetto analizzato è il contesto normativo europeo e dei Paesi Membri, fino ad oggi molto frammentario. Due recenti Direttive hanno però introdotto le definizioni di Comunità Energetiche e "auto-consumatori che agiscono collettivamente" creando una base forte per un prossimo sviluppo di questo fenomeno. Il processo di recepimento di queste direttive in Italia è stato avviato a febbraio 2020.

La tesi presenta poi il lavoro di sviluppo di un modello quantitativo per simulare la struttura di un progetto di generazione collettiva di energia, con tutti i flussi energetici ed economici che lo caratterizzano. Il modello si divide in due parti principali: la costruzione della domanda di energia della comunità, in base a tutte le caratteristiche delle utenze che ne fanno parte, e il dimensionamento degli impianti di produzione di energia di proprietà della comunità, in funzione di variabili tecniche ed economiche. Il modello dà in output tutte i dati necessari per descrivere la comunità e i suoi equilibri energetici ed economici.

Infine, il modello è stato applicato a due casi (un progetto di "auto-consumatori che agiscono collettivamente" e una Comunità Energetica Rinnovabile) per ottenere risultati quantitativi riguardo gli incentivi necessari al supporto di questi progetti e l'impatto economico e ambientale della loro diffusione sul resto della collettività.

Abstract

Ambitious energy and environmental objectives have been set by the UN Sustainable Development Goals and the European Green New Deal to ensure reliable and economic access to energy for all and to eliminate the net impact of its production; therefore innovative solutions are needed to face this challenge. In this context, collective energy production projects emerge: they are distributed renewable energy generation systems, managed or financed directly by consumers, therefore they assume an active role in the energy system.

The aim of this thesis is to analyse the legal, technical and economic context of development of collective energy production systems, and generate a quantitative model of them to identify the useful elements for their diffusion and the interventions necessary to make them sustainable and advantageous for both users and the whole system.

The work starts from the analysis of projects born in Europe before the development of the related legal framework; recurring structures and their advantages and disadvantages have been identified. Another aspect analysed is the European and Member States' regulatory framework, which are very fragmented. Recently, two Directives introduced definitions of Energy Communities and "jointly acting renewable self-consumers" creating a strong basis for the development of this phenomenon. In Italy, the transposition process of these directives started in February 2020.

Then the thesis presents the development work of a quantitative model to simulate the structure of a collective energy generation project, with all the energy and economic flows that characterize it. The model is divided into two main parts: the construction of the community's energy demand, based on all the characteristics of the users that are part of it, and the sizing of the community-owned energy power plants, based on technical and economic variables. The model outputs all the data necessary to describe the community and its energy and economic balances.

Finally, the model has been applied to two cases (a project of "jointly acting renewable self-consumers" and a Renewable Energy Community) to obtain quantitative results about the incentives necessary to support these projects and the economic and environmental impact of their diffusion on the rest of the community.

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1. Introduction

1.1 Context

Current European and world energy scenario makes policymakers, politicians and technicians face the big challenge of guarantee reliable and affordable energy for everyone managing, at the same time, the world climate emergency. In addition, Europe must face the energy security problem, given the dependence of its energy mix on extra EU countries' resources. To address this issue, goals have been imposed at different levels.

In 2010 European Commission proposed a ten-year strategy called European 2020 that contains three goals about energy sustainability and climate change:

- 20% of greenhouse gases emission reduction compared to 1990 levels
- 20% of energy demand provided by renewable sources
- 20% increase in energy efficiency

At world level, in September 2015, United Nations approved the 2030 Agenda for Sustainable Development. It is divided into 17 goals (the Sustainable Development Goals, SDGs) and 169 targets to be reached by 2030. The Goal 7, "Ensure access to affordable, reliable, sustainable and modern energy for all" impose, inter alia:

- By 2030, ensure universal access to affordable, reliable and modern energy services
- By 2030, increase substantially the share of renewable energy in the global energy mix
- By 2030, double the global rate of improvement in energy efficiency

In December 2015, at the Paris climate conference COP21, 195 countries adopted the first-ever universal climate deal, planning to put the world on track to avoid dangerous climate change by limiting global warming to well below 2°C and by pursuing efforts to limit it to 1.5°C.

Nevertheless, the path to reach these ambitious purposes is neither simple neither clearly defined: large investments are needed, grater land use is necessary for big renewable power plants, energy storage technologies are still expensive and, finally, increase renewable share in energy demand bring to some problems too, due to intermittency and non-programmability.

“Based on existing and announced policies – as described in the IEA Stated Policies Scenario (STEPS) – the world is not on course to achieve the outcomes of the UN SDGs most closely related to energy: to achieve universal access to energy (SDG 7), to reduce the severe health impacts of air pollution (part of SDG 3) and to tackle climate change (SDG 13).” (IEA, 2019)

1.2 Purpose

To face such a big challenge, we need to open the path to new types of energy initiatives. In particular, in this process two elements will be crucial:

- decentralisation of energy production, towards consumption sites
- empowerment of smaller actors in the energy market

and Energy Communities and Collective Self-consumption projects are one of the possible applications of these elements.

There are numerous and different definitions of energy communities and in general of collective energy production projects in literature. Here are reported some definitions considered interesting and complete:

“Sustainable energy communities (SECs) are organisations whose members are strongly involved in the planning and implementation of measures aimed at the rational use of energy and the introduction of renewable energy sources (RES) in the production, consumption and/or supply of electricity, thermal energy, mechanical energy or fuel.” (Romero-Rubio & Díaz, 2015)

“Clean energy communities (CECs) are social and organizational structures formed to achieve specific goals of its members primarily in the cleaner energy production, consumption, supply, and distribution, although this may also extend to water, waste, transportation, and other local resources.” (Gui, 2018)

"Energy Community can be defined as set of energy users who decide to make common choices to feed their energy needs with the aim of maximizing the benefits deriving from this participatory approach; it can be implemented through distributed generation solutions and intelligent management of energy flows." (Energy & Strategy Group, 2019)

So they are systems in which groups of users associate with the aim of self-producing energy at local level, therefore diffusion of Energy Communities can lead to some advantages:

- thanks to their structure, smart management of energy flows can be implemented, increasing the overall efficiency of the system;
- they are suitable to the diffusion of renewable power plants, leading to a positive environmental impact and increasing the national renewable share;
- diffusion of small, distributed renewable power plants is easier, in terms of investments and land use, compared to new large renewable power plants implementation managed at national level;
- thanks to shorter distance between energy production and consumption, network losses are reduced;
- thanks to proximity of consumers to their power plants, awareness about energy issue increase;
- buying less electricity from the grid, consumers can reduce their energy bills.

Therefore, the main purpose of this study is to analyse the phenomenon of Energy Communities in Europe: the forms in which this phenomenon developed before the evolution of the relative legislative context, and the opportunities that are opening up thanks to the new European directives and their transpositions in the legal framework of each Member State. Furthermore, basing on Italian recent legal framework developments, the potential economic and environmental impact in Italy is quantified through a model implementation.

1.3 Structure

The present study is structured as follows:

- *Chapter2* analyses the historical development of projects connected to Energy Communities in Europe. This happened before the development of the related legal framework, so the analysis aims to identify recurrent patterns, organizational structures and potential advantages and disadvantages of each form of collective energy production born spontaneously in Europe.

- In *Chapter3*, a detailed analysis of the European regulatory framework regarding collective energy production, and its recent evolution, was developed. Laws of the main Member States are also reported and finally, a more detailed description of the Italian regulatory framework was made. This analysis lets identify the direction toward which this phenomenon is moving in Europe and in Italy.

- *Chapter4* describes the development process of a quantitative model that represents energy communities and collective self-consumption projects in Italy. The model contains all the variables necessary to represent the energy and economic balances of the communities, in order to calculate the market conditions in which they can develop, by bringing advantage to users and to the overall system of the country. Finally, the model has been applied to two cases (a "jointly acting renewables self-consumers" project and a Renewable Energy Community) to obtain quantitative results about economic incentives needed and economic and environmental impact of these project.

2. Current European scenario analysis

In many EU Member States, different types of collective energy projects have emerged for a spontaneous need felt by the population before the European legal framework developed to support them, and these phenomena are increasing in last years. These projects are motivated by different goals and interests, supported by different business models and technologies. Therefore, current situation shows a scattered development that deserves to be analysed in order to understand the future developments and potentials of this phenomenon.

2.1 Methodology

To draw up an analysis of Energy Communities phenomenon, 344 existing cases distributed in all the European countries have been found and analysed. These are real cases that fall within the definition of Energy Communities previously given.

The research started from the REScoop database[1] (the database of the European federation of renewable energy cooperatives) and from case studies of some European energy projects[2]. It has proceeded basing on published researches about collective energy projects at national and international level and basing on national and regional databases[3]. Finally, further targeted researches have been carried out on the Internet, focusing on some countries or regions where the results were more interesting or, on the contrary, excessively poor.

[1] (REScoop.eu, 2019)

[2] (Compile Project, 2019), (Community Power, 2019), (Co2mmunity, 2019), (Clean Energy for EU islands, 2019) (CEER Report, 25 June 2019)

[3] Look at the bibliography for further references

For each of these cases, the following information has been collected:

- Name
- Country
- Legal form
- Main purpose
- Members
- Type of source
- Type of energy produced
- Power plants ownership
- Geographical boundaries
- Internal energy sharing
- Market access
- Activities (generation, consumption, sell, storage, …)
- Ownership and management of the internal network
- Local social or environmental initiatives undertaken
- Use of blockchain technology (for the energy trading or for other initiatives)
- Current status
- Starting year

Basing on these elements, four recurring structures have been identified within the cases analysed; these are four types of energy community in which the aforementioned elements are managed in a characteristic way. They have been analysed with reference to the categorization proposed by Emi Minghui Gui in its article "Typology of future clean energy communities: an exploratory structure, opportunities, and challenges"[4] which is presented below:

- **Community-scale energy projects**: community initiated and invested energy projects, that may involve renewable energies, energy efficiency and conservations, community energy services, etc.
- **Community Microgrids**: A self-contained and self-sufficient local electricity supply system, either standalone or connected to a centralized grid of regional or national scale, comprising residential and other electric loads, and can be supported by high penetrations of local distributed renewables, other distributed energy, and demand-side resources.

[4] (Gui, 2018)

- **Virtual Power Plants (VPPs)**: The aggregation of a fleet of controllable generation units, storage units, and loads, that are operated to behave like a (synthetic) single large power plant.
- **Peer-to-peer (P2P) Trading**: A software trading platform enabled by smart electricity infrastructure that matches renewable energy purchasing customers with local suppliers.
- **Integrated Community Energy Systems (ICES)**: An integrated urban resource management system, not only provide energy supply, but may also involve energy efficient buildings, combined heat and power, water and sanitation, transportation and waste to increase energy efficiency, and reduce greenhouse gas emissions at the local level.

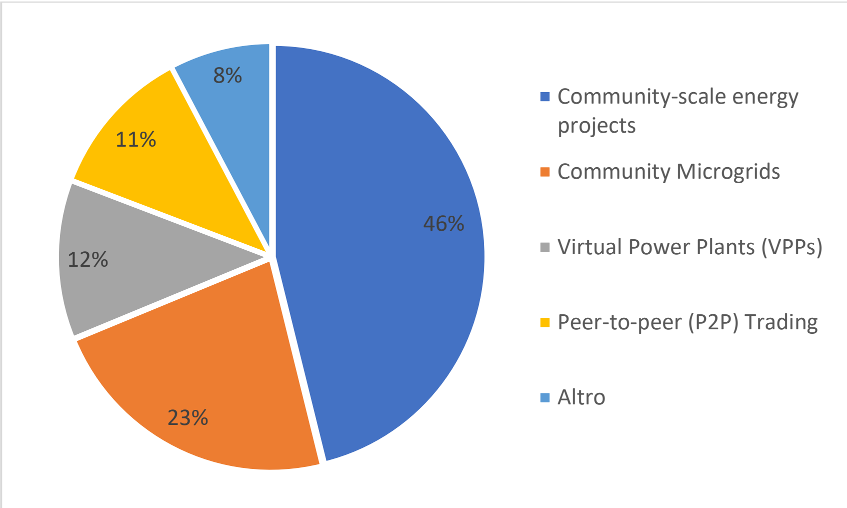
The last system is characterized by the presence of different activities and initiatives in addition to the management of the energy supply; these activities are beyond our main interests of investigation. For this reason, in our analysis this category has not been considered as a separate category but the cases that could match this definition have been distributed among the first four categories seen above, basing on their energy management configuration, and, for completeness, a note about the additional functions performed has been added.

Each case has been considered starting from these definitions and later all the cases fallen under the same category have been analysed together to identify all their common characteristics, the management of their activities and the strengths and weaknesses of each structure.

2.2 Results

Here the results of the data collected are presented starting from a general overview of the data then, in the next chapter, each energy community structure is analysed in detail, reporting characteristics emerged from the case study analysis.

Graph1 represents how the analysed European case are distributed into the different categories taken into consideration. It results that 92% of the cases falls under one of the definitions given in the previous chapter.

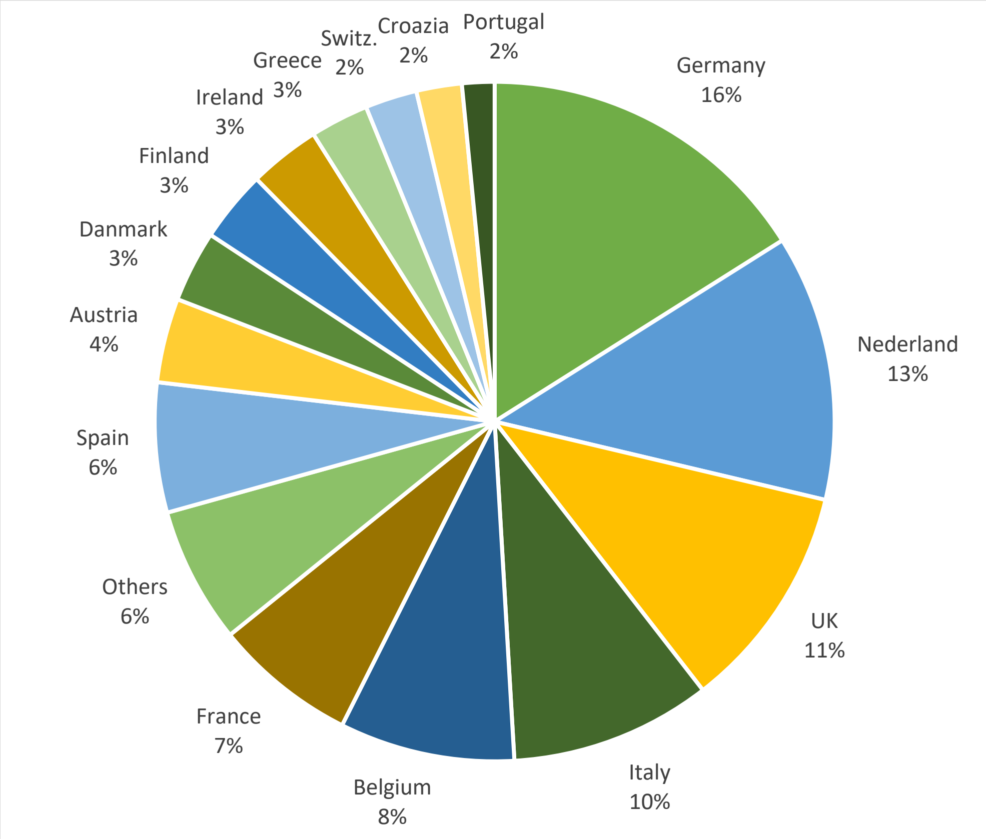


GRAPH 1 – ENERGY COMMUNITY CATEGORIES SHARE

However, the given percentage of the presence of a certain type of energy community, compared to the total of existing energy communities, does not correspond to the percentage of users involved in each configuration. This is because each structure provides different user basins: from a few dozen, up to thousands of people.

In general, for technical and economic reasons, to date Peer-to-peer (P2P) trading and Community Microgrids involve small realities, instead Virtual Power Plants (VPPs) need many users to be sustainable systems. Finally, the Community-scale energy projects do not have technical constraints for their operation, therefore they have very variable dimensions.

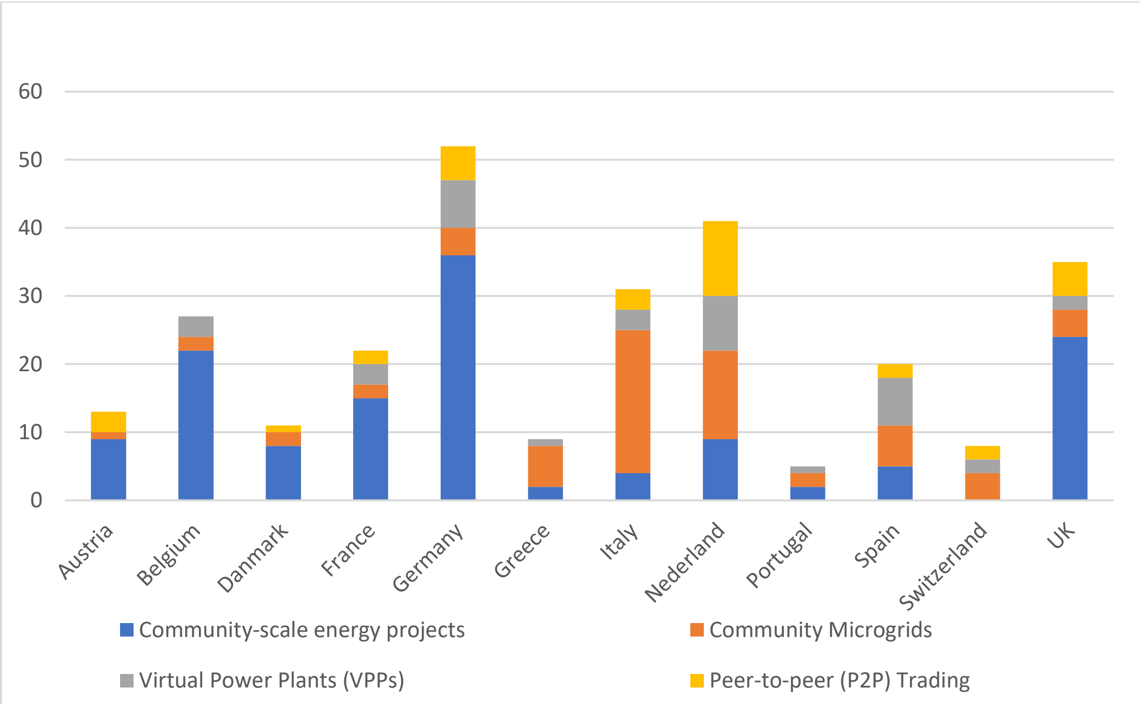
Graph2 shows the distribution of the analysed cases among the European Countries.
"Others" voice includes: Bosnia, Bulgaria, Cyprus, Estonia, Hungary, Luxembourg, Malta, Poland, Czech Republic, Romania, Slovakia, Slovenia and Sweden. In these Countries less than five cases have been found.
From *Graph2*, it is possible to see where this phenomenon developed the most. It is important to notice that the amount of cases found in Italy is not directly comparable to the number of cases found in the other Countries because this study has a direct focus on the Italian scenario and so the analysis in this Country has been deeper. The Italian data are strongly influenced by the presence of mountain energy communities born at the beginning of the XX century to compensate lack of connection to the main grid; they are one third of the Italian energy community analysed.



GRAPH 2 - DISTRIBUTION OF PROJECTS AMONG EUROPEAN COUNTRIES

The greater presence of Energy Communities in some countries than in others is due not only to the legal framework of the country, that in some cases has been supportive and in others created obstacles to the birth of new projects; but also and especially it is due to the cultural background of the country. In general, the four structures of communities' energy projects here analysed don't need specific laws to develop; they mostly need users initiatives. This matter will be explained in more detail in the analysis of the four structures in *Chapter2.3*. Legal framework of main countries will be reported and analysed in *Chapter 3.2*.

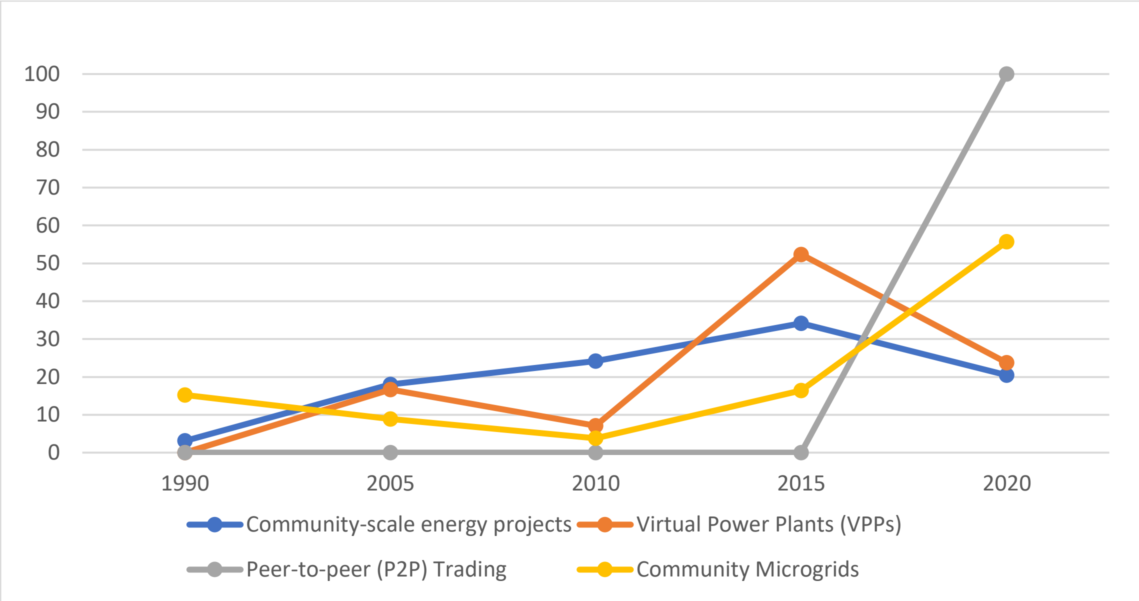
Graph3 shows the distribution of the four structures of energy community within each country. As previously said, each county is different in legal framework and cultural background and this affected both the presence of a different number of projects in the countries, and the distribution of these among the four types of structures identified.



GRAPH 3 – EUROPEAN COLLECTIVE ENERGY PROJECTS

As we will see, Community-scale energy projects are the ones that are most driven "bottom-up", they born from users' awareness about the energy issue and about the chance citizens have in participate in the renewable energy share increasing. On the opposite, Peer-to-peer trading projects and the new Community Microgrids need for an action "top-down" because they high-tech structure.
So, the different development among the countries is strongly related to political, energy and social choices.

Each type of energy community has its own period of greatest development; this fact is show in *Graph4*. The graph has been built basing on the project start dates, representing the distribution over time of the new initiatives; each point indicates the percentage of projects of a given category, that developed in that year compared to the total of the projects of that category. The 2020 data also contain all the cases still in the planning phase.



Graph 4 - Percentage of EC born per year

Looking at the "Community Microgrids" trend, it shows two periods of maximum development: during the XIX century and in the last ten years. This shape is due to the fact that this category contains two different types of energy projects: first simple energy communities, born for the need to bring electricity to the most remote areas, and new innovative Smart Grid. These cases fall within the same classification because both are energy project in which people share energy self-produced, through a private network in a limited geographical area. Further details about their similarities and differences are reported in *Chapter2.3.2*.

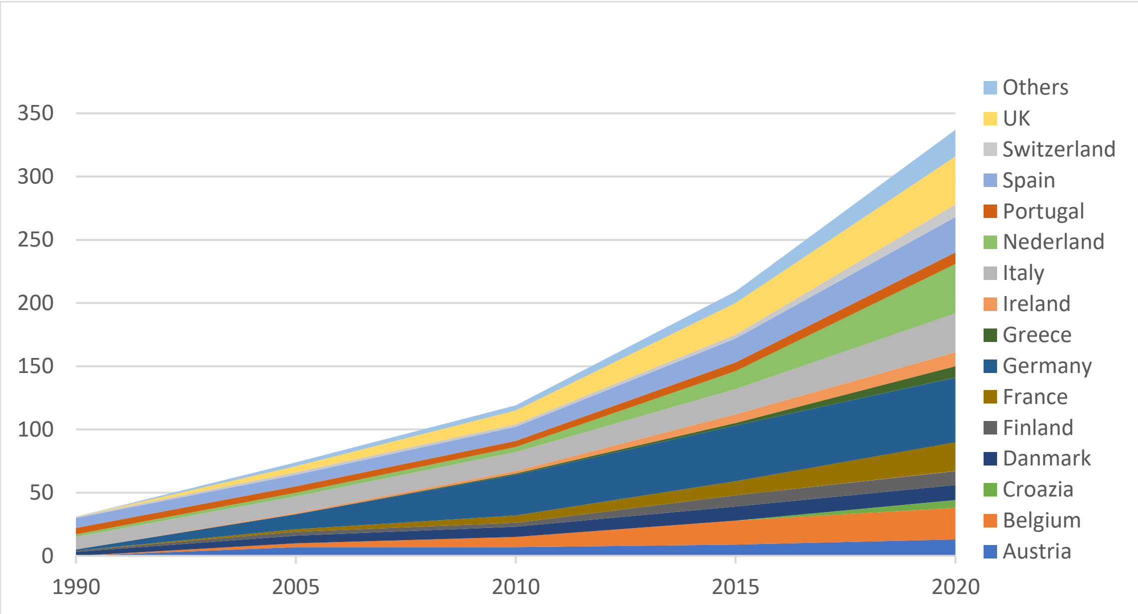
The graph shows that the "Community-scale energy projects" have seen great diffusion until 2015, while in recent years most of the new projects undertaken are the most innovative Smart Grid and Peer-to-peer trading, which experience the new possibilities allowed by technological and legislative developments.

The same historical data (but cumulated) are reported in the *Graph5,* divided by countries. As we can see, the energy communities' phenomenon, which has continuously increased, has not developed uniformly in the Countries.

Italy, Spain and Portugal have projects dating before 1990, which are the projects born spontaneously by populations living in remote areas; but in the following years have not seen significant development of new projects. There is a recovery after 2010 thanks to some research projects but the lack of legislative support has not allowed a significant development of this phenomenon.

Germany, UK, Belgium and France are the countries where there is a greater presence of Community-scale energy projects, as can also be seen from *Graph3*. This type of community developed first in Germany and the UK, where we see an increase in the presence of energy communities starting in 2005, subsequently in Belgium (peak in 2015) and finally in France, where numerous Community-scale energy projects have been founded also between 2016 and 2019.

Nederland, UK and Greece show an important development in recent years; this is given by the legislative initiatives supporting the development of energy communities that have occurred in recent years in these countries[5]. These initiatives have been a good stimulus for the development of new projects, they will be analysed in more detail in *Chapter3.2*.



GRAPH 5 – HISTORICAL DEVELOPMENT OF EUROPEAN ENERGY PROJECTS

Finally, here are reported the data regarding some of the characteristics mentioned in *Chapter2.1,* useful to describe the phenomenon of energy communities. From the data collected it emerges that most of the communities:

- provide only electricity (74%)
- have geographical boundaries (74%)
- don't have further local social initiatives (81%)
- produce energy from renewable sources

[55] (The Official Guide to Greek Law, 2019), (Ofgem, Insights from running the regulatory sandbox, 2019) (Overheid.nl, 2019)

2.3 European Energy Communities' features

In this chapter, main features of the four energy community's structures introduced above are reported. They have been investigated in depth based on the real European cases analysed, following the methodology Chapter2.1.
The analysis is proposed in a descriptive way and later summarized in its main parts. The Annex A contains all the information collected for each community analysed, with its bibliographic references.

2.3.1 Community-scale energy project

This is the most diffuse structure among the projects identified (46% of the total).
In this configuration, people join to invest in the installation of new renewable energy power plants. Members may pay different fees for the purchase and installation of the systems; the power plants become property of all members. The energy produced by the community plant is not self-consumed; it is fed into the public grid and therefore remunerated according to the rules in force in each country, or sold to an energy supplier. The resulting profits are redistributed among the members or re-invested for other activities to benefit the local area.

Members of this kind of energy community are citizens, sometimes supported by local authorities, and only in few of the cases are involved also small local businesses.
Most of the projects considered are born from people initiative, they are composed by people who met on the basis of a common purpose. The main reasons behind these projects are: reducing dependence on fossil fuels; give this possibility even to those who cannot afford the investment by themselves; increase user awareness of the energy issue; investing in the local area, bringing energy production and consumption closer; save on bills; make a profitable and sustainable investment.

In other few cases, this kind of community is born on a top-down initiative of local authorities, research groups, external investors (local businesses or local banks), or other "umbrella cooperatives" that support the development of numerous energy projects. In Spain, for example, the few "community-scale energy projects" identified are all "umbrella cooperatives", that develop new projects in response to the lack of spontaneous initiatives from the citizens.

The legal form in which citizens associate is almost always the cooperative or an equivalent form (association, social enterprise, private-public partnerships, ...).

The structure of this kind of community is the simplest to implement and has no specific legislative limits; these are the reasons why it is the structure most widespread in Europe. For the same reasons, this type of project has started to spread since the 1990s, but the period of maximum development was between 2005 and 2015.

Looking at the distribution among countries of this kind of projects, it can be deduced how their diffusion depends on local legislation which in some cases supports more such initiatives (as in Germany, Belgium, United Kingdom and Denmark) while in others cases has been limiting (as in Spain and Portugal). Furthermore, the influence of a cultural component must be considered: there is a greater presence of community-scale energy projects in countries where this kind of initiative has started to spread since many years (France and Belgium, Denmark and Nederland), and greater resistance to diffusion in countries where the local population is less accustomed to this type of community initiative (Italy, Greece and Portugal). For further details about the difference in historic development of energy community project in European countries refer to *Chapter3.2*.

In these projects there is no energy sharing between the members and there is no need to establish private grid. The power plants can be installed in a diffuse way (for example photovoltaic panels on the roofs of the members) or in a single place (roof of the neighbourhood gym, or of another public building) which can also be far from investors (solution used for larger plants, such as wind turbines).

In these energy communities there is no geographical constraint to be respected, however, in most of the cases analysed (more than 80%), the communities developed in a limited space, gathering the members who are in a single city or region; this is certainly related to the aforementioned desire to act as a community. For the other cases analysed, the investment is made by users scattered throughout the country, contacted for example online. In this case, main objective is to spread the culture of self-production in the population at national level.

The source of energy is always renewable. The choice of the source depends on the space available (e.g. solar panels if the properties of individual members have been widely used), on the availability (wind turbines in the north of the United Kingdom and in Denmark, photovoltaic panels in Portugal and in Italy) and by local culture, which inevitably affects those projects that come from below.

Finally, there is a significant presence of social initiatives developed by the community in parallel with the energy production activity (they are present in 25% of the cases analysed). This fact is conditioned precisely by the nature, described above, of this type of community. Main examples of social initiatives are: training for citizens on energy issues and energy efficiency, creation of jobs (if the facilities are installed in the vicinity of the community), creation of a public library or kindergarten, and support for other local social initiatives.

2.3.2 Community Microgrid

This is the second most widespread phenomenon (23% of the communities we analyse). It provides for self-production and local sharing of energy produced to constitute a self-sufficient (or almost self-sufficient) and geographically limited community. These self-systems generally include a storage, but the community is still connected to the central network to make up for any shortcomings. These communities do not usually participate in the electricity market.

Given the geographically limited nature of this type of community, heat exchange is also possible without excessive technical limits; about half of the communities analysed produce heat too.

Among the communities listed as "Community Microgrid", two very different groups can be identified based on the reason for their formation:

- communities born out of need or desire for energy autonomy, in places not well connected to the central network or to other centralized energy production plants (mountain areas or islands)
- communities created for research purposes to optimize consumption in a limited environment and optimize the use of renewable energy

Community Microgrids are found also in Countries where energy sharing is forbidden, since they are legitimized thanks to exceptions introduced for research purposes or as an aid to remote or special areas.

We deal separately with the analysis of the two cases as they arise from different purposes and therefore developed with different characteristics.

In "remote" communities, whose main objective is energy autonomy, production takes place in a few medium-sized plants owned by the community, such as in the "Community-scale energy project"; however, the energy produced is distributed directly to members (and, often, also to other users, not necessarily members of the community).

The transport and supply of energy are also managed by the community, which for this reason has the concession for the management of the local network.

Some of these communities are also the oldest European energy communities, precisely because they were born out of the need to bring electricity to historically inaccessible areas, a need that developed in Europe around the early 1900s (this is the case of the Italian mountain communities). Others were born later, starting in the early 2000s, in remote villages that want to achieve energy independence to reduce management costs for their users and in islands that seek independence from the importation of diesel fuel from the mainland (there are examples scattered in different countries, supported by European projects such as the "Clean Energy for EU Islands" project[6]).

These communities are generally associated as cooperatives, and their members are locals and local businesses. Only a small part of the members actively collaborates in the organization and management of the system while the majority participate only as a user of the service.

Regarding technology, some of these communities have the constraint of producing only by renewable energy but in rare cases production also takes place with non-renewable plants, since environmental sustainability is not the first objective of these realities. Furthermore, they don’t offer energy efficiency services to the grid, however, compared to the "Community-scale energy projects” the proximity between production and consumption and the need for energy autonomy lead, at least as a goal, to better management of consumption.

Although these communities are geographically circumscribed, and therefore with good contact with the territory, we have found infrequent local social initiatives (in 12% of cases), probably as communities born to respond to an energy need, before a need of participation.

The main countries where these realities are located are UK (islands and remote areas especially in the north of the country), Italy (they are mainly mountain communities, but also some islands) and Greece (in the islands).

Now let's analyse the "Community Microgrids" born as a research initiative, these can also be called Smart Grids, they are innovative projects developed in Europe in the last decade but with an intensification of initiatives since after 2015. These projects are always born with a top-down process, where a research group (public or private), a

[6] (Clean Energy for EU islands, 2019)

company, or local authority decide to invest to develop an innovative solution in a certain place.

The community can be organized with few "centralized" plants, financed and managed by the entity in charge of the project; or with multiple systems distributed among the users involved, in this case the systems can be owned by the relevant user, even if installed on the initiative of the entity promoting the project.
These communities are powered only by renewable energies, for the purpose of research on the optimization of these plants.

Being projects for research purposes, they often also involve research on electric vehicles, and include actions to improve the efficiency of the buildings involved; in some cases the Smart Grid is developed in new neighbourhoods, where buildings are already low in energy consumption. Often the users involved are equipped with smart meters with which users can control their consumption and in some cases an application has been developed with which to keep the production of the systems under control. These elements allow a more efficient use of energy.

In the projects analysed, the users involved are rarely grouped in a legal form since they do not come from a group of citizens who need to join in order to act as a community, but on the initiative of research centres or local authorities. Users involved are: domestic, commercial and industrial users, depending on the area of construction. However, these projects can then include a second phase (some explicitly declare it, but it is still possible in all of them), after the technical optimization, which activates a greater and more direct involvement of users.
These forms of energy communities almost never triggered other social initiatives in the area (4% of cases).

The country with the greatest presence of the Smart Grids identified by us is Nederland, where in fact their development was promoted through a specific law[7]. The country where Smart Grids are the most widespread form of Energy Community is Switzerland, where several innovative initiatives have developed since 2017, even if they were not born with a research intent on Energy Communities but on Smart Cities.
In Greece and Spain, despite started late compared to other countries, there has been an interesting increase in Community Microgrids also thanks to the thrusts given by the

[7] (Overheid.nl, 2019)

new law on Energy Communities[8] and by European projects in the field of promoting energy efficiency and the diffusion of renewable energies[9].
Even in Italy, although there is still no push on the development of Energy Communities, several research projects have been developed on Smart Grids, we refer to the attachment for a more in-depth analysis of these cases.

2.3.3 Virtual Power Plants (VPP)

The energy communities that we have identified as VPP are 12% of the total. These are communities of producers, consumers and prosumers, also located very far apart, which, thanks to the intervention of a common supplier, exchange (only virtually) the energy produced through the public network. The supplier also buys additional energy from the electricity market and supplies it to its users, if that produced by the members is not enough to cover the needs of the community.

The development of the "Virtual Power Plants" took place from the early 2000s, thanks to the liberalization of the electricity market, and spread evenly in the various European countries, since it was not linked to the presence of laws allowing the sharing of energy.

In this case, the legal form that gathers all the members is always determined as the presence of a central entity that is the intermediary between the different actors is necessary. This is the role of the energy supplier, which, in the cases we analysed, is generally set up as a cooperative, in which producers and consumers are the members.

Reasons behind the foundation of a community of this kind are support for the development of renewables (in fact this is the only type of source present), support for small energy producers, stimulate the participation of end users.
Becoming a member of this community does not bring about significant reductions in user bills; the same suppliers offer customers to join the cooperative to support their values, and not to obtain an important economic advantage.

Members of the community are therefore domestic, industrial or service users, interested in financing only the development of renewable energies; and small producers, communities of producers, or prosumers, who seek support for their business, and a more active participation than simply releasing the energy produced on the network, as happens for the "community-scale energy project".

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[8] (244/2019, 5 de Abril), (The Official Guide to Greek Law, 2019)
[9] (COMPILE, June 2019)

All these actors activate a contract with the same supplier for the purchase and sale of energy. The supplier certifies the origin of the energy sold, including that purchased in the energy market, to ensure that it comes from renewable energy plants. The exchange of energy is only "virtual", certified by contracts between users and the cooperative.

This form of energy community allows, from a technical point of view, not to have a geographical limitation to the distribution of members (consumers and producers). Nonetheless, in some cases (23% of the total) the members of the cooperative are limited to a certain area, but only by choice of the cooperative which has decided to serve only local users with the aim of supporting local activities.

To describe this type of energy community it is also necessary to observe that the same organizational form can arise from different paths:

- In most cases (70%) the cooperative is set up by the supplier, who subsequently contacts as many users and producers as possible to implement the exchange. They can join the cooperative as members (and therefore also take part in the decision-making processes) or act as simple supplier customers. The producers can themselves be production cooperatives, or even “community scale energy projects”. In this case, the supplier often also implements his own production projects at a later stage, proposing members to participate in setting up "community scale energy projects". In these cooperatives we therefore have the presence of different roles and levels of involvement for the members. The plants can therefore be owned by the cooperative or by individual producers.
- Alternatively, especially in countries with a strong presence of "community-scale energy projects", it happens that the supplier cooperative is set up by many different production cooperatives, which join together to become suppliers of their own energy, instead of simply continuing to sell the energy to the grid. In this case the plants are owned by the various cooperatives.

In 17% of the cases analysed, these communities also undertake other social initiatives, above all with regards to raising awareness on the energy issue; together with the Community-scale energy projects, they are therefore the two configurations that provide for a significant percentage of social projects additional to the basic energy project. This element is justified once again by the mechanism underlying the foundation of these communities: the members are driven by values of environmental and social sustainability and therefore they are interested in supporting other local social projects.

2.3.4 Peer-to-peer (P2P) trading platform

This kind of Energy Community is certainly the least common type (11% of the projects analysed). The main reason is certainly the technological support it needs which makes these communities the ones that have developed most recently and that their development cannot be driven by a bottom-up process.
The subjects involved in this type of community are consumers, producers and prosumers, who share the energy produced by bypassing the presence of a common supplier, and in general of a third party who certifies the exchanges.
This mechanism requires the use of blockchain technology to certify peer transactions and to manage the large amount of data involved, without incurring privacy issues.

For the exchange of energy between members to take place, they must have energy production plants and smart meters, through which they can control their production and consumption instant by instant. They then have a platform for the exchange of energy which, through an algorithm, optimizes the exchanges between the different users, also determining the price at which the energy is sold and bought, based on the supply and demand in each time interval considered.
This is a more efficient method of energy exchange, which allows to maximize the demand response within the community and therefore to minimize the imbalances created on the data network by the increasing use of non-programmable renewable sources. Thanks to the community functioning system, the exchange of energy takes place through the public grid. Usually the community does not participate in the energy market but it can offer energy efficiency services.

The technologies involved are only renewable by design choice. These projects are born in fact for research, to maximize the energy efficiency of systems containing renewables through the new technologies available. They are therefore also, like the Smart Grids, projects that develop top-down, since the technology necessary for their operation is not within the reach of a simple community of citizens. The legal form is therefore often not determined, as in the case of Smart Grids, because the direct involvement of citizens takes place as a subsequent step in the development of the project.
These projects are promoted by research centres, or in the context of European projects, or by energy or IT service companies that test their developed technologies. The users involved are mainly citizens and SMEs.

All the projects implemented are limited to a certain area, a residential complex or a neighbourhood, but this characteristic is determined more by the need for simpler project management than by technical limits. Virtual energy exchange projects between producers and consumers geographically distant from each other are being studied. The projects we have identified, in fact, were all born after 2016, but most have not yet been fully implemented.

2.4 Analysis conclusions

To conclude the analysis, the main characteristics of the energy communities' structures analysed are summarised in the table below.

	Community-scale energy projects	Remote Community	Smart Grid	Virtual Power Plants	Peer-to-peer Trading
Members	Citizens, local authorities	inhabitants, local enterprises	research groups, companies, local authorities	producers, consumers and prosumers	producers, consumers and prosumers
Key activities	Investments in renewable energy plants	production and distribution for its members	Renewable production and consumption optimisation	share self-produced energy among distant users	Energy sharing without third party certification
Purpose	Reduce dependence on fossil; investing on local area; sustainable investment	Energy autonomy	Research	support renewables and small producers, stimulate participation of end users	optimization of energy consumption and sharing
Power plants ownership	Community	Community	-	Members	Members
Geographical boundaries	No	Yes	Yes	No	No
Internal energy sharing	No	Yes	Yes	Yes	Yes
Ownership and management of the grid	Public grid	Private grid	Private grid	Public grid	Public grid

TABLE 1 – MAIN CHARACTERISTICS OF COMMUNITY STRUCTURES

Finally, here are reported the most interesting positive and negative consequences deriving from the development of each type of energy community defined. This is useful for identifying the key elements of these projects, also in relation to the energy, environmental and social issues described in the introduction to the thesis.

Community-scale energy projects have the main advantage to involve directly the users and to be mainly driven by social and environmental citizens' values. These are key feature to increase people awareness about the energy issue and to increase people acceptance of new renewable energy plants nearby their place of residence. Another positive element of this structure is that it doesn't need a specific law to develop; this allows wide spread of this structure in all the Countries. All these characteristics are important to allow the increase in the renewable share that is needed in Europe.
Main negative factor of this framework is that it doesn't involve actions to increase efficiency on the demand side; the structure of this energy community doesn't encourage to consume energy during the production peak, that is an important element to take into account on the path to an increased share of renewables in Europe.
The increase in the share of renewables, not accompanied by measures to optimize consumption, cannot be considered a fully positive element. In this regard, social training initiatives for citizens on energy efficiency can somehow compensate for this lack.

As said before, the Community Microgrid structure must be analysed separating the two cases: remote communities and smart grids.
The first one has some characteristics in common with the community-scale energy projects. It involves directly the users, and the proximity between production and consumption sites increases people awareness about energy issue although it doesn't promote directly actions about efficiency in the demand side. A negative element is that these communities has not the focus on renewable energy diffusion.
About smart grids, main positive aspects are the aim of increase energy efficiency, both in the production and consumption side, and the contribution given to the development of renewable power plants and their functionality. The main negative aspect is lack of citizen involvement in the project phase and the need to invest large public funds for research for the development of these projects.

Virtual Power Plant projects have as main advantage the large number of users that can be involved by one community. Also, VPP communities support small renewable energy producers. VPPs could provide is balancing system between renewable production and consumption on the network, although this aspect should be developed further; but they still have good theoretical potential to provide flexibility to the network.

About negative aspects, in this structure often the users are not directly involved, also because of their dispersion in geographical terms; but they are in any case united by the goal of incentivizing renewable energies and therefore they are fertile groups for the activation of further social initiatives.

Finally, Peer-to-peer energy trading are very innovative and promising projects. They develop systems that allow a significant increase in energy efficiency, both from the production and the demand side. Their focus is not on the renewable sources, but these systems will have a big improvement from the peer-to-peer energy management.
Negative aspects of this structure are, as for the smart grid energy communities, the users' involvement, that is still limited due to the high level of technology needed to make the system work. *Table2* summarised the elements described.

	Energy efficiency services	Increase share of renewable	Local social initiatives	People involvement	Increase people awareness	Demand management
Community-scale projects	No	Yes	Yes	Yes	Yes	No
Remote Microgrids	No	No	Yes	Yes	Yes	-
Smart Grids	Yes	Yes	No	No	No	Yes
VPP	No	Yes	Yes	-	Yes	No
P2P Trading	Yes	-	No	No	Yes	Yes

TABLE 2 - MAIN ADVANTAGES AND DISADVANTAGES OF COMMUNITY STRUCTURES

To conclude, the elements identified as supporting the development of new energy communities are given:

- supportive legal framework
- correct information to the population about existing technologies and energy community projects
- population awareness about the energy and environmental issues
- presence of "umbrella cooperatives" that support the development of other energy cooperatives

This analysis lets better understand the scenario in which the new European directives are operating, and which are the most important action to be taken to support the development of collective energy self-consumption in Europe.

3. European legal landscape

As described in the previous chapter, self-consumption and various forms of community-driven energy projects have been present in Europe from the beginning of the 20th century, definitely before the legal framework clearly defined them. Just in recent years, the technology improvements let the decentralised energy production and management more accessible, making legislative intervention necessary to regulate the existing projects and letting develop new ones, having identified them as an important driver in the deployment of renewable energy.

European estimates suggest that by 2030, energy communities could own about 17% of installed wind capacity and 21% of solar; and that by 2050, almost half of EU households are expected to be producing renewable energy. (Clean energy for all Europeans, 2019)

The inclusion of energy community projects in European legal framework started with the publication, on 25 February 2015, of the **Energy Union Strategy** by the European Commission. This document aims at strengthening the energy union and at improving the energy service for EU consumers making it more secure, sustainable, competitive and affordable. It gives a framework to pursue the mentioned goal working on different dimension at the same time: diversification, solidarity between EU countries, fully integrated internal energy market, efficiency, decarbonisation, research and innovation.

> "The Commission will prepare an ambitious legislative proposal to redesign the electricity market and linking wholesale and retail. This will increase security of supply and ensure that the electricity market will be better adapted to the energy transition which will bring in a multitude of new producers, in particular of renewable energy sources, as well as enable full participation of consumers in the market notably through demand response. […] One of the priorities: facilitate consumer participation in the energy transition through smart grids, smart appliances, smart cities and home automation systems"
> ("Energy Union" Package - A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, 2015)

Even though self-consumption, prosumers or energy communities, are not directly mentioned in the document, it clearly opens the way to the legislation of these systems, naming "multitude of new producers", "participation of consumers" and "smart grids".
To pursue the Energy Union Strategy, some packages of measures have been published; central is the **"Clean Energy for all Europeans"** Package (CEP) initially published on November 2016 and completed in March 2019. It is a new energy rulebook that brings to a comprehensive update of European energy policy framework, also providing an important contribution to the EU's long-term strategy of achieving carbon neutrality by 2050.
In the final document delivered by the European Commission, among other measures to provide new opportunities for citizens and benefits from different angles, it promotes the transition to a more decentralised energy system where consumers play an active role:

> "Consumers need to be at the centre of a renewed EU energy system: improved rules that will give them more flexibility and better protect them, but also allow them to take their own decisions on how to produce, store, sell or share their own energy. More control and more access for consumers will translate into better quality of life and better finances. And this democratisation of energy will alleviate energy poverty and protect vulnerable citizens. […] The new rules promote this actively with provisions on self-consumption of energy, and local and renewable energy communities."
> (Clean energy for all Europeans, 2019)

Here Energy Communities are mentioned for the first time, highlighting their economic and social advantages for citizens.

The Clean Energy for all Europeans Package contains several legislative acts, about energy performance in buildings, energy efficiency, governance regulation, renewable energy and electricity market design. It includes also non-legislative initiatives aiming at facilitating the clean energy transition and ensuring that it is a fair transition for all Europeans citizens. EU countries have 1-2 years to transpose the new directives into national law.

Focusing on self-consumption and energy communities, the most important directives following the CEP are two:

- the **Renewable Energy Directive (RED II)**, that has as main purpose to increase the renewable share and to raise public acceptance for renewable projects; it sets a target of 32% for renewable energy sources in the EU's energy mix by 2030 and introduces the definition for "Renewable Energy Communities" (RECs) and for "jointly acting renewables self-consumers"
- the **Electricity Market Directive (EMD II)**, that has as main purpose to adapt the EU electricity market to technological and structural changes taking place in these years; it introduces the definition for "Citizen Energy Communities" (CECs) as a new market actor

Whilst collective self-consumption has been recognised in certain EU national legal frameworks or within pilot projects, this is the first time that this concept is formally recognised in EU-level legislation. This is a turning point for the European energy market because to define energy communities let recognize them and enable their creation.

In the *Chapter3.1*, we describe characteristics and differences of "Citizen Energy Communities", "Renewable Energy Communities", and "jointly acting renewables self-consumers" emerging from the directives.

3.1 European Union Initiatives and analysis

3.1.1 Directive (EU) 2018/2001 on the promotion of the use of energy from renewable sources (RED II)

The original renewable energy directive (2009/28/EC) establishes an overall policy for the production and promotion of energy from renewable sources in the EU, it contains the 2020 energy objectives. In December 2018, the revised renewable energy directive 2018/2001/EU entered into force aiming at keeping the EU a global leader in renewables and, more broadly, helping the EU to meet its emissions reduction commitments under the Paris Agreement. The directive needs to be transposed into national law by Member States by 30 June 2021.

Going deeper into the legislation analysis, the RED II directive is crucial because it promotes the possibility of creating renewable self-consumption systems involving

multiple users and introduces the definition of “Renewable Energy Community” for the first time in Europe.
This and other useful definitions contained in Article 2 of the directive are reported below:

1. “renewables self-consumer” means a final customer operating within its premises located within confined boundaries or, where permitted by a Member State, within other premises, who generates renewable electricity for its own consumption, and who may store or sell self-generated renewable electricity, provided that, for a non-household renewables self-consumer, those activities do not constitute its primary commercial or professional activity;

2. “jointly acting renewables self-consumers” means a group of at least two jointly acting renewables self-consumers in accordance with point (14) who are located in the same building or multi-apartment block;

3. “renewable energy community” means a legal entity:
   - which, in accordance with the applicable national law, is 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;
   - the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities;
   - 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;

Self-consumption, as final customer that consume, store and sell energy he produces on-site, is not a new concept in most of the European legislation, but the “renewable self-consumer” definition helps in differentiate the prosumer of both traditional and renewable energy from the ones that operate only with renewable sources, to better support them.

The “jointly acting renewables self-consumers” is the first level of aggregation of prosumers recognised. The only constraint people must respect to join is to be in the same building or multi-apartment block; they don’t have any indication about the primary purpose (economic or social) their activity must have, and about the nature of their jointly acting as separate subjects. This definition definitely opens to self-consumption in condominiums, shopping centres or similar situations, where money

saving is probably the main aim of the decision to became self-consumers and to act together with people live or work near you.
Article 21 of the Directive deeply analyses this definition; it establishes actions that "jointly acting renewables self-consumers" can take and its constraints:

"self-consumers located in the same building, including multi-apartment blocks, are entitled to engage jointly in activities referred to in paragraph 2 (to generate renewable energy, store and sell their excess production) and they are permitted to arrange sharing of renewable energy that is produced on their site or sites between themselves, without prejudice to the network charges and other relevant charges, fees, levies and taxes applicable to each renewables self-consumer. […] The renewables self-consumer's installation may be owned by a third party or managed by a third party for installation, operation, including metering and maintenance." (Directive (EU) 2018/2001 of the European Parliament and of the Council, December 2018)

The "renewable energy communities" (REC), on the contrary, have the clear primary purpose of providing environmental, economic or social community benefits for the members or for the local areas where they operate, so here the "community" aspects are wider. Furthermore, the members must be established as a legal entity, and the renewable energy projects must be owned and developed by that legal entity itself. So, in the RECs members take action as a single entity, and there is a clear indication about who can join the community.
Finally, the directive requires shareholders to be located in the proximity of the renewable energy projects, without the constraint of being in the same building; this provision gives more flexibility to who wants to establish a community driven by not purely economic intentions, letting them find members in a wider area. However, we highlight that the term "proximity" gives the geographic constraint without a more precise definition; the setting of the specific meaning of the proximity constraint is left to the Member States.
The Article of the directive referred to the RECs is the Article 22; it specifies all the activities that RECs can take and how Member States shall and may act to support them and their members.

We will go deeper in the content of the Articles22 in the *Chapter3.1.3* about REC and CEC comparison.

3.1.2 DIRECTIVE (EU) 2019/944 on common rules for the internal market for electricity (EMD II)

This directive aims to update the design of the EU electricity market, given the degree of integration and changes in technology seen in recent years, by allowing more flexibility to also accommodate an increasing share of renewable energy in the grid. It proposes changes in the market to provide the right incentives for consumers to become more active and to contribute to keeping the electricity system stable. To address these issues, the EU has updated the Electricity Directive (2009/72/EC) and the Electricity Regulation (EC/714/2009), the new rules were formally adopted in May 2019; for the Directive, EU countries have 18 months to transpose the new measures into national law.

For us, the crucial point of the EMD II is to first introduce the "Citizen Energy Community", beside the "active customer", whose definitions are reported below:

1. "active customer" means a final customer, or a group of jointly acting final customers, who consumes or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes, provided that those activities do not constitute its primary commercial or professional activity;
2. "citizen energy community" means a legal entity that:
    - is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises;
    - has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits;
    - may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders;

The concept of "active customers" includes also groups of jointly acting customers, whereas the RED II defined "renewables self-consumer" and "jointly acting renewable self-consumers" separately. Moreover, contrary to the RED II definitions, here the production of energy by renewable power plant is not imposed, letting free the choice of the technology installed by the active costumers. Instead, it is highlighted the role of active costumers as participants in grid flexibility or efficiency schemes.

This is due to the main purpose of the EMD II directive: no longer to increase the renewable share but to improve citizen participation in the energy market and flexibility services.

This concept is reflected in the CECs definition too, where, in addition to the activities proper to the RECs too, the point c lists all the new activities in which CECs can take action: distribution, supply, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders. So, CECs organizational structure can be used by citizens, small businesses and local authorities to participate across the energy sector.

Other elements in common to the RECs are the need to be established as a legal entity and the primary purpose of providing environmental, economic or social community benefits to their members or for the local areas where they operate, and the subjects that can join the communities.
We point out the lack of reference about the geographical constraint of proximity of the elements constitute the citizen energy community.

To better describe the CECs' structure and activities we must look at the Article 16 of the EMDII where further information is given. We will analyse it together with the one referred to the RECs, making their comparison in the next section.

To conclude, we want to highlight other two interesting elements supported by the electricity market directive:

- Member States shall allow and foster the participation of demand response through aggregation and allow final customers who offer demand response through aggregation, to participate alongside producers in a non-discriminatory manner in all electricity markets.
- Member States shall ensure the deployment in their territories of smart metering systems that assist the active participation of customers in the electricity market, to promote energy efficiency and to empower final customers.

These two elements are frequently present in energy communities because their structure allows easier participation of demand response through aggregation and because the smart metering systems are often useful for the management of self-produced electricity.

3.1.3 REC and CEC comparison

To better understand the two types of energy communities introduced, here we analyse their commonalities and differences, looking at the definitions and at the related Articles too.

Starting from the common characteristics, both RECs and CECs are defined as:

- legal entity
- based on voluntary and open participation
- effectively controlled by their shareholders or members
- primarily driven by the purpose of provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits
- whose members are natural persons, local authorities, including municipalities, or small enterprises

Talking about differences in the definitions we point out:

- About the legal form, RECs are defined as an *autonomous* legal entity, instead the EMDII does not further define the citizen energy communities' formal structure;
- About members, REDII mentions also medium enterprises, while CEC's definition refers only to small ones;
- About technologies, REC definition refers only to renewable energy projects, instead CECs' source of energy production is not specified; however, EMDII directive refers to electricity only.
- About property and location, REDII links renewable energy community activities to energy projects owned and developed by that legal entity in the proximity of the REC. CEC are not subject to such locational restriction and ownership specification.
- About activities, CEC's definition focuses on all the energy services that the communities can give (generation, distribution, supply, consumption, aggregation, storage, efficiency services, charging services for EVs, provide other energy services to its members or shareholders), while REDII doesn't list them in the REC's definition.

Going to corresponding articles (Article 22 of the REDII and Article 16 of the EMDII), further commonalities and differences emerge.

First, both articles focus on the importance that Member States take actions to promote and facilitate the development of RECs and CECs, and that their members are not subject to discriminatory procedures and charges. Member States shall also ensure that consumers are entitled to joint both kind of EC, maintaining their rights and obligations as final consumers. About RECs, there is explicit mention of accessibility to low-income or vulnerable households too.
These ideas are stressed in the European legislation to let the self-consumption phenomena expand and to promote it, without mistake the private citizens from the energy companies. Otherwise, the prosumers could be exposed to disadvantages for their choice.
In general, Member States shall put in place an enabling framework, based on an assessment of the existing unjustified barriers about some activities that EC could take.

Starting from the common enabled activities we mention:

- to share, within the community, the energy that is produced by the production units owned by that community (the relevant distribution system operator shells facilitate energy transfers within energy communities; about CECs the DSO is subject to fair compensation as assessed by the regulatory authority)
- to access all suitable energy markets, directly or through aggregation, in a non-discriminatory manner
- opening to cross-border participation may be allowed by the MS

In Article 22 of the REDII, the activities characterizing the RECs are mentioned; in the table below, we report them with the ones listed in the CECs' definition:

	Renewable Energy Community	Citizen Energy Community
Activities/services	generation, consumption, storage, sale	generation, consumption, storage, aggregation, supply, distribution, energy efficiency services, EVs services and other energy services to its members or shareholders

TABLE 3 – ACTIVITIES ALLOWED TO ENERGY COMMUNITIES

Member States shall ensure that, doing these activities, RECs and CECs are subject to the provisions relevant for such activities and that they are treated in a non-discriminatory and proportionate manner regarding their rights and obligations (about CECs, is specified that, participating to flexibility services, they are financially responsible for the imbalances they cause in the electricity system).

About tariffs, Member States shall ensure that both types of energy community are subject to relevant charges, levies and taxes, ensuring that they contribute in an adequate, fair and balanced way to the overall cost-sharing of the system. National competent authorities shall develop a transparent cost-benefit analysis of distributed energy sources to evaluate the cost-reflective charges.
The directives don't give further information about tariffs, except for the EMDII directive that contains two indications more: to develop network charges that account separately the electricity fed into the grid and the electricity consumed from the grid, referring at Article 18 of Regulation (EU) 2019/943 (about charges for access to networks, use of networks and reinforcement); and that, where electricity is shared, this shall be without prejudice to applicable network charges, tariffs and levies.

Finally, a key element for the CECs is the DSO activity. In the Article about the RECs, DSO service is only mentioned as a possible activity of the community, while in the one about CECs it is deeper analysed:
Member States may provide that CECs are entitled to own, establish, purchase, lease and manage distribution networks in their area of operation and establish the relevant procedures, subject to rules and regulations applying to distribution system operators.
If such a right is granted, Member States shall ensure that citizen energy communities:
(a) are entitled to conclude an agreement on the operation of their network with the relevant distribution system operator or transmission system operator to which their network is connected;
(b) are subject to appropriate network charges at the connection points between their network and the distribution network outside the citizen energy community;
(c) do not discriminate or harm customers who remain connected to the distribution system.

To conclude this comparison, we sum up the most important features characterising the two defined energy communities:

	REC	CEC
Legal entity	Yes	Yes
Purpose	environmental, economic or social community benefits for shareholders or members or for the local areas where it operates	environmental, economic or social community benefits for shareholders or members or for the local areas where it operates
Members	natural persons, local authorities, including municipalities, SMEs	natural persons, local authorities, including municipalities, small enterprises
Technology	Only RES	All
Type of energy	All RES	Only electricity
Power plants ownership	Community	-
Locational limitation	Yes	No
Electricity sharing	Yes	Yes
Market access	Yes	Yes
Cross-border participation	Possible	Possible
Activities	generation, consumption, storage, sale	generation, consumption, storage, aggregation, supply, distribution, energy efficiency services, EVs services and other energy services to its members or shareholders
DSO status	Not possible	Possible

TABLE 4 – REC AND CEC CHARACTERISTIC COMPARISON

3.2 Member States’ legal framework

Since the citizen energy projects phenomenon is broad, also the approach and aim of the legal frameworks vary immensely between Member States. This leads to a patchy self-consumption regulation in Europe, also because most Member States do not have already transposed the new European directives REDII and EMDII. However, several European Member States have sought to support, through regulatory or policy measures, citizen energy projects born from the bottom before the RED II and EMD II.
Here we analyse most interesting Member States legal frameworks about collective self-consumption and energy community. The information provided come from European Community publications[10] and individual States’ laws[11].

The analysis is useful to identify the contact points between the Member States’ laws and the European directives, and to contextualize the results obtained from the projects’ analysis carried out in *Chapter2*. As we have already anticipated, in fact, some countries have historically been more restrictive in the regulations for self-consumption and collective self-consumption, and they are the ones where the least projects of citizens have emerged.
However, analysing the current legislation, a strong recent legislative development emerges, transversal to all countries, and it is stronger in the countries where fewer bottom-up projects had been found. Spain, Portugal, Greece and Italy, for example, have recently adopted new measures to give new impetus to this phenomenon which is still too little developed in its territory. UK, Denmark and the Netherlands are lagging behind in the transposition of directives, but in these countries this type of activity is already developed. These data give the measure of how this phenomenon is in a phase of great mutation, and the measure of the strong expansion that can occur in the years to come.

3.2.1 France

In France, self-consumption is regulated by Chapter 5 of the “Code de l’énergie”[12]. It was firstly modified in April 2017 to support individual and collective self-consumption. Collective self-consumption (“autoconsommation collective”) was allowed if electricity was produced and consumed by several consumers and producers linked through a legal entity and subtended to the same MV/LV transformation cabin.

[10] (COMPILE, June 2019) (Asset, May 2019)
[11] Look at the bibliography for further references
[12] (Code de l'énergie, November 2019)

On November 8th 2019, France transposed the RED and EMD directives with the LOI n° 2019-1147 on energy and climate for the implementation of the "Clean energy for all Europeans" package. The energy code is modified introducing the definitions of REC and CEC too, and updating those of individual and collective self-consumption as defined by the Directives. So, all the features of the European definitions are transposed in the French law.

The manager of the self-consumer group or the renewable energy community notifies the relevant public distribution system operator of the distribution coefficients to be used to distribute self-consumed production between the end consumers concerned.

3.2.2 Spain

In Spain electricity framework is regulated by the Electric Sector Law 24/2013. Specific regulations for self-consumption have been defined in Royal Decree RD 900/2015. Regulating self-consumption, it expressly prohibited collective self-consumption in residential buildings and introduced the “sun tax”: an additional tax for the individual prosumers, to remain connected to Spain’s electricity grid. Just on June 2, 2017 the Constitutional Court annulled this government's ban, opening to the possibility of generating and consuming the own energy in a shared way.

Finally, with the approval of RDL 15/2018 on October 5, “on urgent measures for energy transition and consumer protection” the “solar tax” has been abolished and the right of shared self-consumption is legally recognized, resolving the outstanding situation. On April 5th, 2019 Spanish Government approved the RD 244/19[13] that recognize collective self-consumption.

With the new Royal Decree prosumers have the possibility to share power surpluses with nearby consumers, also in other buildings, if production facility and consumer satisfied one of the following conditions:

- are within a radius of 500 meters
- match their cadastral reference in the first 14 numbers
- are connected at low voltage to the same transformation centre
- are connected by an internal network

[13] (244/2019, 5 de Abril)

Prosumers can also feed surpluses to the grid, with a simplified mechanism for compensation for prosumers below 100 kW of installed power: they are not obliged to register as an energy producer to sell the surplus energy to the grid. The sale of the surplus is limited to the total energy consumed by the user.

For collective self-consumption, the distribution can be done by making a simple contract or agreement between participants, setting the percentage that corresponds to each one. This percentage is communicated to the supplier and the distributor and cannot be modified for a year. If an agreement is not made by default, is set a percentage proportional to the contracted power of each of the users participating in the shared self-consumption.

Other details will be clarified through the implementing decrees but the transposition of the Directives REDII and EMDII is not expected shortly.

3.2.3 Portugal

The “Lei-Decree n. 162/2019"[14], published in the Portuguese Official Journal n. 206 of 25 October 2019 transpose the REDII Directive. The new framework law doesn’t contain yet all the details necessary for its correct implementation, but it introduces the concepts of collective self-consumption and the energy community. Before this decree-law, only individual self-consumption was allowed. Now, Article n°6 allows self-consumers to group together.

To set up a renewable collective self-consumption initiative in an apartment building is sufficient the approval of the simple majority of the assembly. This rule facilitates new installations in condominiums with many apartment owners. The new law also ensure that communities have all the administrative and economic tools to penetrate the real market and that costs of the national electricity system are shared fairly and impartially, both by companies and by citizens interested in participating, but without public subsidies. So, this decree-law creates an enabling environment for the REC’s diffusion.

The law establishes the fees due to registration and inspections, that must be carried out every eight or ten years. The size of these taxes will be crucial for assessing the affordability of initial investments. These and other details should be defined by some application documents.

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[14] (Presidência do Conselho de Ministros, October 2019)

3.2.4 Belgium

Renewable energy communities in Belgium have been introduced by the Decree of the Gouvernement Wallon of 02 May 2019, published on 13 September 2019.[15]
Specific conditions for local perimeters will be defined by future pieces of legislation in the coming months, until now the decree states that the connection points "must be located within a geographic area that includes the technically, socially, environmentally and economically optimal portion of the network in order to promote local collective self-consumption of electricity".
A supplier license is needed to sell the excess energy out of the "local perimeter".
The law defines "network managers" that implement, according to the regulated tariffs, the technical, administrative and contractual preconditions necessary, particular with regard to electricity metering. Also, the DSO can be mandated by the renewable energy community to manage its distribution network.
The grid tariffs for renewable energy community will still be defined, but the new law states that the tariff methodology should contribute to renewable energy community development. At the same time, the law aims at ensuring the balance between the interest of participating in renewable energy communities as well as the solidary coverage of networks costs and the contribution to taxes, surcharges and other regulated costs.

3.2.5 Greece

In 2016, first step toward collective energy sharing was undertaken in Greece introducing a law on virtual net metering applicable to farmers and municipalities. On January 23rd, 2018 the law 4513/2018 on Energy Communities and other provisions[16] is published. It expanded the scope of virtual net metering to energy communities too.

The law defines Energy Communities as citizen cooperatives with the exclusive aim of promoting a social and solidarity economy and innovation in energy sector, tackling energy poverty and promoting energy sustainability. Energy communities are supposed to encourage production, storage, self-consumption, energy distribution and supply, enhancing energy self-sufficiency and security in island municipalities, and improving energy efficiency in final consumption on the local and regional level.

[15] (Decree of the Gouvernement Wallon, May 2019)
[16] (Law 4513/2018 OF THE GREEK REPUBLIC, 2018)

Energy communities can produce, distribute and supply renewable energy (and cogeneration and high-efficiency heat) from installations of up to 1MW. At least fifty percent plus one of the members should be related to the place where the REC is located. The law regulates that energy communities are a non-profit organization, so they cannot distribute the surpluses to their members, but surpluses remain in the EC in the form of reserves and disposed for purposes by decision of the general meeting. EC will be entitled to distribute profit if they have at least 15 members, 50% of which are individuals. Financial incentives are foreseen for Energy Communities.

3.2.6 Germany

In Germany, self-consumption is regulated by the "Erneuerbare-Energien-Gesetz" (EEG), passed in 2000, that is also the text for promotion of renewable energy.
It guarantees fixed feed-in tariffs for anyone generating renewable power for a 20-year period. This encouraged households to install PV panels on their roofs, either feeding the electricity they produced into the grid, or consuming it themselves[17]. Thanks to this law, Citizens can also band together to invest in larger scale installations that would be too expensive for single individuals alone. These citizen-owned projects may also include companies or municipalities among their members. This explains the large presence of community-scale energy projects in Germany, mentioned in *Chapter2.2*.

In 2017, the so-called "Mieterstrommodell"[18] allowed collective energy projects at building scale: the inhabitants of a residential building can consume energy generated by a plant located within the perimeter of the building. The energy produced and consumed on site does not pass through the public network but only through the condominium network. In order to guarantee all users of the condominium the freedom to participate or not in the self-consumption model, it is necessary to install several smart meters to virtually connect non-participating users upstream of the condominium connection point. The plant has a maximum capacity of 100 kW.

3.2.7 Netherlands and UK

In these countries, governments have implemented derogations from the basic energy legal framework to gain experiences with new types of legislation about collective self-consuming and power market space. They imposed some criteria and after evaluated each project proposed, to give them the possibility of a trial for a set period of time.

[17] (Wire Clean Energy, 2020)
[18] (Bundesnetzagentur, July 2017)

Netherlands: the testing phase started with the Decree "Decree on experiments on decentralized sustainable electricity generation" of 28 February 2015[19]. It is aimed at projects with the purpose of increase renewable energy share and efficiency of the infrastructure and increase users' involvement. Applicants must be associations entirely controlled by their members and they are entitled to provide proposals of integrated hybrid energy solutions. So far, 17 projects have been approved[20]; they are reported in the Appendix, together with the other projects analysed.

UK: here there is not a derogation specific for collective self-consumption projects; the Office of Gas and Electricity Markets (Ofgem) delivered a call[21] for innovative proposal of businesses that encounter a regulatory barrier, to learn how regulation may need to evolve in future. Trials must be completed within two years of approval.
So far, two application rounds have been run; they cover a wide array of projects[22], mainly run by large organisations and testing new tariffs and application of local RES solutions.

3.2.8 Denmark

In Denmark there are no laws about collective self-consumption in buildings or Energy Communities, but it has a long and well-established renewable energy cooperatives tradition thanks to some supporting measures:

- the "option-to-purchase" scheme obliges wind energy project developers to offer 20% of financial shares in new wind energy projects to local citizens. Local co-investors share the same rights, obligations, risks and benefits as other investors.
- the Guarantee Fund provides financial guarantees to the financial institutions that lend money to local wind energy cooperatives.

Cooperatives must have at least 10 natural persons living within 4.5 kilometres distance, and they have co-decision rights as members.

[19] (Overheid.nl, 2019)
[20] (Experiments Electricity Law 2015-2018, 2019)
[21] (Ofgem, Ofgem Regulatory Sandbox Now Open, 2019)
[22] (Ofgem, 2019)

3.2.9 Austria

In Austria, collective private and commercial self-consumption at building level is introduced by the amendment of the 2017 Electricity Law (EIWOG). The amendment defined the role of the different involved actors and the required contractual relationships between them. Neighbouring buildings so far are not covered.
In late 2018, a first outline for a new renewable energy legislation was presented that will come into force in 2020 (‘Erneuerbaren Ausbau Gesetz 2020’). The new law will extend the scope of the collective self-consumption framework to energy communities.

3.2.10 Switzerland

Even if Switzerland is not a Member State, is interesting analyse also this case for their proximity to EU territory. Collective self-consumption is introduced in Switzerland by the energy law adopted in 2016 (Energiegesetz, EnG). By this regulation, locally produced electricity (renewable or not) can be locally consumed by a “self-consumption consortium” (“Zusammenschluss zum Eigenverbrauch”- ZEV) or sold to the grid. ZEV can be organized by the residents themselves or by an external service provide. All involved buildings have to be behind the same point of common coupling and the public grid cannot be used, so the ZEV is considered as one final consumer by the public grid operator. The management of the private grid is in charge of the ZEV itself.

	Implementation of Directive REDII started	Collective self-consumption permitted
Austria	-	√
Belgium	√	√
Denmark	-	-
France	√	√
Germany	-	√
Greece	√	√
Netherlands	-	-
Portugal	√	√
Spain	√	√
Switzerland	-	√
UK	-	-

TABLE 5 – MEMBER STATES LEGAL FRAMEWORK OVERVIEW

To conclude, this analysis identifies how each Country interpreted the main open elements left by the directives: the definition of "proximity", the division between the members of the self-consumed share of energy, the management of condominiums with numerous owners, the values of the incentives, the shares of energy that can be fed into the network, the role of the community manager. And therefore, it allows to collect useful information for a possible future comparison between the development paths of collective self-consumption in the Countries.

We underline that the approval of the REDII directive has achieved the desired effects, activating a path of updating for all those Countries that historically have not facilitated the participation of consumers in the energy system, and opening the way to the homogenization of the national laws on this subject.

3.3 Italian legal framework

Up to 2020, Italian legal framework did not allow to set up Energy Communities as defined by European legislation, nor even collective self-consumption initiatives; a power plant could in fact give energy to a single final consumer.

Over the years, some exceptions to this rule have been established to allow some self-consumption configurations, filling gaps produced by technological innovation or regularizing some existing systems, such as in the case of historic Consortia and Cooperatives described in *Chapter2.3.2*; this path created a fragmented legal framework.

Among them, only one is in fact suitable for new collective self-consumption initiative: Other Self-Supply Systems (in italian: Altri Sistemi di auto APprovigionamento ASAP).
For ASAP there is no constraint on the technology of the power plant and the consumers can be multiple, but all belonging to the same corporate group (which must coincide with that of the producer). Therefore, this definition is not suitable for the development of energy communities as it refers just to companies and not private users.

Another structure to be mentioned are the Closed Distribution Systems (**SDC**); they are systems that:

- distribute electricity within a site (services or industrial or commercial type) geographically confined
- include only processes or operations integrated with each other
- or distributing electricity primarily to the owner or operator of the system or to companies related to him.

SDCs are the only form of private electricity network (plurality of end users and/or electricity producers) currently present in Italian legislation. Over the years, it has been identified as a key tool in the path toward collective self-consumption, but in the current legislation nothing is said about the feasibility of new SDCs.

Energy communities and active participation in markets for small prosumers have been only mentioned in the National Energy Strategy (SEN)[23], updated in December 2017, referring to them as phenomena that will develop more and more thanks to technological innovation.

Finally, on 6th June 2019 the Resolution "Support for the use of electricity generation systems"[24] presented in the Senate by the Permanent Commission "Industry, trade, tourism" introduced some commitments aimed at promoting self-consumption of energy; it has been approved unanimously.

Government and Parliament are urged to "establish a favourable framework for promotion and facilitation of the development of renewable energy self-consumption, taking into account existing unjustified barriers and, at the same time, their potential in the territories and energy networks". It is also underlined that RECs, for their roots in the territory, could also have the social function of providing energy at reduced costs to the most deprived citizens. The implementation of the European directives is urged, and it is also urged the acceleration in the installation of second-generation "smart" meters, in particular where the citizens themselves ask for their installation to be able to create a renewable energy community. Finally, the Government is asked to guarantee the right to self-consumption of energy from renewable sources by allowing direct lines between production and consumption, even if not contiguous, and by allowing self-consumption distributed with multiple consumers in condominiums, through closed distribution systems (SDC), local energy communities and peer to peer systems.

[23] (MISE, MATTM, November 2017)

[24] (Commissione permanente Industria, commercio, turismo, 2019)

On a regional basis there are two interesting cases to report: the regional law n. 12 of 3 August 2018 of the Piedmont Region[25] and Regional Law n.45 of 9 August 2019 of the Puglia Region[26], both called "Promotion of the institution of energy communities".
Regions Piemonte and Puglia developed laws that anticipate national standards, looking at the new European directives and introducing the concept of Energy Community in Italy for the first time. This is possible thanks to Title V of the Italian Constitution according to which the production, transport and national distribution of energy are matters of concurrent legislation, that is to say the Regions have legislative power, except for the determination of the fundamental principles, reserved for state legislation.

These regional laws are based on the national law 221/2015 which, in article 71, reports the definition of "Oil free zone": "a territorial area in which, within a certain period of time and on the basis of a specific act of address adopted by the municipalities of the reference territory, the progressive replacement of oil and its derivatives with energies produced from renewable sources is scheduled". This law is established in order to promote, on an experimental and subsidiary basis, a carbon free economy, looking at European standards about environmental sustainability. The methods for organizing the Oil free zones are governed by the regions.

In their main points the two regional laws are basically the same; they promote the establishment of energy communities as non-profit entities, set up in order to overcome the use of oil and its derivatives and to facilitate both the production and exchange of energies generated mainly from renewable sources, and to promote forms of efficiency and reduction of energy consumption. Public and private entities can participate in the Energy Communities so the constraint of industrial or commercial users set by national legislation is overcame for the first time.
They acquire and maintain the status of "energy producers" if annually the share of the energy produced intended to self-consumption by members is not less than 70 percent of the total (60 percent for the Puglia Region).
Municipalities who wants to establish an Energy Community must adopt a specific memorandum of understanding with the Region, draw up an energy balance for their area, and a strategic document identifying the actions they intend to implement for the reduction of consumption from non-renewable sources and for the efficiency of its community. They may also enter into agreements with ARERA, in order to optimize the management and use of energy networks.

[25] (Regione Piemonte, August 2018)
[26] (Regione Puglia, August 2019)

In both cases the Regions have undertaken to financially support the phase of setting up the energy communities and provide for the establishment of permanent technical coordination between the energy communities and the Region, in order to acquire data. The Puglia Region, in its own law, has also added a clear reference to the energy communities as a tool to provide energy to tackle energy poverty by exploiting the reduction in consumption and in supply rates that they can achieve thanks to the increase in efficiency.

The latest and most important legislative news concerning Energy Communities and collective self-consumption comes from the DL “Milleproproghe”, converted into a law on February 28th, 2020. This law contains an article, the n° 42bis, about “self-consumption from renewable sources” that aims to anticipate the transposition of the EU REDII Directive in the Italian legal framework. The purpose is to collect on an experimental basis, elements that will be useful to draft the measure transposing the directive; the transposition must take place by June 2021.

The article essentially reproduces what is contained in Directive (EU) 2018/2001 regarding "jointly acting renewable self-consumer" and "renewable energy community". In particular, it confirms definitions and activities stated by the Directive in article 21, paragraph 4 for the "jointly acting renewable self-consumer" and in article 22 for the "renewable energy community".

Furthermore, the Italian law:

- sets at 200 kW the maximum limit of total power for renewable sources production plants, for each energy community or association of self-consumers
- sets the time interval for the commissioning of these new plants, between the date of entry into force of the conversion law of the decree containing this article and sixty days after the entry into force of the final transposition of the Directive (EU) 2018 / 2001
- states that the energy produced must be shared through the existing distribution network, therefore excludes the creation of private distribution networks
- establishes, as a geographical limit for the Renewable Energy Communities, that production plants and consumers must all be under the same MV/LV transformer substation.
- for "jointly acting renewable self-consumers", the geographical limitation given by their directive is confirmed: users must be in the same building or block.

About the economic aspect, the article establishes, among other things, that:

- users must identify a delegate responsible for the allocation of shared energy
- the "shared energy" within the group of self-consumers or the Energy Community, is defined on hourly basis: it is the minimum between the electricity produced at that time by the production plant and the total energy taken in that same time by all associated users
- for each energy community or association of self-consumers the general system charges are calculated on all the energy that all the associated users withdraw from the public grid, without considering how much energy was produced and how much self-consumed
- the "energy as raw material" charges will be applied, on an hourly basis, only to the part of the energy consumed that exceeds the energy produced, that means, energy charges are not applied in full to the portion of self-consumed energy. For the energy self-consumed what has been paid extra, will be returned at the end of the year.

By 60 days after the conversion of the decree in law, the Ministry of Development must identify an incentive for the remuneration of these plants which must

- reward instant self-consumption and the use of storage systems
- do not increase the trend costs compared to the current ones
- do not create new or greater burdens on public finance

So, the path toward the development of collective self-consumption in Italy is definitely open. From the technical point of view, choices have been made to simplify the development of these systems:

- there is no need of a private grid, energy sharing occurs through the existing one
- users will receive bills calculated on all consumption made, as before entering the community, and later the portion not due is returned at the end of the year
- the geographical limit of the REC is the simplest identified by other countries too.

Some elements still need to be defined:

- the role of the delegate, responsible for the allocation of shared energy
- how the self-consumed energy in each time interval will be divided among users
- the value of the incentive on self-consumption

In June 2021 results of this experimentation will be gathered and all the details necessary to make collective self-consumption a sustainable and widespread system in Italy will probably be defined in the transposition of the directive.

4. Energy Community model

To support the spread of Energy Communities and of collective self-consumption in Italy it is necessary to examine in depth these systems and all the elements that affect their functioning.
In this section is described the model developed to represent these self-consumption's structures with all the variables that affect them. The purpose of the model is to analyse the impact of Energy Communities and collective self-consumption initiatives and the extent to which these will bring an advantage to the population.
The model allows to study how changes in installed power, number of users, tariff, incentives, and other variables, affect the energy and economic output.
In the last part of this Chapter, the market conditions in which Energy Communities can develop by bringing advantage to users and to the overall system of the country are calculated.

To carry out the analysis, the model developed forecasts consumption and production profiles of a users' group with a common PV; these outputs are combined with the economic data of investments, tariffs and incentives to describe all the techno-economic aspects of the community.

4.1 Outline

The model is based on the structures of Energy Community and "jointly acting renewable self-consumers" currently envisaged in the last Italian decree[27], so, without substantial changes compared to the REDII Directive.
Members currently modelled are domestic users; the model represents users in a single building or block and communities of domestic users downstream of the same MV/LV transformer substation (as required by the Italian decree). Therefore, they are geographically limited communities.

[27] (Decreto Milleproroghe, 2020)

We consider the production of energy only from renewable sources, as required by the decree; in particular, photovoltaic power plant has been included as a community owned system. The community can also have a community owned storage system; this is an interesting element since storage sized for a group of users is better optimized. Users can also have solar thermal systems for their own home.

The model represents the demand for both electricity and heat and cooling utilities; the community plants considered are only for electricity production because this is the main purpose of the communities described by the Italian decree.
The model represents the energy sharing within the community, permitted by the new legislation. The group of users is still connected to the main grid, to cover the peaks of demand and to input the electricity generated but not consumed instantly by the community.

4.2 Model description

The Model for the Energy Community is developed with Excel VBA.
It consists in two main steps:

- generation of the hourly community demand profile for one year (trough CREST Demand Model [28]) basing on the characteristics of the community to be represented
- sizing of the community's PV plant and storage basing on economic and environmental variables too

The variables entering the Model are:

- To generate the demand profile:
    - geographical position of the community (choice among 7 Italian cities)
    - number of dwellings participating
    - number of residents for each dwelling
    - type of buildings (choice among 4 types of buildings that differ in their thermal balance)
    - users' heating and cooling systems

[28] (Loughborough University, 2020)

    - presence of a solar thermal system owned by the user (type of ST and its size)
    - presence of a photovoltaic solar system owned by the user (type of PV and its size)

- To generate the community's energy production profile:
    - geographical position (North, Centre or South)
    - installed power of the plant (kWp)
    - available area (m^2)
    - m^2 panel / kWp ratio (m^2/kWp)
    - slope (deg.)
    - azimuth angle (deg.)
    - panel efficiency (%)
    - temperature coefficients of the panel (%/°C; °C)

- To size the storage:
    - battery capacity (kWh)
    - charging efficiency (%)
    - discharge efficiency (%)

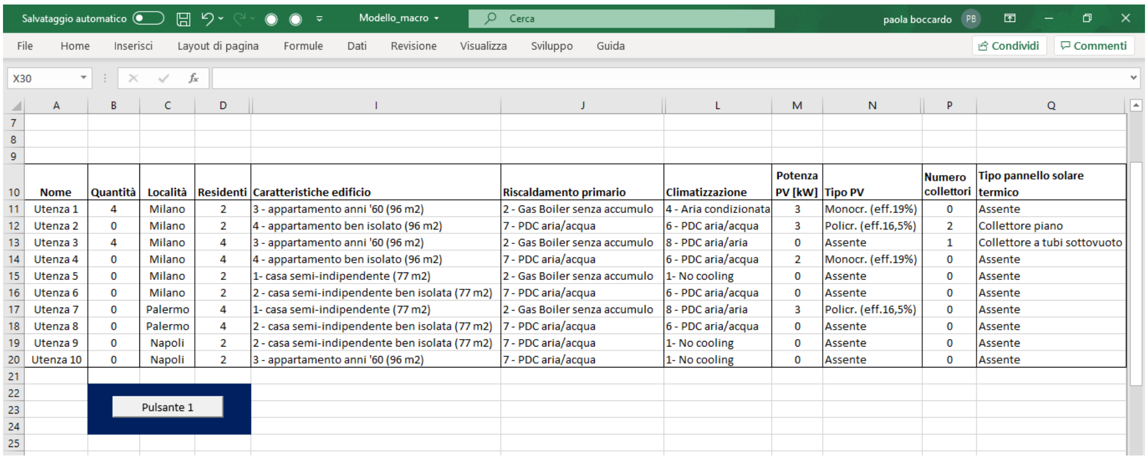
- To generate the economic balance:
    - users' tariff (one or two timeslot)
    - electricity tariffs per timeslot (F1, F23) (€/kWh)
    - incentives for the renewable energy produced (€/MWh)
    - incentives for the self-consumption quota (€/MWh)

In addition, lot of parameters are set in the model, they are described in the following chapters together with the functions that involve them. The user can modify them too to make it closer to the situation he wants to represent.

The description of the model begins with the presentation of the CREST Demand Model and the changes made to its parameters to adapt it to the representation of a group of users in Italy. Later, choices about the plants dimensioning and about the economic variables are shown. The results about the impact of variables changing are shown and commented in the *Chapter4.3*.

4.2.1 Demand profile

First step to use the model is to set all the characteristics listed above for each dwelling part of the community to analyse. For each item it is possible to choose among some options as shown in *Figure1*.



Nome	Quantità	Località	Residenti	Caratteristiche edificio	Riscaldamento primario	Climatizzazione	Potenza PV [kW]	Tipo PV	Numero collettori	Tipo pannello solare termico
Utenza 1	4	Milano	2	3 - appartamento anni '60 (96 m2)	2 - Gas Boiler senza accumulo	4 - Aria condizionata	3	Monocr. (eff.19%)	0	Assente
Utenza 2	0	Milano	2	4 - appartamento ben isolato (96 m2)	7 - PDC aria/acqua	6 - PDC aria/acqua	3	Policr. (eff.16,5%)	2	Collettore piano
Utenza 3	4	Milano	4	3 - appartamento anni '60 (96 m2)	2 - Gas Boiler senza accumulo	8 - PDC aria/aria	0	Assente	1	Collettore a tubi sottovuoto
Utenza 4	0	Milano	4	4 - appartamento ben isolato (96 m2)	7 - PDC aria/acqua	6 - PDC aria/acqua	2	Monocr. (eff.19%)	0	Assente
Utenza 5	0	Milano	2	1- casa semi-indipendente (77 m2)	2 - Gas Boiler senza accumulo	1- No cooling	0	Assente	0	Assente
Utenza 6	0	Milano	2	2 - casa semi-indipendente ben isolata (77 m2)	7 - PDC aria/acqua	6 - PDC aria/acqua	0	Assente	0	Assente
Utenza 7	0	Palermo	4	1- casa semi-indipendente (77 m2)	2 - Gas Boiler senza accumulo	8 - PDC aria/aria	3	Policr. (eff.16,5%)	0	Assente
Utenza 8	0	Palermo	4	2 - casa semi-indipendente ben isolata (77 m2)	7 - PDC aria/acqua	6 - PDC aria/acqua	0	Assente	0	Assente
Utenza 9	0	Napoli	2	2 - casa semi-indipendente ben isolata (77 m2)	7 - PDC aria/acqua	1- No cooling	0	Assente	0	Assente
Utenza 10	0	Napoli	2	3 - appartamento anni '60 (96 m2)	7 - PDC aria/acqua	1- No cooling	0	Assente	0	Assente

FIGURE 1 - FIRST VIEW OF THE MODEL

As said before, CREST Demand Model has been used as basis to build the demand profile of the community. This model is an open-source development in Excel VBA freely available to download for users to configure and extend, or to incorporate into other models. CREST Demand Model is described as follows:

"The CREST Demand Model is a high-resolution stochastic model of domestic thermal and electricity demand. The model produces one-minute resolution demand data, disaggregated by end-use, using a bottom-up modelling approach. […] The model has been validated and can be used to simulate demand of aggregations of dwellings such that dwelling diversity is duly represented and end-use demand appropriately correlated."[29]

The most interesting features of this model are the bottom-up structure, the stochastic approach to determine some variables, and the one-minute resolution output.

The CREST model is constructed from several sub-models, as show in the *Figure2*.

The occupancy model generates stochastic sequences of occupancy for each dwelling, which form a basis for the calculation of appliance, lighting and water-fixture switch-on events. These are aggregated to determine the dwelling's electricity and hot water demands. The thermal demand model simulates the dwelling's thermal dynamics and

[29] (E. McKenna, M. Thomson, 2016)

gas demands given the climate data, internal heat gains, and dwelling-specific building fabric data.

In this section, all the changes made in the CREST Demand Model are explained, together with the way in which they are processed by the model.

In particular, the parameters that are modified are:

- Historic climate data
- Activity profiles and presence of appliances
- Building thermal model
- Heating and cooling settings
- Photovoltaic and solar thermal parameters

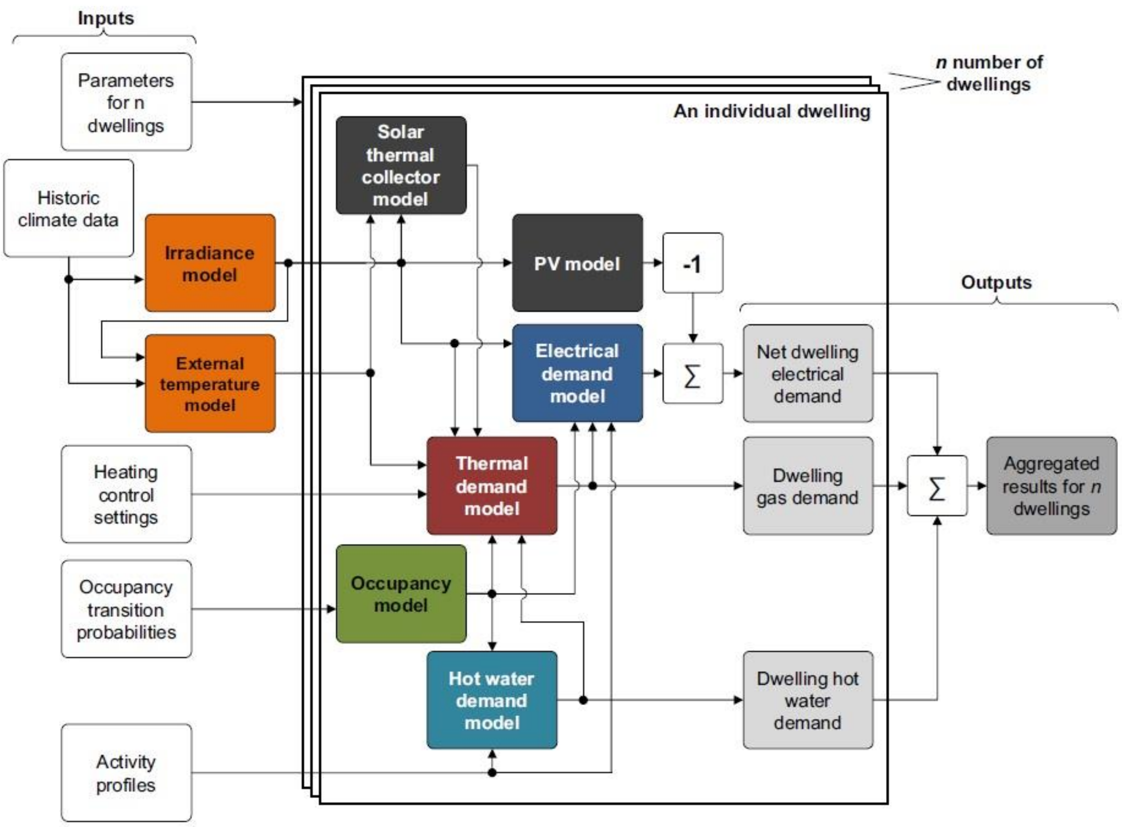


FIGURE 2 - CREST DEMAND MODEL STRUCTURE

4.2.1.1 Climate Data

Temperature input data of the CREST Demand Model have been adjusted for the Italian average. CREST Model takes as input the city where the energy project is located, and then it uses the temperature data provided for each city in the "Climate Data" sheet of the model.

CREST Model develops an irradiance and external temperature stochastic profile with a one-minute resolution for each day that is simulated. The external temperature is simulated basing on historical minimum, medium and maximum temperature data for each month, for the chosen city. To develop the daily external temperature profile, first an average temperature for the day is simulated, and then this is used as a basis for the construction of the profile with a stochastic deviation around the average. Temperature changes are also dependent on the clearness index. Clearness Index is stochastically constructed too; it is based on global irradiance database, measured at Loughborough University in 2007, and adjusted according to latitude and longitude of the chosen city. The output is the array of temperature values on a one-minute basis for the chosen day.

Cities added to CREST are: Aosta, Milan, Rome, Naples, Bari, Cagliari and Palermo; they represent the diversity of the Italian climate zones. For each city the values of minimum, maximum and average temperature for each month have been taken as average of the values recorded between 2008 and 2018 by the ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale) Institute[30].

These climate data, together with the other input data (building, activity, number of occupants), affect the heating and cooling status and so the energy consumption.

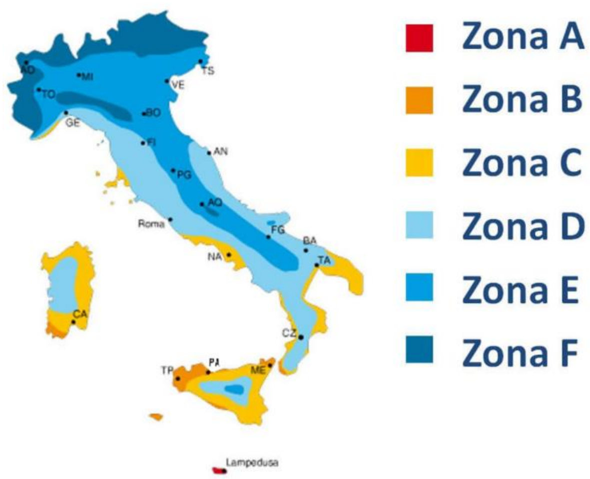


FIGURE 3 - ITALIAN CLIMATIC ZONES (DPR 412/93)

[30] (ISPRA, 2020)

4.2.1.2 Appliance demand

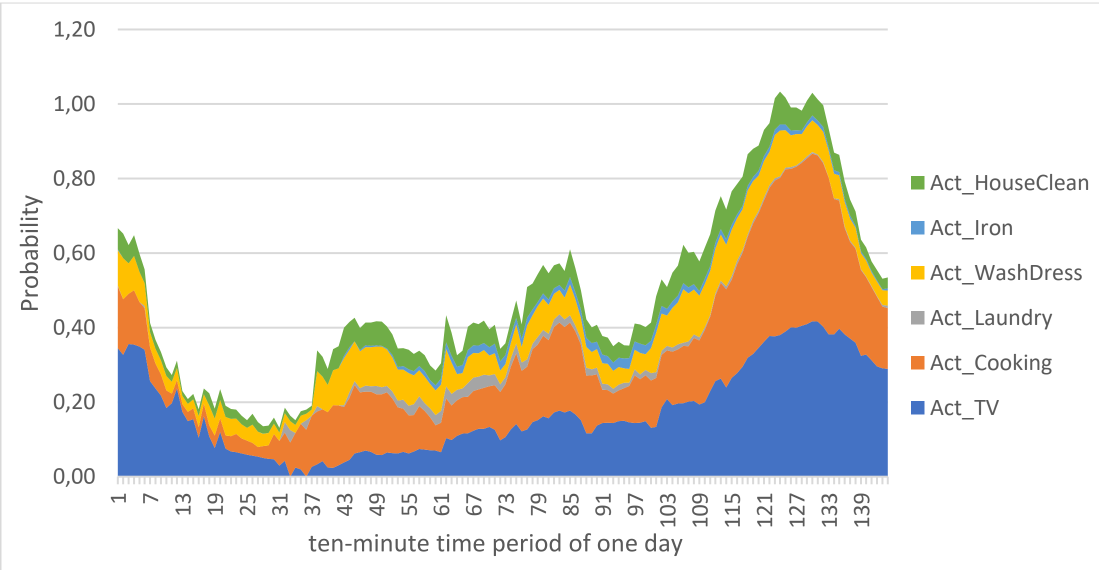
Information needed for the construction of the electricity demand profile are:

- occupancy of the dwellings and activity of the residents for each time step
- activity occurring in each time step
- appliance owned by each dwelling

these information are collected by CREST with a stochastic approach, basing on probability curves.

First, occupancy model is implemented: it creates stochastic profiles of dwelling occupancy using transition probability matrices based on UK time-use survey data and info about the day chosen (weekday or weekend) and the number of residents of the dwelling. The occupancy model has four-states: each resident can be at home and active, at home and asleep, away from home and active, or away from home and asleep. The data collected by the UK survey have not been modified for our model.

Second, model combines the output from the occupancy model with activity probability profiles determined from the UK time-use survey too. The activity probability profiles depend on the weekday/weekend data and on the number of residents too; it represents the proportion of households where at least one occupant is engaged in a particular activity during a particular ten-minute period. These probability curves have been slightly modified to better represent Italian habits. An example of activity probability profile is shown in *Graph6*; it is developed for a weekday for a dwelling with three residents.



GRAPH 6 – PROBABILITY THAT AT LEAST ONE OCCUPANT IS ENGAGED IN A PARTICULAR ACTIVITY

Finally, data about appliances owned by the residents are needed to output the electricity demand for each activity, when it occurs. They are stochastically determined too, basing on probability data. These data have been modified to better represent the Italian scenario, basing on different databases[31], and they are listed in *Table6*.

Appliance	Proportion of dwellings with appliance	Annual energy demand [kWh/y]	Operating load [W]
Chest freezer	0,253	357	155
Fridge freezer	0,996	350	190
Cassette / CD Player	0,900	33,3	15
Clock	0,900	17,5	0
Cordless telephone	0,900	8,8	0
Hi-Fi	0,900	88,8	100
Iron	0,800	150	1300
Vacuum	0,996	150	1250
Personal computer	0,800	160	160
Printer	0,665	49,	335
TV 1	0,998	170	124
TV 2	0,580	170	124
TV 3	0,180	170	124
VCR / DVD	0,896	20	34
TV Receiver box	0,934	152,5	27
Hob	0,200	276	1000
Oven	0,500	130	1300
Microwave	0,400	100	1000
Kettle	0,975	161	2000
Small cooking group	1,000	32	1000
Dish washer	0,393	260	1500
Tumble dryer	0,033	426	2000
Washing machine	0,962	250	500

TABLE 6 – APPLIANCES DATA

All the data described are combined to build the electricity demand from dwelling appliances.

[31] (ISTAT, 2013) (RSE Ricerca Sistema Energetico, 2017) (ENEA, 2009)

4.2.1.3 Buildings thermal model

To calculate the energy needed from the heating and the cooling systems, it is used the sub-model for the thermal demand shown in *Figure4*.
So, dwelling thermal parameters (in the lower part of the image) are needed. They are linked to a simplified request about the type of building in which the user is interested.

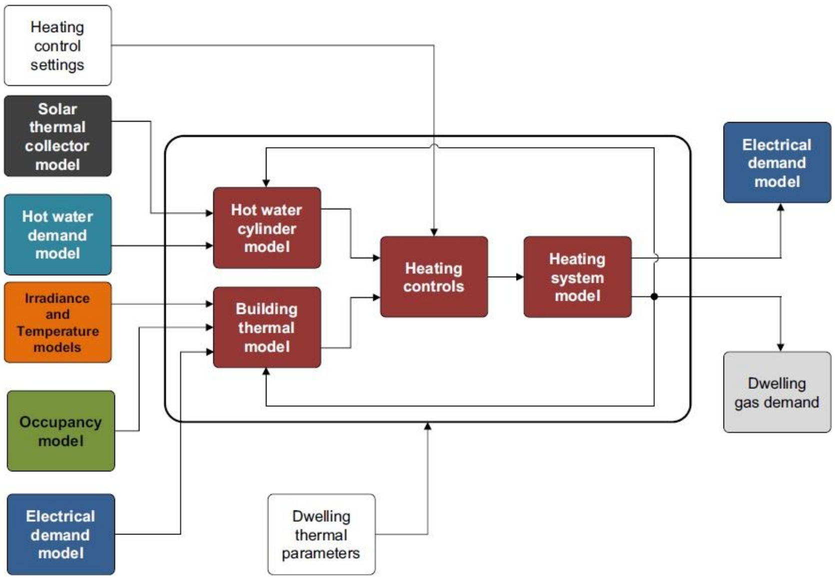


FIGURE 4 - THERMAL DEMAND MODEL

CREST Demand model allowed to choose from eight building type based on the English standards. They are not the usual Italian buildings so the choices have been updated.

Two type of building have been identified as the most common in Italy:

- semi-detached house in a village or in a remote area
- flat of a block in a city

Each of these two types of building have also been considered in two different features:

- old existing building (build for instance between '60s and '70s)
- new or renovated building

they change in the insulation level, thanks to different materials used for the walls, the windows and the fixtures.

The model takes as input variables:

- Thermal transfer coefficient between outside air and external building thermal capacitance (W/K)
- Thermal transfer coefficient between external building thermal capacitance and internal building thermal capacitance (W/K)
- Thermal transfer coefficient representing ventilation heat loss between outside air and internal building thermal capacitance (W/K)
- External building thermal capacitance (J/K)
- Internal building thermal capacitance (J/K)
- Global irradiance multiplier (m^2)
- Ventilation rate, air changes per hour (h^{-1})
- Floor area, living space (m^2)
- Height, living space (m)

All these data have been obtained from the Cambridge Housing Model 3.02[32]; the model uses English Housing Survey 2011 data, coupled to a SAP-based energy calculator, to estimate energy use and CO_2 emissions for all homes in England, broken down by final use. It contains the technical features of 14'951 buildings; among them, specific housing types most similar to the Italians, have been identified.
Parameters of each building type are given in the *Table7*.

These data have been validated comparing the results in energy need for heating and cooling in kWh/m^2 given by CREST model, with the data reported in the "Piano Nazionale Integrato per l'Energia e il Clima" (PNIEC) 2019[33].

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[32] (Department for Business, Energy & Industrial Strategy UK government, 2020)
[33] (MISE, MATTM,MIT, 2019)

	Old semi-detached house	New semi-detached house	Old flat in a block	New flat in a block
Thermal transfer coefficient between outside air and external building thermal capacitance (W/K)	566, 2	348,3	487,6	300,4
Thermal transfer coefficient between external building thermal capacitance and internal building thermal capacitance (W/K)	566, 2	348,3	487,6	300,4
Thermal transfer coefficient representing ventilation heat loss between outside air and internal building thermal capacitance (W/K)	57,1	48,7	50,3	52,3
External building thermal capacitance (J/K)	15101241,5	14338008,0	13187215,4	8946596,9
Internal building thermal capacitance (J/K)	604049,7	573520,3	527488,6	357863,9
Global irradiance multiplier (m^2)	1,6	1,3	2,9	2,3
Ventilation rate, air changes per hour (h^{-1})	1	0,4	1	0,4
Floor area, living space (m^2)	80,94	88,48	91,52	90,72
Height, living space (m)	2,63	2,43	2,73	2,65

TABLE 7 – BUILDING PARAMETERS

4.2.1.4 Heating and cooling settings

For each dwelling analysed, there is the possibility to select its primary heating and cooling systems. The choices have been updated adding the option of the use of heat pumps.

The user can choose from:

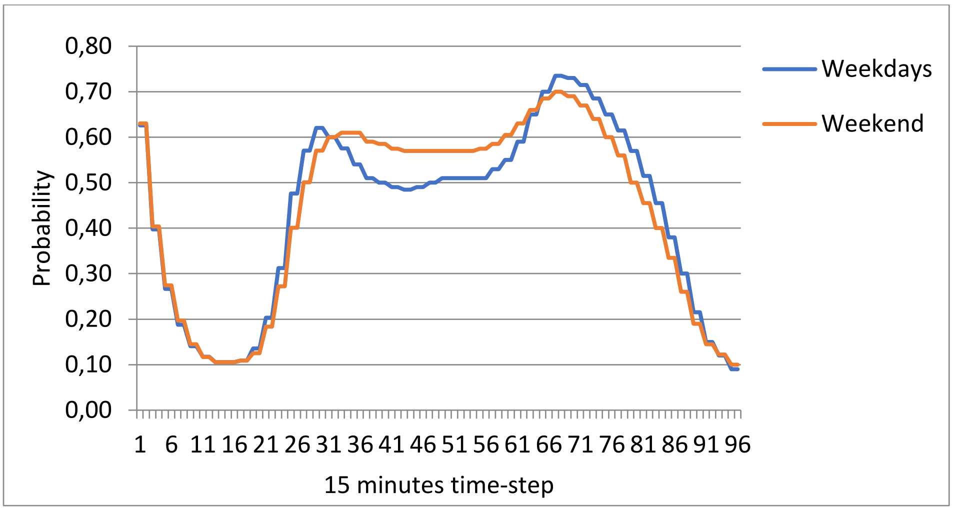
- For the heating system:
  - No heating system
  - Gas boiler without storage
  - Gas boiler with storage
  - Heat pump water/water
  - Heat pump air/water
- For the cooling system:
  - No cooling system
  - Fans only
  - Air cooler
  - Air conditioning
  - Heat pump water/water
  - Heat pump air/water
  - Heat pump air/air

Input parameters for the heat pumps have been set basing on technical features of plants currently available on the market[34] .

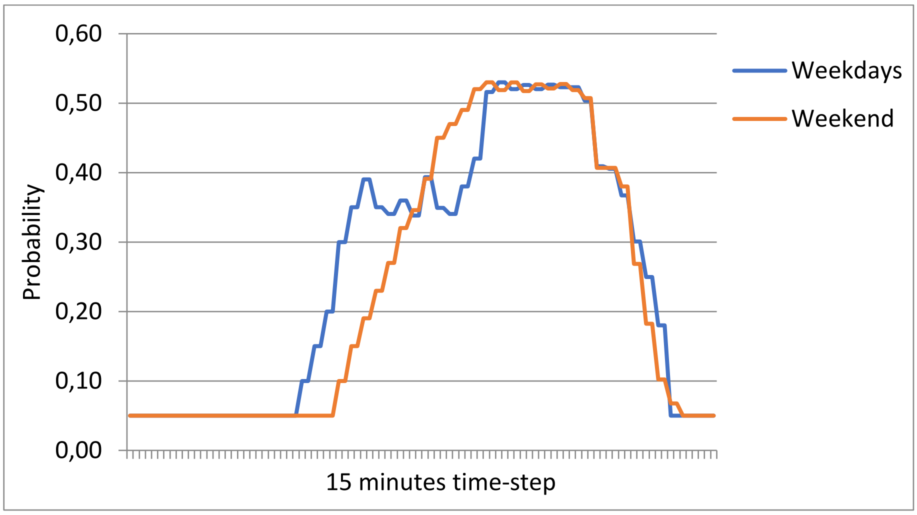
The nominal temperature of the emitters, previously set at 50°C, has been updated at 35°C for the heat pumps air/water and water/water. This is because 50°C is the temperature suitable for radiators; usually heat pumps air/water and water/water are used with radiant floor, where the operating temperature is lower.

From *Figure4*, we see that the thermal model needs also the heating (and cooling) control settings. Timer settings for space heating are not given as fixed because the model is based on a stochastic approach to represent the wide range of real cases. They are based on empirical distributions for the probability of space heating/cooling being switched on for weekdays and weekends. *Graph7* and *Graph8* show the probability curves given to the model, with a 15 minutes time step.

[34] (Viessmann, 2020)



GRAPH 7 – HEATING SETTINGS PROBABILITIES



GRAPH 8 – COOLING SETTINGS PROBABILITIES

The heating system model generates the output ON or OFF for each minute basing on the temperature inside the dwelling (derived by the temperature model and the building thermal model) and the timer settings resulted.

4.2.1.5 Photovoltaic and solar thermal parameters

CREST model allows to add PV power plant and/or solar thermal panels for each dwelling, to feed its energy needs. In case these private plants are added to a dwelling, the energy needs of this dwelling are summed up to the energy needs of the other community's members net of the energy supplied by the private plants.

For the PV plant, the user can choose from:

- No PV
- Monocrystalline silicon panel
- Polycrystalline silicon panel
- For the Solar Thermal, the user can choose from:
- No Solar Thermal
- Evacuated tube collector
- Flat plate collector

Parameters for these plants are:

- For the PV:
    - Efficiency
    - Area
    - Slope
    - Azimuth
- For the solar thermal:
    - Number of panels
    - Aperture area
    - Absorber area
    - Gross Area
    - Efficiency
    - Slope coefficient
    - Curvature coefficient
    - Efficiency factor
    - Total loss coefficient
    - Pump muss flow rate
    - Pump Power
    - Heat capacitance
    - Transmission absorption product
    - Slope
    - Azimuth

These parameters have been updated with technical features of plants currently available on the market[35].

[35] (LG, 2020) (Sunerg, 2020) (EnelX, 2020)

4.2.2 Community owned power plants

After determining the energy demand of the energy community, it is necessary to size the photovoltaic system owned by the community. The solar system is the easiest power system for a residential community so the model is initially based on it but other power system could be added.
The model gives the possibility to size the systems according to the user's interest. All the formulas used to construct the sizing are illustrated below. The user can modify the input variables and observe the production, self-consumption, investment and IRR outputs and decide what to maximize.

4.2.2.1 PV sizing

The variables that characterize a photovoltaic system are numerous and the model allows you to modify the following:

- geographical position (North, Centre or South)
- P_{inst}: installed power of the plant (kWp)
- A_{av}: available area (m^2)
- k: m^2 panel / kWp ratio (m^2/kWp)
- β: slope (deg.)
- γ: azimuth angle (deg.)
- η_r: panel efficiency (%)
- temperature coefficients of the panel (%/°C; °C)
- BOS: balance of system (%)

The model is based on historical data collected from the European Commission Database PVGIS (Photovoltaic Geographical Information System)[36]. The historical data of 2013, 2014 and 2015 are used (more recent data were not available) and an average of these values is made to use a value not too affected by the specific conditions of a given year.

Data collected from the European Database are:

- G_b: beam radiation on the horizontal plane (W/m^2)
- G_r: diffuse radiation on the horizontal plane (W/m2)
- α_s: sun height (deg.)
- Tm: air temperature (°C)

The data are available in time series of hourly values.

[36] (European Commission Science Hub, 2020)

Data were collected for the cities of Milan, Rome and Palermo; the choice of these cities is to represent the values of radiation in northern, central and southern Italy.

The calculation started from the radiation data on the horizontal plane to keep variable the inclination and the orientation of the photovoltaic panel.
The radiation on the tilted surface of the panel G_t is given by the sum of three components: direct radiation, diffuse radiation and reflected radiation from the surrounding ground. Each one of these elements is given by the value on the horizontal plane, modified as the following formula shows:

$$G_t = G_b \frac{\cos\theta}{\cos\theta_z} + G_d \frac{1 + cos\beta}{2} + G_r \frac{1 - cos\beta}{2}$$

In which:

- β is the slope of the panel
- θ_z is the angle of zenith given by: $\theta_z = 90° - \alpha_s$
- θ is the angle of incidence of the solar irradiation on the tilted surface given by:

$$\cos\theta = \cos\theta_z \cos\beta + \sin\theta_z \sin\beta \cos(\gamma_s - \gamma)$$

In which:

- γ is the azimuth angle of the panel
- γ_s is the solar azimuth

γ_s depends only on the day of the year and on the hour of the day; the day of the year is represented by the letter n and it assume a value between 1 and 365.
Formula to derive γ_s are given:

$$\sin\gamma_s = \frac{\sin\omega}{\sin\theta_z}\cos\delta$$

Where δ is the declination of the sun, given by:

$$\delta = 23{,}45° \sin\frac{360 * (284 + n)}{365}$$

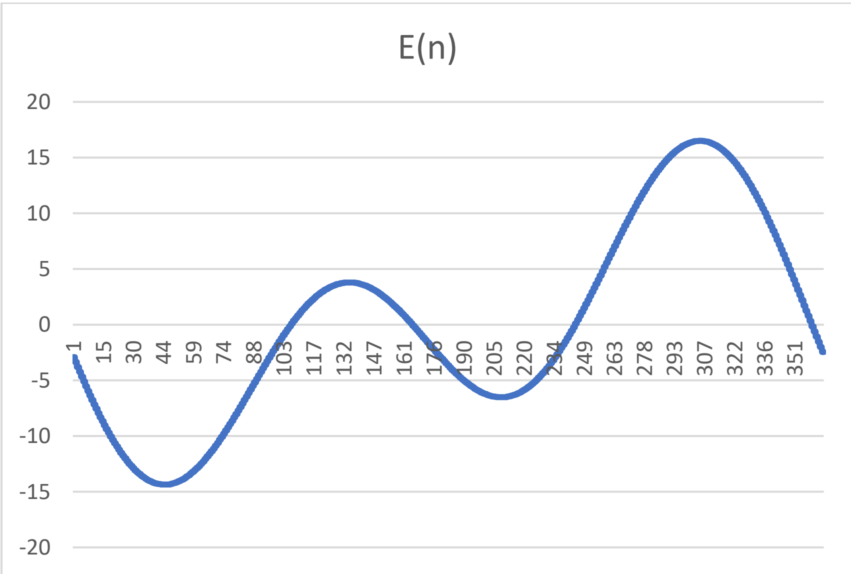
ω is the hour angle depends on the Solar Time (ST) as follow:

$$\omega = 15°(ST - 12)$$

Solar Time depends on:

- the Clock Time (CT), an integer between 1 and 24
- the observer longitude L_p compared to the time zone longitude L_{st}
- the presence of the Daylight Savings time DS
- the function E(n); it takes into account the variation in the length of the days according to the day of year n; this function is represented in the *Graph9*.

$$ST = CT + \frac{E(n) + 4(L_{st} - L_p)}{60} - DS$$



GRAPH 9 – EQUATION OF TIME

From all these formulas is obtained the irradiation of the sun on a surface tilted with an angle β, with an azimuth angle γ, for each day n of the year, for each hour CT, starting from the value of the irradiation on the horizontal plane recorded in the north, centre or south of Italy.

To calculate the total production of the PV, the production of each hour is need because each hour G_t and η change.
The hourly production is given by:

$$P = G_t * A * \eta * BOS$$

A is the area of the panel, it is given by

$$A = P_{inst} * k$$

Where k is the ratio of the m^2 of panel needed for a P_{inst} of 1 kW.
The model takes as input also A_{av}, the area available for the plant, it can be the area of the roof of the building or another space chosen for the plant.
If

$$A > A_{av}$$

the model uses A_{av} to calculate the hourly power production of the community power plant.

The efficiency η of the panel linearly decreases with the increase of the modules' temperature, according to the following equation[37]:

$$\eta = \eta_r[1 + \frac{T_{coeff}}{100} * (T_p - T_{ref})]$$

Where:

- η_r is the reference module efficiency
- T_{coeff} is the temperature coefficient of P_{max} (%/°C) that tell how much power is lost for every °C that the panel is hotter than the T_{ref}=25°C. It is given by the technical specifications of the panel.
- T_p is the temperature of the panel (°C)

The temperature of the panel T_p depends on:

- G_t irradiance on the tilted panel in that hour (W/m^2)
- T_{air} current ambient temperature (°C)
- Nominal Module Operating Temperature (NMOT)

NMOT is given by manufacturer information and it is defined as the temperature reached by cells in a module under the standard conditions:

- Irradiance on cell surface G_{st} = 800 W/m2
- Air Temperature T_{st}= 20°C
- Wind Velocity = 1 m/s

[37] (Sandnes B., Rekstad J., 2002)

Finally, the equation for the panel temperature is given:

$$T_p = T_a + G_t * \frac{NMOT - T_{st}}{G_{st}}$$

Now that all the needed parameters and formulas are given, it is possible to calculate the production of the photovoltaic panels for each hour of the year and the total annual production is given by the sum of the power production each hour:

$$P = \sum_{i=1}^{8760} P_i$$

To validate the result obtained, an error verification has been implemented varying the input variables (slope, azimuth angle and location) and comparing the results given by the model and the results collected from the European Commission Database PVGIS (Photovoltaic Geographical Information System) for a panel with same properties.
An error ranging from 3% to 6% was obtained; it is considered acceptable as the energy production from solar panels in a year is strongly conditioned by the climatic and weather conditions that occurred each year[38].

4.2.2.2 Storage sizing

The presence of storage is a key element in the energy communities and jointly acting self-consumers because it allows to maximize self-consumption and reduce the energy introduced into the grid, explicit objective of the legislation reported in *Chapter3*.

About the storage, the model takes as input variables:

- Storage capacity SC (kWh)
- Charge efficiency η_{ch} (%)
- Discharge efficiency η_{dis} (%)

The user can change these values based on the type of battery chosen, and its size.

[38] (GSE, June 2019)

The model calculates:

- Input flow of the energy in the battery
- State of Charge (SOC) of the battery
- Output flow of the energy in the battery

for each hour of the year, basing on the PV production and the energy demand in each time step, previously calculated (*Chapter4.2.1* and *Chapter4.2.2.1*).

To calculate the Input in the battery, first, the model verifies if, in the considered time step:

$$PVproduction > energy\ demand$$

because if it is not, the input flow is 0, that means that all the energy produced is used as self-consumption to fill the energy demand.

If the production exceeds the energy demand, the surplus is calculated as

$$surplus = PVproduction - energy\ demand$$

and it goes into the storage until it achieves the Storage Capacity SC.
State of Charge SC of the first hour of the year is imposed as 0.

So, the model checks if:

$$SOC + surplus < SC$$

so,

$$Input = surplus * \eta_{ch}$$

Otherwise,

$$Input = (SC - SOC)$$

That means that if the Input flow doesn't exceed the Storage Capacity SC, so it is equal to the surplus; otherwise it is only equal to the energy that can still be contained in the storage, until achieving the maximum Storage Capacity SC.

In the first case, the surplus must be multiplied by the charge efficiency η_{ch} to consider the losses during the charging step; not all the surplus will fill the battery. In the second case charge efficiency η_{ch} is not used because the input is calculated on the basis of the maximum energy that can be stored in the battery.

To calculate the Output flow from the battery, is necessary to very, for each hour, if:

$$PVproduction > energydemand$$

If it is so, the Output flow from the storage is equal to 0, because it means that all the energy demand in that time step is covered by the production of the PV, so is not necessary to use the energy stored.

If the energy demand is higher than the energy produced in that timestep and

$$(energydemand - PVproduction)/\eta_{dis} < SOC$$

that means there is enough energy in the battery to cover all the energy demand; then,

$$Output = (energydemand - PVproduction)/\eta_{dis}$$

Otherwise, the Output is given by all the remaining energy in the storage:

$$Output = SOC$$

Finally, the State of Charge each hour is calculated as:

$$SOC_i = SOC_{i-1} + Input - Output$$

4.2.2.3 Self-consumption, Surplus and Net Demand calculation

After calculating the energy produced by the PV and the energy flows of the battery, the model calculates:

- the share of the energy produced by the PV that is self-consumed
- the share of the energy produced by the PV that goes into the grid
- the net energy demand of the community

all these quantities are calculated for each time step of one hour.

To calculate the energy Self-consumed the formula follows the definition given by the Italian law reported in *Chapter3.3.2*, that says that the energy shared within the community is, on hourly basis, the minimum between the electricity produced at that time by the production plant and the total energy taken in that same time by all associated users.

Here there is the storage too; the Output flow of energy from the storage can be considered as energy produced for the system. So, the Self-consumption formula in the model is:

$$Selfconsumption = \min\left(energydemand; Output + PVproduciton\right)$$

About the Surplus, it exists only if

$$PVproduction > energydemand + \frac{(SC - SOC)}{\eta_{ch}}$$

That means that the PV is producing more than the energy needed by the community and the energy that can be stored in the battery (divided by the charge efficiency because the charging phase involve losses). In this case, the Surplus is equal to:

$$Surplus = PVproduction - energydemand - \frac{Input}{\eta_{ch}}$$

Finally, the Net Demand of the community is the share of the energy demand that must be taken from the central grid because the energy produced by the community itself (including the one stored in the battery) is not enough to cover all the community need. It has been calculated in the model as:

$$Netdemand = Energydemand - PVproduction - Output * \eta_{dis}$$

And it exists only if

$$energydemand > PVproduction + Output * \eta_{dis}$$

Now all the terms representing the energy flows of the community are calculated, on an hourly basis.
The model also implements the sums on the year of each term to give an overall view of the results. The most important data are the percentages that represent:

- how much energy produced by the PV power plant is actually used to cover the community energy needs

$$\frac{Selfconsumption}{PV\ produciton}$$

- on the opposite, how much energy produced by the PV power plant is released to the grid

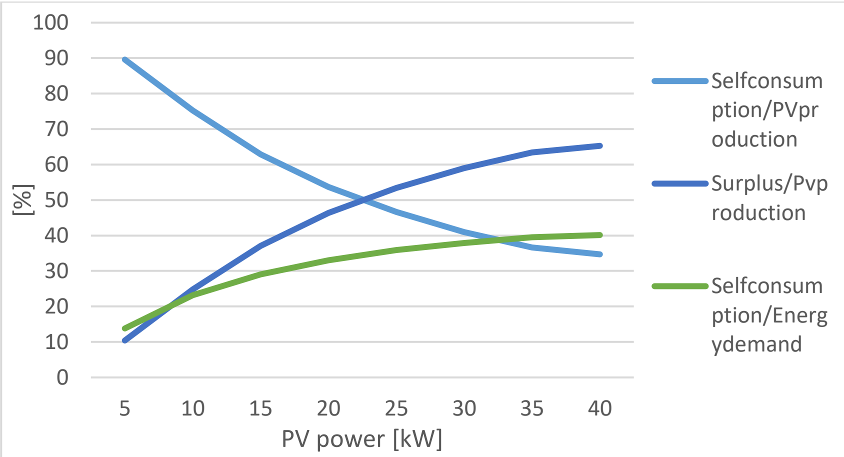
$$\frac{Surplus}{PV\ produciton}$$

- how much of the energy demand is covered by the energy produced within the community

$$\frac{Selfconsumption}{energydemand}$$

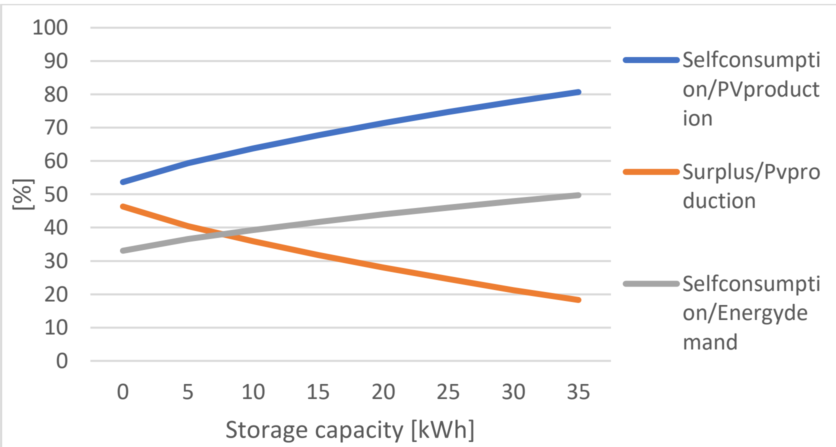
These percentages give to the user of the model the representation of the balances of its system and how they change with different choices of the input data of the PV power plant and the storage.

Considering an example community without the battery, *Graph10* shows how the percentages before explained change, maintaining fixed the energy demand of the community.
Increasing the installed power of the PV, the energy produced will increase, and the self-consumption and the surplus will increase with it. But, as shown in the graph, the ratio between self-consumption and PV production decrease, while the ratio between surplus and PV production increase. This is because, without a battery, self-consumption is limited at the hour in the middle of the day, when usually the demand is low. So, the increase in the PV production goes more in the surplus flow than in the self-consumption flow.



GRAPH 10 – DEPENDENCE OF SELF-CONSUMPTION ON PV SIZE

To exploit better the energy produced by the PV, for the community self-consumption, the storage is need. Increase the Storage Capacity, at fixed PV installed power, make the self-consumption increase and the surplus decrease. This is because the storage let less energy to be released to the grid, it is stored and used when needed, making decrease the energy drawn from the grid. *Graph11* shows the percentage of self-consumed energy on the energy produced by the PV that increase and, on the contrary, the percentage of the surplus that decrease (basing on an example community). The graph shows also the change in the percentage of the energy demand covered by the self-consumption; thanks to the battery, it goes from 33% to almost 50%.
These graphs are not enough to fix the optimum size of the PV and the storage because they still don't consider the increase in the investment that we have with the increase of the plants' size and the presence of incentives on the renewable energy produced and on the share of self-consumption.



GRAPH 11 - DEPENDENCE OF SELFCONSUMPTION ON STORAGE CAPACITY

4.2.3 Economic variables

This part of the model describes the economic flows linked to the energy flows of the community. The model calculates the Net Present Value (NPV) the Internal Rate of Return (IRR) and the Pay Back Time (PBT) of the investment in a power plant (with, if required, a storage system) for a community of users. Furthermore, it calculates the change that occurs in the users' bills if they joint a community and the impact at Country level of the spread of these energy projects (in terms of total incentives needed and CO_2 saved). These are all variables needed to analyse the investment and understand in which conditions it results cost-effective and sustainable.

All the parameters, hypothesis and equations used are described below.

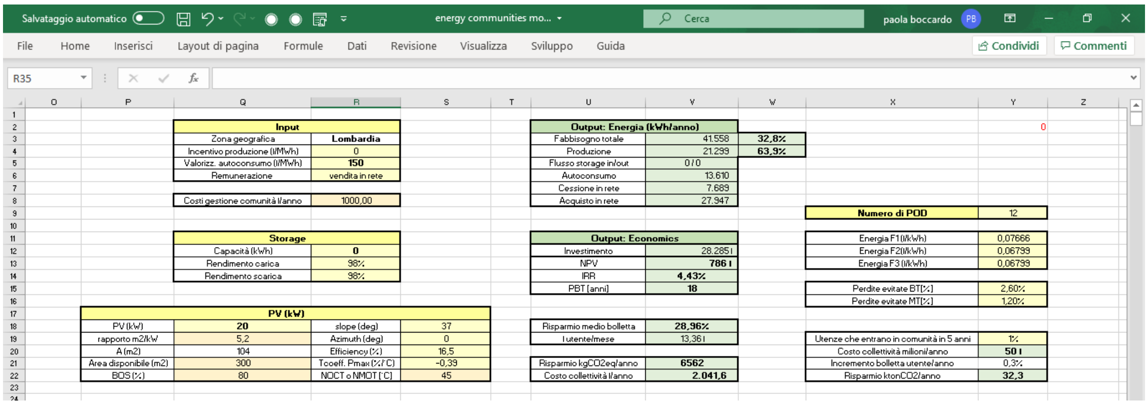


FIGURE 5 - SECOND VIEW OF THE MODEL

The annual Cashflow of the investment considers the following items:

As outflows:

- Initial investment
- Costs of Operations and Maintenance (O&M)
- Insurance
- taxes

As inflows:

- Deduction on the initial investment[39]
- Enhancement of electricity input into the grid
- Incentive on the renewable energy produced
- GSE refund
- Incentive on the self-consumed energy

[39] (D.P.R. 22 dicembre 1986, n. 917, 2019)

Initial investment considers:

- Capital expenditure of the PV power plant ($CAPEX_{PV}$); an approximation of this value is calculated directly by the model as the product of the PV size and value of €/kW that changes for size steps based on suppliers' data[40].
- Capital expenditure of the storage ($CAPEX_{st}$); calculated, as for the PV, as storage size multiplied by €/kW given by suppliers[41].
- Costs for the connections depending on the distance of the plant from the users and on the installed power[42].
- After 10 years, the cost of a new inverter is added

The model allows to consider four ways to manage the investment:

- Entire investment made by the community members at the beginning of the project
- Initial investment made through a loan; in this case the cash flow includes the share of the loan's refund due, calculated basing on the term of the loan and the interest rate
- Depreciation of the investments; the amount due each year is calculated as the investment divided by the years of payback
- Investment made by an energy service company who is in charge of plant feasibility, design, installation and testing and it recoups its investment sharing the economic advantages (incentives, energy enhancement, deduction of the investment, …) with the members of the community
- Furthermore, the investment can be made by only one member of the community, or a part of the members. In this case, as for the previous, the cash flows for the investment and for the other costs must be considered separately.

Costs of Operations and Maintenance (O&M) are divided in two items:

- One referred to the PV power plant; it varies linearly with the PV size by a factor expressed in €/kW set basing on suppliers' data
- Management costs; as said before, the community needs a subject delegated to manage it, all the costs of his activities are included in this item

Insurance is calculated as a percentage of the CAPEX of PV and storage.

[40] (Fotovoltaico.it, 2020)

[41] (EnelX, 2020)

[42] (Fotovoltaico.it, 2020)

Deduction on the initial investment is intended only for plants with installed power equal or lower than 20 kW. The deduction is 50% of the total investment (until an investment of 96'000 €) and it is given in 10 years, starting from the first year after the beginning of the project[43]

Enhancement of electricity input into the grid is calculated on all the energy produced by the PV community plant, it is enhanced by the GSE (Gestore Servizi Energetici) basing on the market price. The total amount of this item is given by the sum of the hourly values:

$$\sum_{i=1}^{8760} (PVproduction_i * MGPprice_i)$$

MGPprice is the €/MWh given by the hourly data of the "day-ahead market" (Mercato del Giorno Prima, MGP)[44] in 2019

Incentive usually applied on the renewable energy produced[45] is not allowed for the energy produced within a community energy project[46]; this item has been included in the model as a variable to analyse the effect of the possibility of adding this incentive on the community's cash flow.
It is defined as the guaranteed price of the energy input into the grid; so, each hour of the year the income coming from the incentive on the renewable energy produced is equal to:

$$income = (incentive - MGPprice) * PVproduction$$

This means that, if the MGP price is lower than the price guaranteed by the incentive, so the users received the difference. On the contrary, when the MGP price will be higher than the incentive, the user will return the difference.

Finally, the hourly data are summed and added to the community cash flow.

GSE refund is based on the ARERA document "Guidelines for the economic regulation of the electricity subject of collective self-consumption and renewable energy

[43] (D.P.R. 22 dicembre 1986, n. 917, 2019)
[44] (Gestore Mercati Energetici GME, 2020)
[45] (Decreto del Ministero dello Sviluppo Economico , 2019)
[46] (Decreto Milleproroghe, 2020)

communities" of the 1st April 2020[47]. In the energy community projects the users will pay the electricity bill as usual and all the incentive are given only at the end of the year. This means that users pay in the bill all the energy consumed, included the energy self-consumed, as bought from the grid. Therefore, the cost of the "energy as raw material", not technically applicable to shared energy[48], is included.
ARERA sets that GSE must refund:

- For the "energy as raw material", 0,822 c€/kWh self-consumed by REC and by "jointly acting renewable self-consumers"
- For the losses avoided, only for the "jointly acting renewable self-consumers", a percentage of zonal price equal per kWh self-consumed. The percentage is 1,2% for production plants connected to medium voltage grid and 2,6% for plants connected to low voltage grid

Incentive on the self-consumed energy is the additional incentive envisaged by the Milleproroghe Decree analysed in *Chapter3.3.2*. Until now, this is an unknown value so this item depends on the incentive the user of the model sets in the INPUT page of the model; it is multiplied by the quantity of energy self-consumed each hour, defined and calculated as described in *Chapter4.2.2.3*, and summed for all the hours of the year to be included in the cash flow equation.

All the items related to the energy produced by the PV take into account the performance drop of the power plant by multiplying the value of the energy produced by

$$(1 - PC)^n$$

where PC is the performance coefficient and n is the year considered.
Energy demand, on the contrary, has been assumed constant during the years.

All the items described above are summed up to obtain the annual cash flow. Then, each annual value is discounted at the year zero as follows, to obtain the Discounted Cash Flow (DCF):

$$DCF = \frac{CF_i}{(1 + r)^i}$$

[47] (ARERA, 2020)
[48] (Decreto Milleproroghe, 2020)

Where $i = 0, \dots, 20$ and it is the year in which that amount was spent or earned and r is the discount rate

Finally, is possible to calculate the Net Present Value NPV defined as the present value of expected cash flows in the 20 years following the investment:

$$NPV = \sum_{i=0}^{20} DCF_i$$

Then Payback Time, defined as the number of years required to recoup the funds expended, is obtained identifying the year in which NPV achieve a positive value.

Internal Rate of Return IRR r is the rate of return that sets the Net Present Value to zero, calculated from the following equation.

$$NPV = \sum_{i=0}^{20} \frac{CF_i}{(1+r)^i} = 0$$

4.3 Simulation

To complete the analysis, the model has been applied to two example cases, to identify the incentives that can support the development of Renewable Energy Communities and jointly acting renewable self-consumers, making the investment in the community sustainable and encouraging users to joint these projects, as required by the recent regulatory changes in the Italian framework.

The analysis has been carried on with multiple goals:

- Increase the renewable share in Italy
- To achieve a high percentage of self-consumption in the communities
- Make these energy projects a sustainable investment
- Do not reach too high costs for incentives

4.3.1 Assumptions

The model has been applied to two cases:
- a non-renovated building of 12 flats composed as follows:
  3 flats of 2 residents each, with no cooling system
  3 flats of 3 residents each, with air conditioning
  3 flats of 3 residents each, with air/air PDC for the cooling system
  3 flats of 4 residents each, with air/air PDC for the cooling system

all the flats have a gas boiler heating system. Total electricity demand of the community is 41.558 kWh/year.
This is an example of “jointly acting renewable self-consumers”, as they are all in a block, so they are subject to the incentive on the losses avoided too. The dimension of the community (12 users) has been chosen basing on Italian building data from ISTAT and from the Elemens estimation[49] in which small apartment buildings are identified as the most diffuse.

- a district composed by:
  3 blocks of 10 flats each
  20 semi-detached houses (10 with 2 residents, 10 with 4 residents)
  10 offices

All the buildings are non-renovated, the total electricity demand of the community is 512.797 kWh/year.

[49] (Elemens, Associazione Energy@Home, 2019)

This is an example of Renewable Energy Community. This is a quite big community and probably it requires more time to develop in the Italian context, but it has been chosen to compare the results obtained from the first community with an example of future development.

The two cases are both located in Milan, with new PV power plants. About the investment, the hypothesis is of an initial total payment, equally divided by the users that joint the community.

Here are summarised the input parameters and the values assumed:

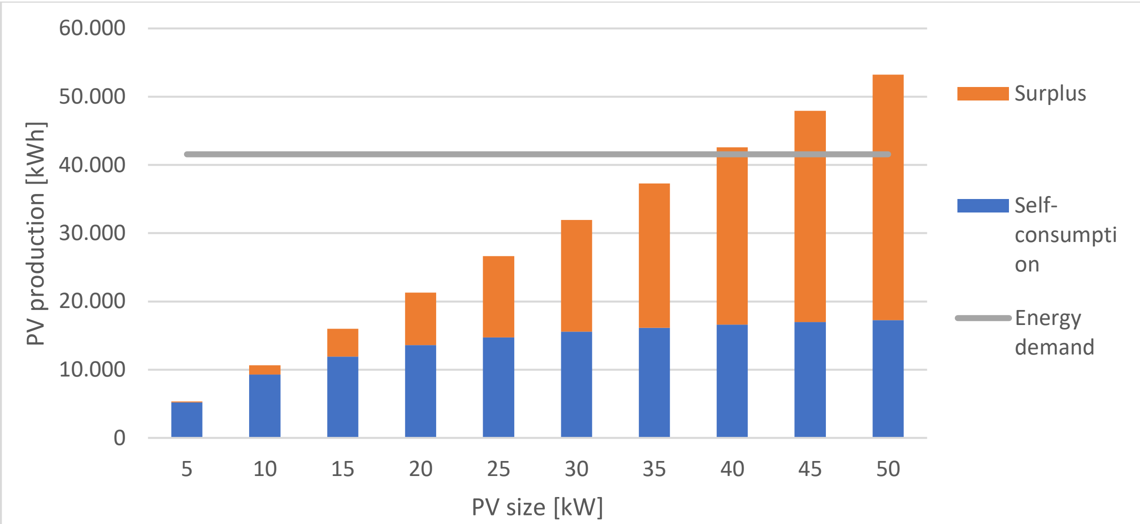
Parameter		Performance coeff.	-0,7 %
PV slope	37 °	Charge efficiency	98 %
Azimuth	0 °	Discharge efficiency	98 %
Efficiency	16,5 %	Management costs	1000 €/year
m2/kW ratio	5,2	Discount rate	4 %
BOS	80 %	Taxes	40 %
T_{coeff} of P_{max}	-0,39 %/°C	Insurance	0,7 %
NOCT	45 °C	Useful period	20 years

TABLE 8 – PARAMETERS OF THE SIMULATION

4.3.2 Results

The analysis starts from *Graph12*. It represents the change, with the PV power plant size, of the percentage of self-consumption and surplus on the PV production. From the graph it is passible also to compare the energy produced by the PV, with the energy demand of the community.

PV production increases linearly with the PV size but there is a change in the percentage of the energy produced used for self-consumption and the percentage of energy produced input into the grid. This scenario doesn't include a storage to increase the energy self-consumed so the part of the energy demand that can be cover by the energy self-produced is only the one consumed during the hours of production (in the middle of the day). So, form one point on, the increase in the PV size leads only to an increase of the quantity of energy input into the grid, and not to an increase in energy self-consumed.



GRAPH 12 – DEPENDENCE OF SURPLUS AND SELF-CONSUMPTION ON PV SIZE

As said before, to choose the optimal size of the PV, economic variables are needed too. An incentive on energy produced leads to choose solutions with big PV size, because all the energy produced brings to a profit regardless how much of this energy is effectively needed by the community; an incentive on the energy self-consumed leads to choose smaller plants because to increase the PV size means make a bigger investment and it is not repaid because the energy self-consumed cannot increase beyond a certain quantity.

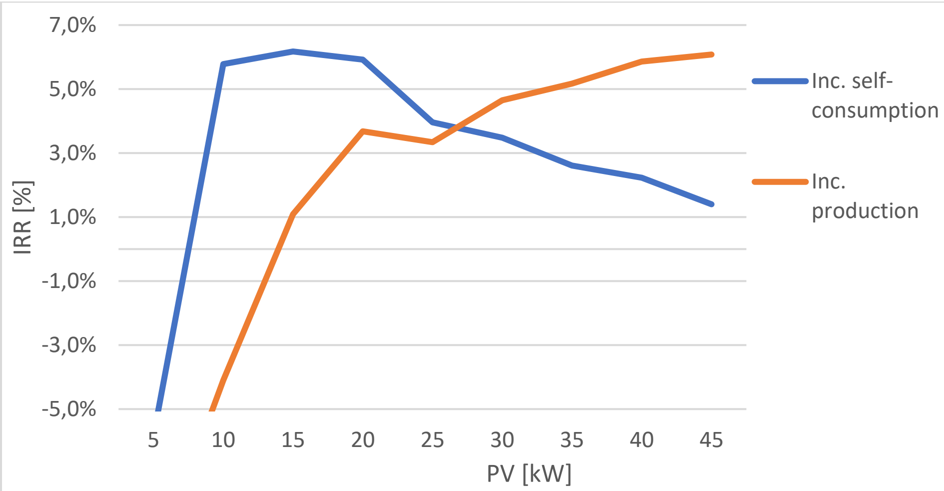
The economic variable that is here used as reference is the internal rate of return (IRR); it must be maximised to make the investment profitable but we consider 4% as a minimum reasonable value for a private investment.

Graph13 represent the variation of the IRR with the PV plant size, for the two cases:

- only incentive on the energy self-consumed
- only incentive on the energy produced

for now, the value of the incentives used is not important because the analysis aims to look at the shape of these curves.

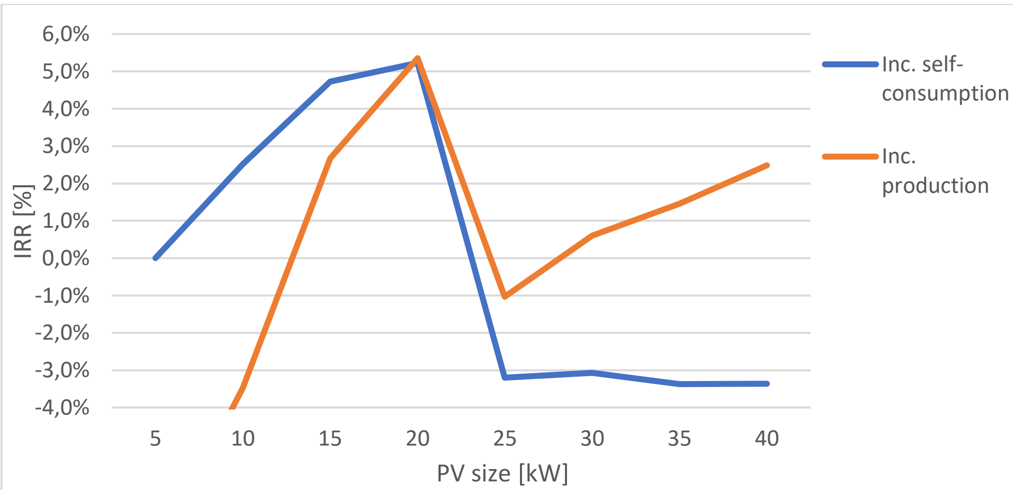
It is clear from Graph13 that an incentive on the energy produced brings to an optimum investment for a big PV plant, and on the opposite, the incentive on the energy self-consumed brings to lower PV size because the investment for a bigger plant is not covered by the profit of the incentives.



GRAPH 13 – CHANGE IN IRR DEPENDING ON TYPE OF INCENTIVE

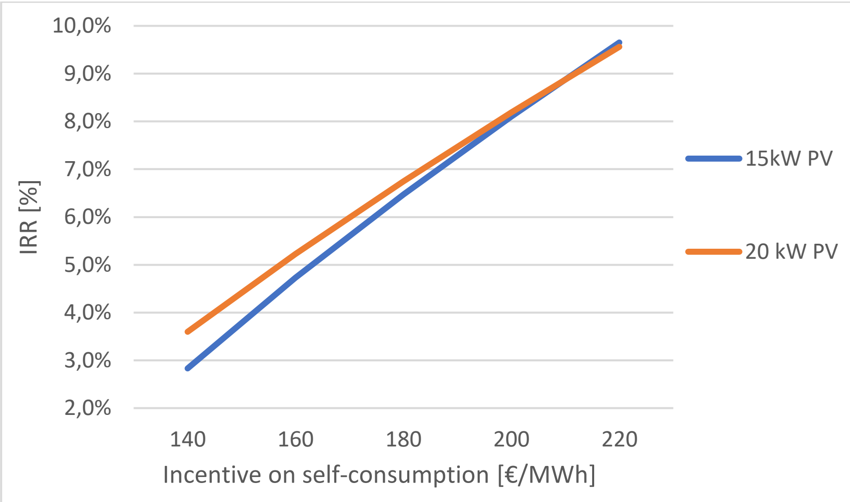
The aim of the Italian legislation is to support self-consumption and the use of storage so now we study the case of incentive only on the self-consumption and its variation. With these conditions, good solutions are achieved with a PV size between 10 and 20 kW. We must also consider that another important goal is to increase the share of energy produced by renewable sources in Italy. So, if there's enough space available, is preferable move to solution with bigger PV size, until they are affordable.

To show the trend, *Graph13* is constructed without considering the deduction of the investment given by the Agenzia dell'Entrate, that is provided only for plants of size not exceeding 20 kW. The presence of this incentive (that is renewed on an annual basis) makes the curve raise before the 20 kW size and rapidly decline beyond it, as shown in *Graph14*.



GRAPH 14 – CHANGE IN IRR DEPENDING ON TYPE OF INCENTIVE, WITH DETRACTION ON THE INVESTMENT

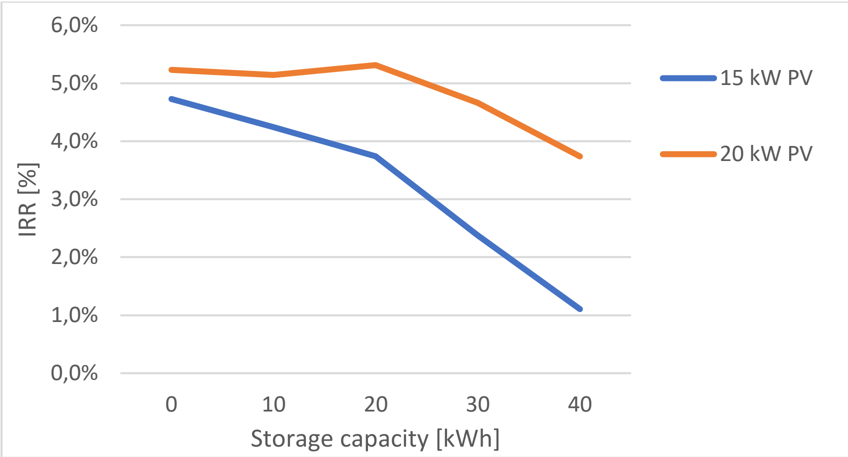
Now, working on incentives on the energy self-consumed, we want to analyse the solutions of 15 and 20 kW PV size and the variation of the IRR with the incentive value in €/MWh.



GRAPH 15 – IN IRR DEPENDING ON INCENTIVE VALUE

From *Graph15* we see that incentive must be higher than 150€/MWh to achieve reasonable IRR values and that until 210 €/MWh the 20kW solution is more profitable than the 15kW solution.
Obviously, we don't want to put too high incentives because money needed for the incentives are redistributed in the users bills as system charges (this aspect will be deeply analysed below). So, until now the best solution for the community considered is a PV plant of 20 kW, if the incentives on the energy self-consumed are between 150 and 200 €/MWh.

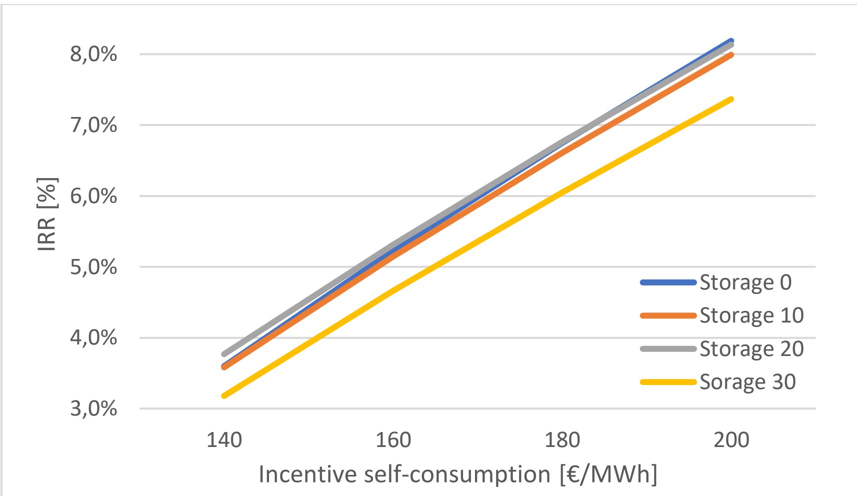
As said before, another purpose of the Italian legislation is to support the use of storage by the community, to increase the share of energy self-produced. *Graph16* shows that to add the storage makes the IRR of the 15 kW PV drop; it means that the additional income that comes from the increase in energy self-consumed is not enough to cover the significant investment of the storage. The graph has been developed considering an incentive of 160 €/MWh but the shape is the same also with the other values.
The impact on the 20 kW line is not the same; until 20 kWh storage, IRR maintains high values and decrease only for too big storage systems.



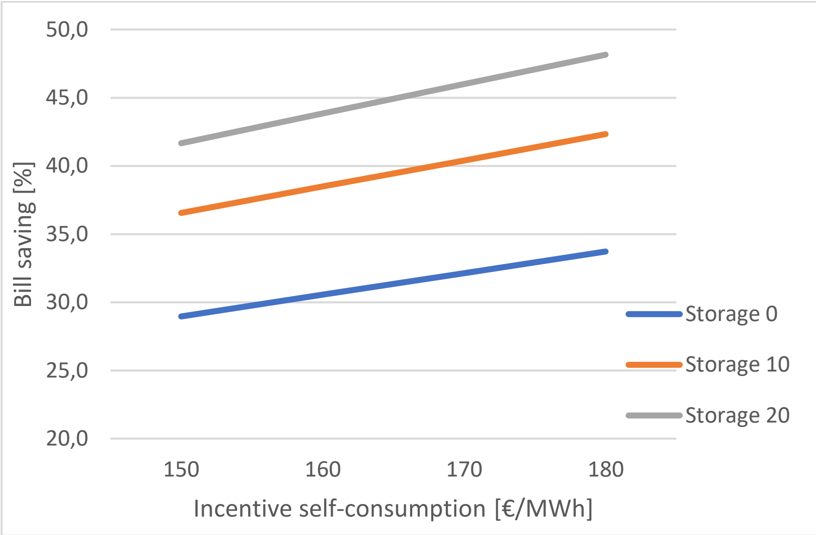
GRAPH 16 – CHANGE IN IRR DEPENDING ON STORAGE SIZE

Graph17 shows in detail the 20 kW PV solution to varying of storage size and incentives. Solutions from 0 to 20 kWh storage are comparable and only slightly different for different values of the incentives. Therefore, the choice on the presence of the battery must be based on the decisions to reduce the amount of the initial incentive or to maximize the self-consumed energy; to move from a no-storage system to a 20kWh storage system leads the share of energy self-consumed by the community from 64% to 87%. The choice is in charge of the investors of the community.

One other important element to consider for this choice is the user point of view to understand if the single user finds the stimulus in join an energy community; main impact for the user entering in an energy community is the bill saving he gets each year. *Graph18* shows the average bill saving of a member of this community.



GRAPH 17 – IRR CHANGE WITH STORAGE SIZE AND INCENTIVE



GRAPH 18 – AVERAGE USER BILL SAVING

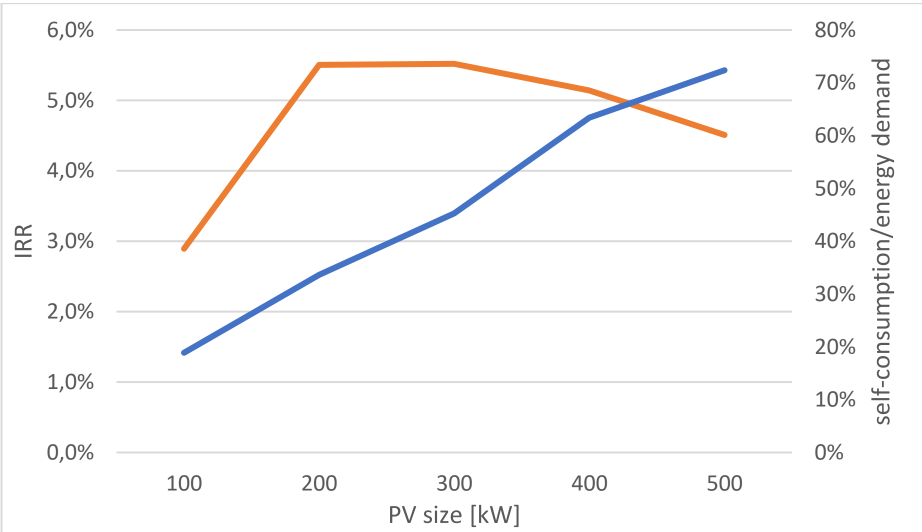
Bill saving for the cases with the storage are higher because the energy self-consumed is more and so the incentives received are higher; but the higher bill saving is achieved in response to a higher investment. Investors of the community must choose between these solutions.
These results have been obtained considering that all the members of the community contribute equally to the investment and so that the bill saving is equally distributed among the members. As said in *Chapter4.2.3* this is only one of the possible ways to share the investment.

Assuming PBT<16 years a reasonable value for a private investment, incentive of 150€/MWh on energy self-consumed is not enough to make users decide to join a community because with this incentive it takes 19 years to return the initial investment. Incentive from 160 to 200 €/MWh lead to PBT between 16 and 10 years so they are suitable values for the new incentive on the self-consumed energy.

It is important to consider that these results have been obtained considering the 50% tax deduction for new renewable energy plants. In the absence of this incentive, the values of 160-200 €/MWh are not enough to support the development of new energy communities. To obtain the same IRR and PBT values we should have incentive values 240-300 €/MWh.

To validate the result, these values have been applied to the other community introduced before. This community is widespread in a district, not just in a building or block; hypothesis of participation of a greater number of users was made. The electricity demand of this community is more than ten times the previous one (500’000 kWh/year) so it needs larger plants. In this case the presence of the tax deduction on the investment is not an issue.

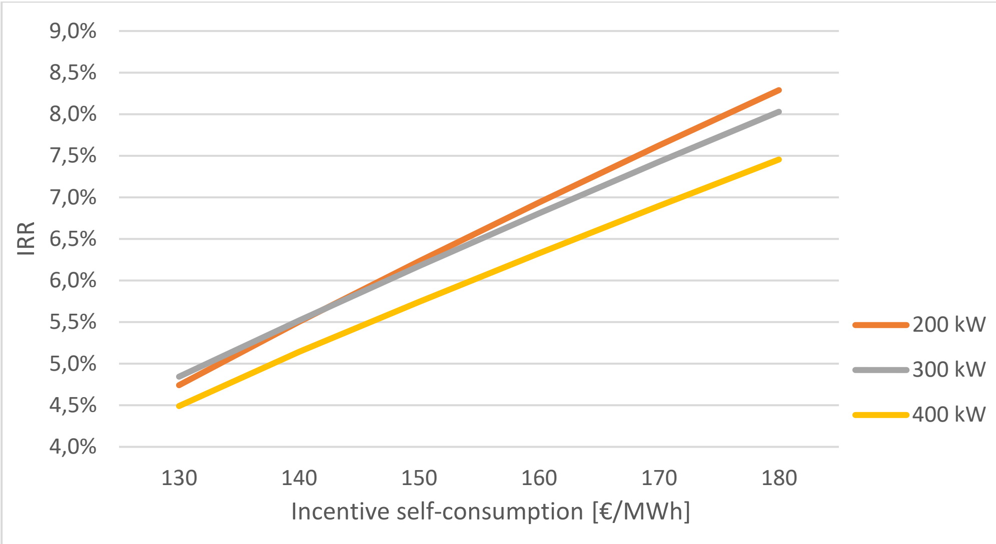
In *Graph19* the IRR trend is shown; it follows the increase in self-consumed energy, and so the increase of incentives get, and then decreases for oversized plants, whose investment is not rewarded by the advantages of self-consumption.



GRAPH 19 – IRR AND SELF-CONSUMPTION CHANGE WITH PV SIZE

Graph20 shows the change in the IRR with the incentive’s values previously identified, applied to PV power plants of 200, 300 and 400 kW. Same incentives of the building community lead to higher IRR values; it is because this community is larger and so the investment is better optimized. Acceptable IRR values are obtained with just an incentive of € 130/MWh.

The incentive on self-consumption could therefore be set at different values depending on the size of the community and the size of its power plants.



GRAPH 20 – IRR CHANGE WITH INCENTIVE VALUE AND PV SIZE

About the storage, in this case there is no solution with storage that could be considered profitable. The reason lies in the huge investment necessary for the installation of a battery sized for such a large requirement. Being the 200kW and the 300kW solutions comparable, if the space available is enough the 300kW system is preferable to increase the share of self-consumed energy. To push the choice toward bigger power plants (and so to more renewable energy produced) a threshold on the share of self-consumed energy on the energy demand could be applied.

To conclude the analysis, the phenomenon has been analysed from a different point of view, calculating the positive and negative impact that would have the diffusion of the energy communities in Italy in next years.

The analysis is based on the data about the potential of the residential self-consumption provided by Elemens[50]. Their calculation has been carried out starting from the ISTAT data of residential buildings, then an estimate of available space for new photovoltaic systems has been applied; so the technical potential of MW of PV power plants that can be added on buildings in Italy has been defined. Finally, the elasticity of the users at the bill saving proposed has been considered, together with the maximum physical limit of installations that can be made every year.

[50] (Elemens, Associazione Energy@Home, 2019)

The results of this work are shown in *Figure6* and *Figure7*; they are the “growth scenario” and the “decrease scenario” of the annual potential increase for the residential self-consumption with PV power plants.

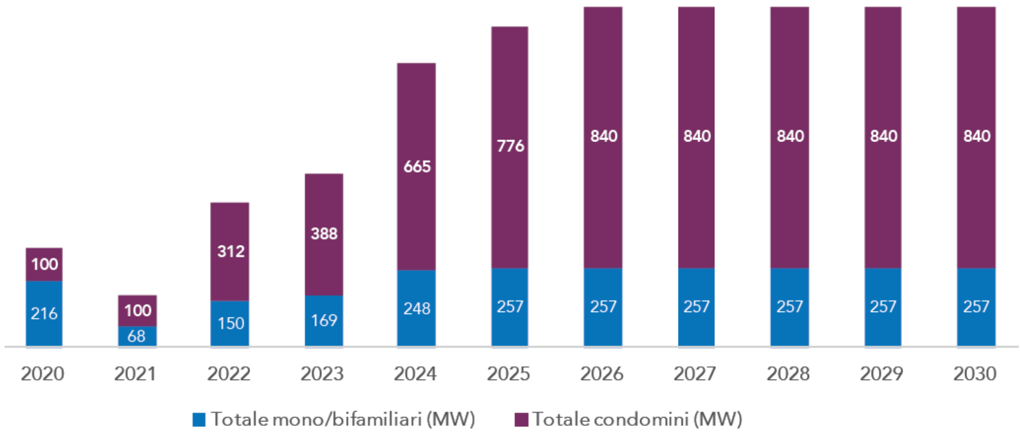


FIGURE 6 – ANNUAL POTENTIAL OF RESIDENTIAL SELF-CONSUMPTION, GROWTH SCENARIO

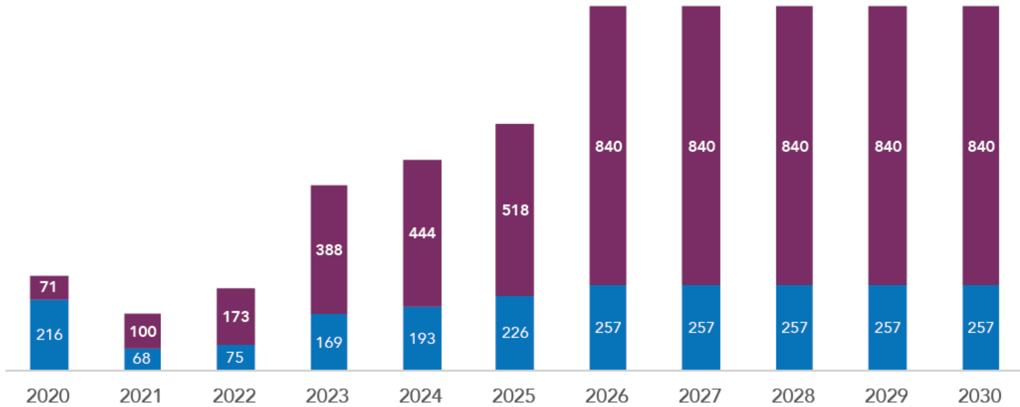


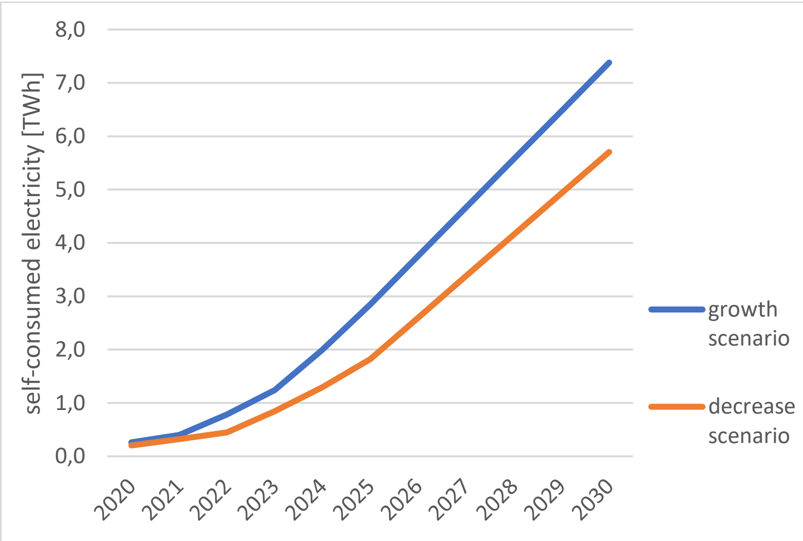
FIGURE 7 – ANNUAL POTENTIAL OF RESIDENTIAL SELF-CONSUMPTION, DECREASE SCENARIO

A hypothesis of 1180 equivalent hours (average of the medium Italian values of the last three years[51]) has been applied to obtain the potential production of these new residential power plants.

Another hypothesis needed is about the percentage of energy produced that is self-consumed. Basing on the results obtained before, the hypothesis on 60% of self-consumption has been applied to the decrease scenario and the hypothesis of 70% of energy self-consumed has been applied to the growth scenario.

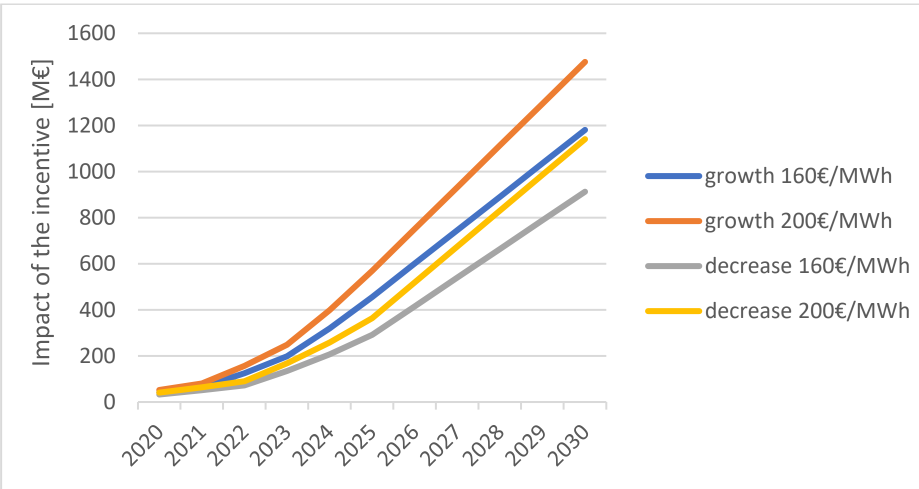
[51] (GSE, June 2019)

The results obtained are shown in *Graph21*; for each year it represents the energy self-consumed by the increasing energy communities.



GRAPH 21 – INCREASE IN SELF-CONSUMED ELECTRICITY

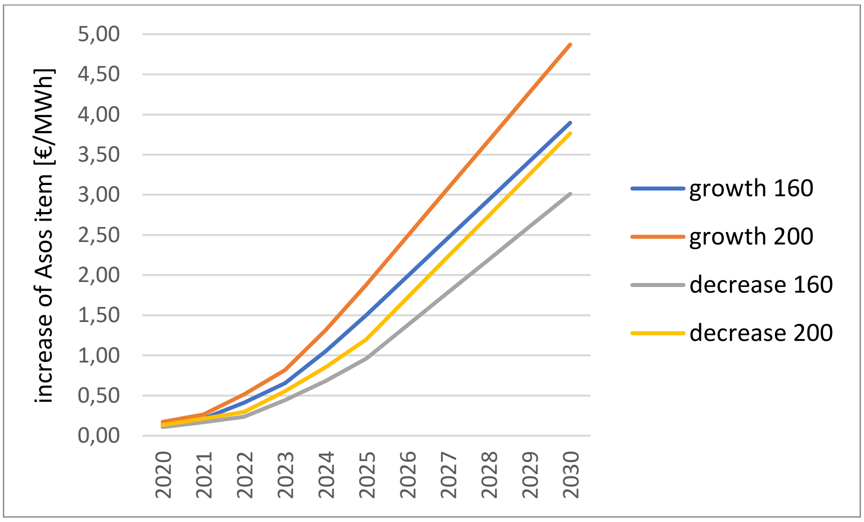
The maximum and minimum incentive's values found before (160€/MWh and 200€/MWh) have been applied to the energy self-consumed to obtain the total costs incurred countrywide each year to support the energy communities; results are plotted in *Graph22*.



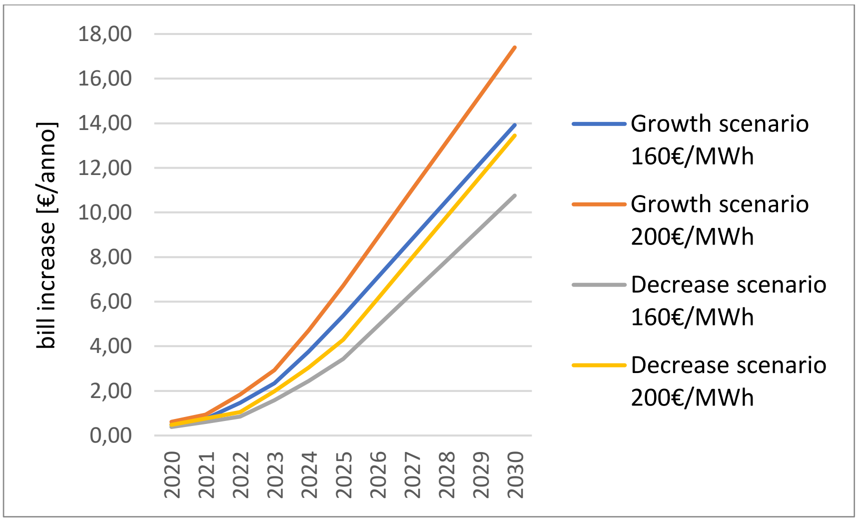
GRAPH 22 – TOTAL ECONOMIC IMPACT OF THE INCENTIVE

The cost for the incentives is redistributed in the user bills within the "system charges" item; the component of the system charges relating to the support of renewable energy is a variable cost named A_{sos} and it is currently equal to 32,05 €/MWh consumed.

Graph23 shows the increase of the variable costs of the bill, compared to the current value, necessary to cover the self-consumption incentives assumed each year. *Graph24* shows the change in the bill, on a year basis, for an average user (consumption 3500kWh/year; 560€).



GRAPH 23 – INCREASE OF VARIABLE COSTS OF THE BILL

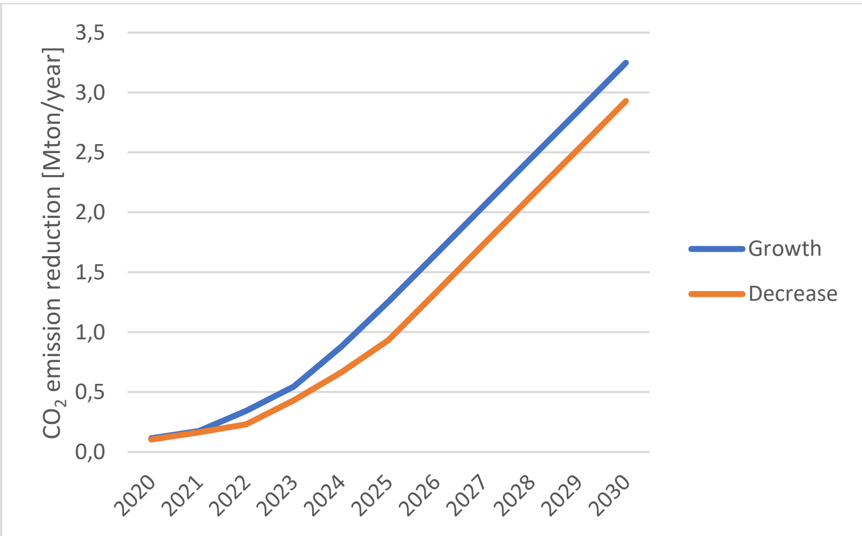


GRAPH 24 – INCREASE OF AN AVERAGE BILL COMPARED TO THE CURRENT VALUE

Looking at these results, it must be considered that other items that are part of the variable costs of the energy in the bill will decrease in the coming years (for example, the incentive for renewable plants that came into operation more than 10 years ago).
However, from the graphs we see that the incentive on the energy self-consumed should be reviewed over the years, to avoid an excessive increase in users' bills. Moreover, the change will be necessary based on the actual development of the phenomenon of the

energy communities and, above all, based on the variation in the costs of the technologies. From past data, it is known that these values can vary considerably even in few years and therefore the economic balance of a new energy community will be more advantageous if the necessary investment is to be reduced significantly.

Finally, *Graph25* shows the environmental impact of the spread of energy community projects. Data about renewable energy produced by new PV power plants in residential communities have been multiplied by the emission factor of Italian electrical production and consumption that is equal to 308,1 gCO_2/kWh (2017 data)[52].
It results in an overall decrease in CO_2 emissions per year of 3Mton in 2030. In 2017 electricity generation in Italy causes 93Mton of CO2 emissions[53], so the contribution of energy communities could lead to a 3% decrease in electricity production emissions for 2030, compared to 2017 value.



GRAPH 25 - CO_2 EMISSION REDUCTION

The PNIEC (Piano Nazionale Integrato per l'Energia e il Clima) 2020[54] sets as goal for the electricity sector in 2030 emissions of 57Mton CO2eq that means a decrease of 36Mton CO2; looking at this data the energy community phenomena could contribute at 8% at this goal. The PNIEC set also the goal of 187 TWh produced by renewable sources in 2030, starting from 113TWh produced in 2017. As shown above, energy community projects can contribute to this goal with 10TWh at 2030, that is the 13,5% of the growth needed.

[52] (ISPRA, 2019)
[53] (ISPRA, 2019)
[54] (MISE, MATTM,MIT, 2019)

4.3.3 Comments

In conclusion to this analysis, we obtained that if only incentives on self-consumed energy are applied, these must be in the order of 150-200 €/MWh; the final choice must take into account the elasticity of the users with respect to the economic stimulus.
For this reason, an incentive should be set for the communities set in the early years, and an update of the same incentive should be scheduled after four or five years to adapt to the development of the phenomenon of collective self-consumption in Italy. A high incentive would now lead to a faster spread of the phenomenon, without an excessive impact on the bills of all users; it could be reduced when self-consumption systems will be considered riper.
Non-economic actions can also be envisaged to stimulate users to enter an energy community, such as raising awareness among the population on energy and environmental problems and on the impact of distributed generation. Also, the development of energy communities can be promoted alongside other local social development actions.

From an economic point of view, analysing the results obtained above, it is necessary to consider, as already mentioned, the large variation in the cost of technologies, a phenomenon that can strongly vary the economic balance. Furthermore, the 50% deduction on the investment has a strong impact on the economic balance of the small energy communities, and it must be highlighted that it is an incentive renewed on an annual basis.

About management aspects, it is necessary to know how the role of the community manager will develop; this factor affects the costs relating to this item, included in the model. Companies will probably begin to provide this service to condominiums, perhaps at the same time as the installation of the power systems, and therefore the costs may drop. Furthermore, the problem of the share of the self-consumption quota among the users remains to be resolved.

Finally, from a technical point of view, the addition of demand response mechanisms, when it is possible to apply them to domestic users, can significantly increase the efficiency of the communities and consequently make them more cost-effective.

5. Conclusions

Distributed energy production is a key element for energy transition thanks to the reduction of grid losses it leads and its dimension that better suits the generation from renewable sources. In this paper, different aspects of energy community and collective self-consumption solutions have been analysed to allow a comprehensive assessment of this phenomenon.

The analysis of the projects set up spontaneously by the population in absence of specific legislation, highlighted some elements for the spread and the success of these projects. Among these it is important to remember the awareness of users about the energy issue, element that can be achieved also thanks to the geographical proximity of people to their production power plant, and the involvement of the users in the community dimension, with its human and cultural aspects, element that can also lead to positive local social impact.

The analysis of the legislative processes gave further elements to read the development of collective self-consumption projects in Europe: Countries with more development and acceptance of these projects are those who boosted them with initiatives to involve citizens and with experimental projects; not the ones that just did not ban them.

From the analysis of the European legal framework emerged the determined choice of improve the tools available for the citizen to became active in the energy production sector. The Directive 2018/2001 on the promotion of the use of energy from renewable sources (RED II) and Directive (EU) 2019/944 on common rules for the internal market for electricity (EMD II) have been compared to identify the opportunities they open.
The definitions they introduce are very different in the intent and in the activities allowed and so they probably will be applied in different context and they will develop in different ways. Until now, only the transposition of the Directive REDII started in several European Countries; it activated stimuli in all the Member States fallen behind in the collective self-consumption field. So is open the path for a homogeneous and stronger development of this phenomenon in Europe.

With the decree of February 28th, 2020 Italy has taken this path too, so we must expect new projects to be born shortly in our Country. The Italian decree provides that the intent is to incentive self-consumption and the use of storage systems but, until now, it doesn’t define the value of the incentive. Our analysis continued on the basis of the directives of this decree.

To carry on a quantitative analysis of the development of the collective-self consumption projects in Italy a model has been developed. The model allows to quantitatively represent different type of collective self-consumption projects and their energy and economic flows; it can be used both for specific cases, to assess their sustainability, and for general cases, to support decision-making processes on this topic. The model implementation needed an analysis of the Italian main features about buildings and appliances used, to develop the energy demand curve and an analysis on the irradiation in different locations to develop the PV production curve. These elements allowed to achieve the community representation, with a one-hour time period accuracy, varying with the location of the community, the buildings insulation, the number of residents, their heating and cooling systems, the number and size of their PV power plant and the storage. The demand curve is developed for all the days of the year, considering the variation for the different seasons and for the working days and the weekend days.

The model has been implemented on two example cases; this analysis allowed to identify an optimal amount of the incentive to be set in Italy on energy self-consumed. The result of 160-180 €/MWh self-consumed, has been achieved as a trade-off between the support to new collective self-consumption projects and the not excessive impact on the costs for the whole community to finance this program. Looking at the results it turns to be necessary to remodel the value of the incentive after few years (approximately 5) to adapt to the development of this phenomenon and to the variation of the other elements that affect it, such as the costs of the technologies. Then the result will be affected by the issues yet to be defined about the person in charge of community management and the subdivision of the amount of self-consumed energy among users.

Remain to be quantified the opportunities that will be open by the activation of Citizen Energy Communities, defined by the Directive EMDII, with the network services and energy efficiency services they are allowed to activate. But for this we need to see how the Directive EMDII will be transposed in the Member States’ legal framework

Appendix

NAME	COUNTRY	STRUCTURE	year	SOURCE
Simmering	Austria	Community Microgrid		https://www.smartertogether.at/
Wien Energie	Austria	Community-scale energy project	2012	https://www.wienenergie.at/
STERNWIND Errichtungs GmbH & Co KG	Austria	Community-scale energy project	2003	www.sternwind.at
solar Anlage(n) Judendorf	Austria	Community-scale energy project	2012	http://mitdersonne.at
Michelbacher Windkraft GmbH	Austria	Community-scale energy project	1995	http://citeseerx.ist.psu.edu/
Ökostrombörse Salzburg	Austria	Community-scale energy project	2005	http://www.salzburg.oekostromboerse.at/
WEB Windenergie AG	Austria	Community-scale energy project	1999	www.windenergie.at
Windkraft Innviertel GmbH	Austria	Community-scale energy project	1992	http://windkraft-innviertel.at/
Windkraft Simonsfeld AG	Austria	Community-scale energy project	1996	http://www.wksimonsfeld.at
Windpark Spörbichl	Austria	Community-scale energy project	1999	http://www.windhaag-freistadt.ooe.gv.at/
Böheimkirchen	Austria	P2P trading platform	2017	https://futurezone.at/
Köstendorf	Austria	P2P trading platform	2018	https://www.fh-salzburg.ac.at
Viertel Zwei	Austria	P2P trading platform	2019	https://www.wienerzeitung.at/
OUD-HEVERLEE	Belgium	Community Microgrid		http://www.muse-grids.eu/demosites/
WattArdenne	Belgium	Community-scale energy project	2018	https://www.wattardenne.be/
Asse	Belgium	Community-scale energy project	2009	http://citynvest.eu/content/asse-belgium
Energiris	Belgium	Community-scale energy project	2014	http://energiris.coop/
Energent	Belgium	Community-scale energy project	2013	https://energent.be/
Allons en Vent	Belgium	Community-scale energy project	2001	http://allonsenvent.be/
Eeklo	Belgium	Community-scale energy project	2001	http://citynvest.eu/content/eeklo-belgium-0
BocagEn	Belgium	Community-scale energy project	2017	https://bocagen.be/
Champs d'énergie	Belgium	Community-scale energy project	2013	https://champsdenergie.be/
CLEF scrl	Belgium	Community-scale energy project	2006	http://www.clef-scrl.be
Condroz Energies Citoyennes	Belgium	Community-scale energy project	2014	http://coopcec.be/
Courant d'Air	Belgium	Community-scale energy project	2009	https://www.courantdair.be/wp/
Emissions Zéro	Belgium	Community-scale energy project	2007	https://www.emissions-zero.coop/
EOLE-LIEN	Belgium	Community-scale energy project	2013	http://eole-lien.be/
Ferréole	Belgium	Community-scale energy project	2012	http://www.ferreole.be/
HesbEnergie	Belgium	Community-scale energy project	2014	https://www.hesbenergie.be/
Lucéole	Belgium	Community-scale energy project	2019	https://luceole.be/
Nosse Moulin	Belgium	Community-scale energy project	2011	https://www.nossemoulin.org/
Vent d'ENFAN	Belgium	Community-scale energy project	2018	https://ventdenfan.be/

Vents du Sud	Belgium	Community-scale energy project	2012	https://www.ventsdusud.be/
Volterra	Belgium	Community-scale energy project		http://www.volterra.be/index.html
EcoPower	Belgium	Community-scale energy project + Virtual Power Plants	2013	https://www.ecopower.be
Energie 2030	Belgium	Virtual Power Plants	1995	https://www.energie2030.be/fr
COCITER	Belgium	Virtual Power Plants	2013	https://www.cociter.be
Moulins du Haut Pays	Belgium	Community-scale energy project	2009	http://citynvest.eu/content/dour-belgium
BUURZAME STROOM (Wisegrid)	Belgium	Community Microgrid		https://www.wisegrid.eu/pilot-sites/ghent
Solarna Pecka	Bosnia	Community-scale energy project	2019	https://www.foeeurope.org/
Sofia	Bulgaria	Community-scale energy project		https://www.communitypower.eu/
Greeneum	Cipro	P2P trading platform	2019	https://www.greeneum.net/
ZEZ (Green energy cooperative)	Croatia	-	2016	http://www.zez.coop/index_en.html
Cres-Lošinj Archipelago	Croatia	Community-scale energy project	2019	https://www.total-croatia-news.com/
Kapela	Croatia	Community-scale energy project		https://bib.irb.hr/datoteka/828110.energetske_zadruge_2.pdf
Kaštela	Croatia	Community-scale energy project		https://bib.irb.hr/datoteka/828110.energetske_zadruge_2.pdf
Lug	Croatia	Community-scale energy project		https://bib.irb.hr/datoteka/828110.energetske_zadruge_2.pdf
Otok Krk	Croatia	Community-scale energy project		https://bib.irb.hr/datoteka/828110.energetske_zadruge_2.pdf
Križevci	Croatia	P2P trading platform	2018	https://www.compile-project.eu/sites/pilot-size-krizevci/
Compile Project	Croatia	P2P trading platform		https://www.compile-project.eu/sites/pilot-size-krizevci/
Føns	Denmark	Community Microgrid	2012	https://climatelab.middelfart.dk/
Hvidovre Offshore Wind	Denmark	Community-scale energy project	2009	https://uploads.strikinglycdn.com/
Middelgrunden	Denmark	Community-scale energy project	2000	https://www.greeneconomycoalition.org/
Isola di Samso	Denmark	Community-scale energy project	1997	https://www.h2020smile.eu/the-islands/samso-denmark/
Project zero	Denmark	Community-scale energy project	2012	https://www.forbes.com/
The Energy Collective	Denmark	P2P trading platform	2018	https://the-energy-collective-project.com/context/
Dansk Fjernvarme	Denmark	-	1957	www.danskfjernvarme.dk
The solar house (Avedøre Fjernvarme)	Denmark	Community Microgrid	1984	https://uploads.strikinglycdn.com/
Hillerød Biogasification P/S	Denmark	Community-scale energy project	2011	https://uploads.strikinglycdn.com/
Hvide Sande	Denmark	Community-scale energy project	2010	https://climatepolicyinfohub.eu/
Ærø	Denmark	Community-scale energy project	1981	http://www.aeroe-emk.dk/eng/index.htm
Marstal	Denmark	Community-scale energy project	1994	https://www.solarmarstal.dk/
WePower	Estonia	P2P trading platform	2018	https://elering.ee/
Vilde 70	Estonia	Community-scale energy project	2014	http://co2mmunity.eu/outputs/community-energy-cases
Kagu	Estonia	Community-scale energy project		http://co2mmunity.eu/outputs/community-energy-cases
LEMENE, Lempäälä Energy Community	Finland	Community Microgrid	2017	http://www.lempaalanenergia.fi/

Smart Energy Åland	Finland	Community Microgrid	2014	http://energiakokeilut.fi/
Sundom Smart Grid	Finland	Community Microgrid	2014	http://energiakokeilut.fi/
Lappeenranta Green Campus	Finland	Community Microgrid	2011	https://www.lut.fi/green-campus
Perho Energy Cooperative	Finland	Community-scale energy project	1994	http://web2.vtt.fi/virtual/afbnet/perho-engl-2.pdf
South Karelia	Finland	Community-scale energy project	2013	https://www.communitypower.eu/
Alpua village	Finland	Community-scale energy project	1947	http://co2mmunity.eu/outputs/community-energy-cases
Oulu Electricity Sales Ltd	Finland	Virtual Power Plant	2013	https://www.oulunenergia.fi/
Tuupovaara Energy Co-operative	Finland	Virtual Power Plant (e Community-scale energy projects)	1996	https://www.pathways-project.nl/
Lumituuli	Finland	Virtual Power Plant + Community-scale energy project	2014	https://www.lumituuli.fi/
Housing Haapalahdenkatu 11	Finland	Community Microgrid	2017	https://finsolar.net/
Hoom	France	-		https://www.hoom.nl/
Energie Partagée	France	-	2010	https://energie-partagee.org/
Les Haies	France	Community Microgrid	2014	http://www.regiondecondrieu.centralesvillageoises.fr/
Combrailles solar	France	Community-scale energy project	2010	http://combraillesdurables.org
sociétés locales Centrales Villageoises	France	Community-scale energy project	2010	http://www.centralesvillageoises.fr/
Buxia Energies	France	Community-scale energy project	2015	http://www.buxia-energies.fr/
Electrons Solaires	France	Community-scale energy project	2015	https://www.electrons-solaires93.org/Historique.html
EnerCit'IF	France	Community-scale energy project	2018	https://enercitif.org/
Plaine Eneegie Citoyenne	France	Community-scale energy project	2018	https://www.plaine-energie-citoyenne.fr/
Sud Paris Soleil	France	Community-scale energy project	2019	https://sudparis-soleil.fr/
Vincennes en transition	France	Community-scale energy project	2019	https://94.citoyens.com/2019/
O'Watt Citoyen	France	Community-scale energy project		https://www.facebook.com/
Gresi21	France	Community-scale energy project	2016	https://gresi21centralesvillageoises.com/
Energ'Y Citoyennes	France	Community-scale energy project	2016	https://energy-citoyennes.org/
Jurascic	France	Community-scale energy project	2016	https://www.jurascic.com/
Landes du Mené	France	Community-scale energy project	2013	https://www.banquedesterritoires.fr/
Saint-Gant'Eole Citizen	France	Community-scale energy project	2018	https://www.enr-citoyennes.fr/
EnR Citoyenne	France	Community-scale energy project + other energy services	2003	https://www.enr-citoyennes.fr/
Enercoop	France	Virtual Power Plants	2005	https://www.enercoop.fr/
Enercoop Ardennes	France	Virtual Power Plants	2009	http://www.enercoop-ardennes.fr/
Urban Solar Energy	France	Virtual Power Plants (+ Community Microgrid + P2P)	2018	https://www.urbansolarenergy.fr/
IssyGrid	France	Community Microgrid	2012	https://www.issy.com/issygrid
Lyon Confluence	France	P2P trading platform	2016	http://www.lyon-confluence.fr
Sunchain	France	P2P trading platform	2018	https://www.sunchain.fr/
Bioenergiedorf Heubach	Germany	Community Microgrid	2008	https://www.energieatlas-bw.de/

Klimakommune Saerbeck	Germany	Community Microgrid	2008	http://citynvest.eu/
Texel Island	Germany	Community Microgrid		http://files.constantcontact.com/
Isola di Pellworm	Germany	Community Microgrid	2013	https://kraftwerkforschung.info/
Steinfurt	Germany	Community-scale energy project	2014	https://www.steinfurt.de/
Energy supply Honigsee eG	Germany	Community-scale energy project	2007	https://www.genossenschaften.de/
Energy Cooperative Lieberhausen eG	Germany	Community-scale energy project	1999	https://www.genossenschaften.de/
Jühnde	Germany	Community-scale energy project	2005	https://www.genossenschaften.de/
Dardesheim	Germany	Community-scale energy project	2010	http://www.kommunal-erneuerbar.de/
Barchschole	Germany	Community-scale energy project	2016	https://www.lochemenergie.net/
Bürger Solar Willich eG	Germany	Community-scale energy project	2009	www.buerger-solar-willich.de
Bürger Solargenossenschaft Mönchengladbach eG	Germany	Community-scale energy project	2011	www.buerger-solar-mg.de
BürgerEnergie Berlin	Germany	Community-scale energy project	2011	https://www.buerger-energie-berlin.de/
De Vullerschool	Germany	Community-scale energy project	2015	https://www.lochemenergie.net/
Emden eG	Germany	Community-scale energy project	2008	https://www.genossenschaften.de
EnergieGenossenschaft-Flensburg eG	Germany	Community-scale energy project	2011	https://www.genossenschaften.de/
HEG Heidelberger Energiegenossenschaft eG	Germany	Community-scale energy project	2010	www.heidelberger-energiegenossenschaft.de
Rosengarten	Germany	Community-scale energy project	2007	https://rosengartenenergie.de/
Sonnenstadt Jever eG	Germany	Community-scale energy project	2007	https://www.genossenschaften.de/
UrStrom	Germany	Community-scale energy project	2010	https://www.urstrom.de/
Friedrich Wilhelm Raiffeisen Energie eG	Germany	Community-scale energy project	2008	https://www.genossenschaften.de/
EWS	Germany	Community-scale energy project	1989	https://www.ews-schoenau.de/
Bürger Energie Region Regensburg – BERR eG	Germany	Community-scale energy project	2010	http://www.berregensburg.de/
Odenwald (EGO)	Germany	Community-scale energy project	2009	https://eg-odenwald.de/
Energiegenossenschaft Starkenburg eG	Germany	Community-scale energy project	2010	www.energiestark.com
Cooperativa energetica di Magonza	Germany	Community-scale energy project	2011	https://www.mainz-energie.de/
Wiemersdorf GmbH & Co. KG community wind farm	Germany	Community-scale energy project	2001	http://co2mmunity.eu/
Windpark Ellhoeft	Germany	Community-scale energy project	2000	https://windpark-ellhoeft.de/
Windfang eG	Germany	Community-scale energy project	1992	https://www.genossenschaften.de/
Wolfhagen	Germany	Community-scale energy project	2012	http://www.beg-wolfhagen.de/
Zschadraß	Germany	Community-scale energy project	2009	http://www.kommunal-erneuerbar.de/
Sprakebüll	Germany	Community-scale energy project	1998	http://co2mmunity.eu/
Prokon Regenerative Energien eG	Germany	Community-scale energy project + Virtual Power Plants	1995	https://www.prokon.net/
Enyway	Germany	P2P trading platform	2017	https://en.enyway.com
Conjoule + Innogy	Germany	P2P trading platform	2018	https://newenergyupdate.com
Lition	Germany	P2P trading platform	2019	https://www.lition.de/
Nordgröen	Germany	Virtual Power Plant	2012	https://www.nordgroon.de/

EWS	Germany	Virtual Power Plant + Community-scale energy project	1997	https://www.ews-schoenau.de/
Next Kraftwerke	Germany	Virtual Power Plants	2009	https://www.next-kraftwerke.de/
Helmetal	Germany	Virtual Power Plants	2013	https://eg-helmetal.de/start.html
Bürgerwerke eG	Germany	Virtual Power Plants	2013	https://buergerwerke.de/
NATURSTROM AG	Germany	Virtual Power Plants	1998	https://www.naturstrom.de/
Windpark Druiberg	Germany	Community-scale energy project	1995	https://climatepolicyinfohub.eu/
Bürgerwindpark Galmsbüll GmbH	Germany	Community-scale energy project	2009	http://www.lei.lt/co2mmunity/
Teningen eG	Germany	Community-scale energy project	2009	http://buergerenergie-teningen.de/
Free-sun	Germany	Community-scale energy project	2008	https://climatepolicyinfohub.eu/
Bolheimer Sonnenstrom eG	Germany	Community-scale energy project	2005	https://www.genossenschaften.de/
Neue Energie Leverkusen eG	Germany	Community-scale energy project	2012	https://www.genossenschaften.de/
Community Network	Germany	P2P trading platform	2018	https://news.innogy.com/
Neue Energie Genossenschaft eG	Germany	Community-scale energy project	2009	https://www.genossenschaften.de/
Norddeutsche EnergieWende (NEW 4.0)	Germany	P2P trading platform	2016	https://www.new4-0.de/
Electra Energy Cooperative	Greece	-	2012	http://electraenergy.coop/
Rafina-Pikermi	Greece	Community Microgrid	2019	https://www.compile-project.eu/
Kimmeria student campus	Greece	Community Microgrid		https://www.renaissance-h2020.eu/
Sifnos Island Cooperative	Greece	Community Microgrid	2019	https://euislands.eu/island/
Isola di Tilos	Greece	Community Microgrid	2018	https://www.tiloshorizon.eu/
KYTHNOS	Greece	Community Microgrid		https://www.wisegrid.eu/
MESOGIA	Greece	Community Microgrid		https://www.wisegrid.eu/
AgroEnergy	Greece	Community-scale energy project	2009	http://www.agroenergy.gr/
Hyperion	Greece	Community-scale energy project + Virtual Power Plants	2016	http://electraenergy.coop/
Nyíregyháza	Hungary	Community-scale energy project	2013	https://www.communitypower.eu/
The Cloughjordan Eco Village	Ireland	Community Microgrid	2005	https://www.communitypower.eu/
South Kerry Development Partnership Limited	Ireland	Community-scale energy project		http://www.southkerry.ie/
Claremorris Energy Coop	Ireland	Community-scale energy project	2015	http://www.claremorris-energy-coop.com/
Aaran	Ireland	Community-scale energy project	2019	http://www.aranislandsenergycoop.ie/
Birdhill Energy	Ireland	Community-scale energy project	2014	https://energycommunitiestipp.ie/
Drombane/Upperchurch Energy Team	Ireland	Community-scale energy project	2012	https://energycommunitiestipp.ie/
KRHET	Ireland	Community-scale energy project	2014	https://energycommunitiestipp.ie/
Terryglass Improvements Association	Ireland	Community-scale energy project	2018	https://energycommunitiestipp.ie/
Community Power	Ireland	Virtual Power Plant + Community-scale energy project	2016	https://communitypower.ie/
Callan Nexus	Ireland	Community-scale energy project	2009	https://www.communitypower.eu/
Templederry	Ireland	Community Microgrid	2014	https://www.communitypower.eu/

SEV - Unione Energia Alto Adige	Italy	Community Microgrid	1998	https://www.sev.bz.it/
Salina	Italy	Community Microgrid	2019	https://www.repubblica.it/
e-Prosume	Italy	P2P trading platform	2019	https://www.evolvere.io/
ComESto	Italy	Virtual Power Plants	2019	https://www.e-distribuzione.it/
ènostra	Italy	Virtual Power Plants	2014	https://www.enostra.it/
Power Cloud Campus	Italy	Community Microgrid	2016	http://www.distrettodomus.it/
Smart Grid	Italy	Community Microgrid	2019	http://www.comunirinnovabili.it/
GECO	Italy	P2P trading platform	2019	https://www.canaleenergia.com/
Solare in multiproprietà	Italy	Community-scale energy project	2010	http://www.dossoenergia.it/
Bioenergia Fiemme spa	Italy	Community Microgrid	1999	http://www.mountainblog.it/
SIEC	Italy	Community Microgrid	1895	http://www.siec-chiavenna.it/
Retenergie Società Cooperativa	Italy	Community-scale energy project	2008	https://www.corriere.it/
CONIEM	Italy	Community Microgrid	1922	https://www.coniem.it/
Azienda Energetica Funes	Italy	Community Microgrid	1922	https://www.energie-villnoess.it/it/
CEG	Italy	Community Microgrid	1927	http://www.ceg-energia.it/
Lampedusa	Italy	P2P trading platform	2020	http://www.nextville.it/
WeForGreen Sharing	Italy	Virtual Power Plants	2015	https://www.weforgreen.it/
microrete	Italy	Community Microgrid	2018	http://www.sardegnaricerche.it/
Cooperativa di Comunità	Italy	Community-scale energy project	2011	http://www.vita.it/
SEM	Italy	Community Microgrid	1897	https://www.sem-morbegno.it/
Energia Positiva	Italy	Community-scale energy project	2015	http://www.comunirinnovabili.it/
WEG	Italy	Community Microgrid	1999	http://www.comunirinnovabili.it/
Osimo	Italy	Community Microgrid		http://www.muse-grids.eu/demosites/
SECAB	Italy	Community Microgrid	1911	https://www.secab.it/home/
Territorio Sostenibile	Italy	Community Microgrid	2018	https://www.trancemedia.eu/
CEP	Italy	Community Microgrid	1914	http://www.comunirinnovabili.it/
E-Werk PRAD	Italy	Community Microgrid	1926	https://www.e-werk-prad.it/it/
Campus Università di Genova	Italy	Community Microgrid	2011	http://www.energia2020.unige.it/
CEIS	Italy	Community Microgrid	1907	https://www.ceis-stenico.it/
CEDIS	Italy	Community Microgrid	1904	https://www.cedis.info/
ASM Terni	Italy	Community Microgrid	2018	https://www.wisegrid.eu/
Energy Revolt	Luxemb.	Community-scale energy project	2013	https://www.eida.lu/
progetto PEGASUS Interreg	Malta	Community Microgrid	2017	https://www.buildup.eu/
Strandeiland	Nederland	Community Microgrid		https://spectral.energy/
Nordstraat 11 Tilburg	Nederland	Community Microgrid	2016	https://www.rvo.nl/
Zeuven heuvels Wezep	Nederland	Community Microgrid	2018	https://www.rvo.nl/
Zvijsen Veghel	Nederland	Community Microgrid	2015	https://www.rvo.nl/
Smart Grid Groene Mient	Nederland	Community Microgrid	2018	https://www.rvo.nl/
Meckenbach	Nederland	Community Microgrid		http://files.constantcontact.com/

Duurzame Wijkenergiecentrale Trudo	Nederland	Community Microgrid	2018	https://www.rvo.nl/
Smart Energy Grid Bajeskwartier	Nederland	Community Microgrid	2018	https://www.rvo.nl/
Kleine Duinvallei Katwijk	Nederland	Community Microgrid	2019	https://www.rvo.nl/
Coöperatie LochemEnergie U.A.	Nederland	Community-scale energy project	2011	https://www.lochemenergie.net/
Nieuwe Polderjongen	Nederland	Community-scale energy project	1989	https://www.meerwind.nl/
WindpowerNijmegen	Nederland	Community-scale energy project	2016	https://www.windparknijmegenbetuwe.nl/
Windvogel	Nederland	Community-scale energy project	1991	https://www.communitypower.eu/
De Eendragt	Nederland	Community-scale energy project	1989	https://uploads.strikinglycdn.com/
Windpark Krammer	Nederland	Community-scale energy project	2016	https://www.windparkkrammer.nl/
Energie Van Ons	Nederland	Community-scale energy project	2014	https://energie.vanons.org/
Dommelstroom	Nederland	Community-scale energy project + Virtual Power Plants	2016	https://dommelstroom.com/
WINDpostcoderoos	Nederland	Community-scale energy project + Virtual Power Plants	2015	https://windpostcoderoos.nl/
Micro Energy Trading Amesfosrt	Nederland	P2P trading platform	2017	https://www.rvo.nl/
Micro Energy Trading Eamnes	Nederland	P2P trading platform	2017	https://www.rvo.nl/
Powerpeers	Nederland	P2P trading platform	2016	https://www.powerpeers.nl/
The Energy Collective	Nederland	P2P trading platform	2018	https://the-energy-collective-project.com/
Shared energymobility community Amersfoort	Nederland	P2P trading platform	2019	https://www.rvo.nl/
GRONINGEN MUNICIPALITY	Nederland	P2P trading platform		https://spectral.energy/
Hilverstroom	Nederland	Virtual Power Plant	2012	https://www.hilverstroom.nl/
Huismerk Energie	Nederland	Virtual Power Plant	2013	https://huismerkenergie.nl/
Greenchoice & Qurrent	Nederland	Virtual Power Plant	2014	https://www.greenchoice.nl/
om| nieuwe energie	Nederland	Virtual Power Plant	2014	https://www.samenom.nl/
Schoonship	Nederland	Community Microgrid	2010	http://www.spaceandmatter.nl/
Kringloopgemenschap	Nederland	Virtual Power Plant	2016	https://www.rvo.nl/
Republica Papaverweg	Nederland	Community Microgrid	2017	https://www.rvo.nl/
Endona	Nederland	Virtual Power Plant	2015	https://www.rvo.nl/
Aardehousen	Nederland	P2P trading platform	2016	https://www.rvo.nl/
Greenparq	Nederland	Community Microgrid	2015	https://www.rvo.nl/
Power to Share - Green Village	Nederland	P2P trading platform	2018	http://www.toblockchain.nl/
BlockLab	Nederland	P2P trading platform		https://www.portofrotterdam.com/
LEF at Hoog Dalem	Nederland	P2P trading platform		https://www.energy21.com/
Villa de Verademing	Nederland	Community Microgrid	2016	https://www.rvo.nl/
De Ceuvel, Juliette	Nederland	P2P trading platform	2017	https://www.jouliette.net/
Spółdzielnia Nasz Energia	Poland	Community Microgrid	2014	https://www.gramwzielone.pl/
Pszczelna street housing community	Poland	Community-scale energy project	2016	http://co2mmunity.eu/
Cooperativa de Abast. Energia Eléctrica crl	Portugal	-	1934	http://www.cooproriz.pt/

Cooperativa Eléctrica de Vilarinho CRL	Portugal	-	1939	http://www.cevilarinho.pt/
Cooperativa Electrica do Vale d'Este CRL	Portugal	-	1930	http://www.ceve.pt
Cooperativa Eléctrica São Simão Novais CRL	Portugal	-	1932	http://www.cessn.pt/
Cooperativa Eléctrica de Loureiro CRL	Portugal	-	1933	http://www.celoureiro.com/
Lisbona	Portugal	Community Microgrid		https://www.compile-project.eu/
Culatra	Portugal	Community Microgrid	2019	https://www.euislands.eu/
Coopernico	Portugal	Community-scale energy project + Virtual Power Plants	2013	https://www.coopernico.org/
São Luís	Portugal	Community-scale energy project	2012	http://proseu.eu/
Kněžice	Repubblica Ceca	Community Microgrid	2000	http://www.localeconomies.eu/
Brno	Romania	Community-scale energy project	2001	https://www.communitypower.eu/
RED Platform	Romania	P2P trading platform	2019	https://restartenergy.ro/
Bioenergia Bystricko	Slovakia	Community-scale energy project	1994	http://www.localeconomies.eu/
Luce	Slovenia	Community Microgrid	2019	https://www.compile-project.eu/
Zadruga sončnih elektrarn,	Slovenia	Community-scale energy project	2014	www.zses.si
SunContract	Slovenia	P2P trading platform	2016	https://suncontract.org/
Ampere Energy	Spain	-		https://ampere-energy.com/
CEA	Spain	-	1930	https://www.electricadealginet.com/
Megara energia	Spain	-	2015	https://www.megaraenergia.com/
Electrica de Vinalesa	Spain	-	1911	http://www.coop-vinalesa.com/
Coopelec	Spain	-	1931	https://www.electricaguadassuar.es/
la energia de las personas	Spain	-	2015	https://www.emasp.org/
La corriente	Spain	-	2015	https://lacorrientecoop.es/
Electrica de Chera	Spain	-	1928	http://www.unionrenovables.coop/
Electrica de Meliana	Spain	-	1922	http://electricademeliana.com/
Electrica de Sot de Chera	Spain	-	1947	http://www.unionrenovables.coop/
Coop. Electrica de Castellar	Spain	-	1924	https://coopcastellar.com/
Rubì	Spain	Community Microgrid	2017	https://www.elperiodico.com/
Crevillent	Spain	Community Microgrid		https://www.compile-project.eu/
Enercoop	Spain	Community Microgrid	1924	https://www.enercoop.es/
La Palma	Spain	Community Microgrid	2019	https://euislands.eu/
Manzaneda	Spain	Community Microgrid	2019	https://www.renaissance-h2020.eu/
La Serna	Spain	Community-scale energy project	2004	https://www.communitypower.eu/
Viure de l'aire del cel	Spain	Community-scale energy project	2009	http://www.viuredelaire.cat/
Union renovables	Spain	Community-scale energy project	2017	http://www.unionrenovables.coop/
GoiEner	Spain	Community-scale energy project + Virtual Power Plants	2012	https://www.goiener.eus/
Som Energia	Spain	Community-scale energy project + Virtual Power Plants	2010	https://www.somenergia.coop/
Pylon Network in GoiEner energy cooperative	Spain	P2P trading platform	2018	https://pylon-network.org

energetica	Spain	Virtual Power Plants	2015	https://www.energetica.coop/
Nosa Enerxia	Spain	Virtual Power Plants	2014	https://www.nosaenerxia.gal/
Solabria	Spain	Virtual Power Plants	2013	https://www.solabria.es/
econactiva	Spain	Virtual Power Plants	2014	https://econactiva.es/
La solar	Spain	Virtual Power Plants	2016	http://www.lasolarenergiacoop.es/
FlexiDAO	Spain	P2P trading platform	2017	https://www.flexidao.com
Walqa Technology Park	Spain	Community Microgrid		https://elandh2020.eu/
EON Simris	Sweden	Community Microgrid	2019	https://www.eon.se/
Torneby and Nobble (2)	Sweden	Community-scale energy project	2016	https://kalmarenergi.se/
Kalmarsund Vind	Sweden	Community-scale energy project	2006	https://kalmarenergi.se/
Energie Genossenschaft Schweiz	Switzerland	-	2012	www.energiegenossenschaft.ch
VESE	Switzerland	-	1990	https://www.vese.ch/fr/
Thierrens Lien Lieneco-district	Switzerland	Community Microgrid	2018	https://www.swissinfo.ch/
GROUPE-BILAN FLEX	Switzerland	P2P trading platform	2019	https://www.electron.org.uk/projects
Ökostrom Schweiz	Switzerland	Virtual Power Plants	2000	http://www.oekostromschweiz.ch/
aliunid IOT platform	Switzerland	Virtual Power Plants	2019	https://www.aliunid.com/
Smart Living Lab	Switzerland	Community Microgrid	2017	https://www.smartlivinglab.ch/
Inera	Switzerland	Community Microgrid	2019	https://www.inera.ch/
Power-ID	Switzerland	P2P trading platform	2018	https://phys.org/
Greencity	Switzerland	Community Microgrid	2017	http://www.greencity.ch/de/
RecorDER	UK	-	2019	https://www.nationalgridgas.com/
Easton Energy Group	UK	-		http://www.eastonenergygroup.org/
Home Response	UK	-		https://www.repowering.org.uk/
Energy4All	UK	-	2002	https://energy4all.co.uk/
Mid Argyll Community Enterprises	UK	Community Microgrid	2003	https://uploads.strikinglycdn.com/
Isle of Eigg	UK	Community Microgrid	2000	http://isleofeigg.org/eigg-electric/
Trent Basin	UK	Community Microgrid	2018	https://www.gov.uk/
Torrs Hydro New Mills Limited	UK	Community-scale energy project	2007	https://www.gov.uk/
Whalley Commmunity Hydro	UK	Community-scale energy project	2011	https://www.whalleyhydro.co.uk/
HKD Energy Limited	UK	Community-scale energy project	2014	https://www.hkdenergy.org.uk/
Malvern Community Energy	UK	Community-scale energy project	2014	https://malverncommunityenergy.wordpress.com/
Chase Community Solar	UK	Community-scale energy project	2015	http://chasesolar.org.uk/
West Solent Solar	UK	Community-scale energy project	2014	https://westsolentsolar.coop/
Gower Regeneration	UK	Community-scale energy project	2015	http://regengower.co.uk/
Brighton Energy Coop.	UK	Community-scale energy project	2010	https://brightonenergy.org.uk/
Baywind	UK	Community-scale energy project	1997	https://www.baywind.coop/
Kilbraur Wind Farm	UK	Community-scale energy project	2008	https://www.kilbraur.coop/
Udny Community	UK	Community-scale energy project	2011	https://udnytrust.wordpress.com/

TraDER	UK	P2P trading platform	2020	https://www.electron.org.uk/projects
Dajie	UK	P2P trading platform	2016	https://www.f6s.com/dajie
Enernext	UK	P2P trading platform	2019	https://enernext.io/
Co-op Energy	UK	Virtual Power Plants	2016	https://www.cooperativeenergy.coop/
BWCE	UK	Community-scale energy project	2010	https://www.bwce.coop/
Cyd Ynni	UK	Virtual Power Plants	2016	http://www.energylocal.co.uk/
Brixton Energy Solar (3 projects)	UK	Community-scale energy project (outside investor)	2011	https://www.repowering.org.uk/
Ovesco	UK	Community-scale energy project	2014	https://ovesco.co.uk/
Tidal Energy	UK	Community-scale energy project		https://transitionbrogwaun.org.uk/
Abergwaun Community Turbine	UK	Community-scale energy project	2011	https://transitionbrogwaun.org.uk/
Banister House Estate	UK	Community-scale energy project (outside investor)	2015	https://www.repowering.org.uk/
Banister House Solar	UK	P2P trading platform	2017	https://www.solarpowerportal.co.uk/
City of London CE	UK	Community-scale energy project		https://www.repowering.org.uk/
Lambeth Community Solar	UK	Community-scale energy project		https://www.repowering.org.uk/
North Kensington CE	UK	Community-scale energy project	2011	https://www.repowering.org.uk/
Vauxhall Energy	UK	Community-scale energy project	2011	https://www.repowering.org.uk/
Orkneys Islands	UK	Community Microgrid	2015	https://theferret.scot/
Lewis Island	UK	Community-scale energy project	2008	https://www.theguardian.com/
Tiree Island	UK	Community-scale energy project	2010	http://www.tireerenewableenergy.co.uk
Ghia Island	UK	Community-scale energy project	2004	http://www.gigha.org.uk/
Exergy	UK	P2P trading platform	2018	https://lo3energy.com/

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