Politecnico di Torino

MASTER'S DEGREE IN ENERGY AND NUCLEAR ENGINEERING

Master's Thesis in Renewable Energy Systems

Modeling Renewable Energy Communities in Italy: performance, economics and geographic optimization

Supervisor

Prof. Marco Badami

Co-Supervisor

Ing. Leonardo Bello

Candidate

Lorenzo Cuviello

S316501

Partner Company

Altea Green Power S.p.A.

Degree session October 2024

Academic year 2023/2024

Summary

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List of acronyms

AGP = Altea Green Power

AUC = Aggregated Utility Companies

CAPEX = Capital Cost of Expenditure

CEC = Citizen Energy Community

ES = Energy Strategy

GSE = Gestore dei Servizi Energetici

GWA = Global Wind Atlas

IEA = International Energy Agency

LCOE = Levelized Cost Of Electricity

OPEX = Operational Cost of expenditure

PMI = Piccole Medie Imprese

PNIEC = Piano Nazionale

REC = Renewable Energy Community

RID = Ritiro Dedicato

S.p.A. = Società per Azioni

SSP = Scambio Sul Posto

Abstract

This thesis aims to explore Renewable Energy Communities (RECs) from multiple perspectives, including technical, regulatory, economic, and performance aspects. The main objective is to develop an accurate simulation model that reflects how RECs function within the Italian context, particularly focusing on the integration of renewable energy technologies and their potential in different regions. To achieve this, the study is divided into different key sections:

1. **Energy Production Profiles**: Using simulation tools like PVsyst, PVGIS, and GWA, the thesis generates detailed hourly energy production profiles for three major renewable sources, solar photovoltaic (PV), wind, and hydroelectric power. These profiles are based on varying geographic conditions in Italy's North, Central, South, and Island regions.
2. **Consumption Data Analysis**: The analysis incorporates real consumption data, especially from energy-intensive industrial entities (Piccole Medie Imprese), provided by Altea Green Power SpA. These consumption profiles will be examined as part of case studies, where industrial users may participate as either energy prosumers or consumers within RECs.
3. **Economic and Performance Evaluation:** The data collected is processed through a custom-built Excel model, meticulously designed to evaluate RECs' energy performance and economic viability. This model calculates both virtual and actual self-consumption percentages and simulates scenarios where various configurations of renewable technologies and industrial users are tested. Key metrics include shared energy levels, the payback period (PBT) for investments in renewable energy, and the potential for industrial PMIs to benefit from RECs.

Finally, the thesis provides a comparative analysis of the economic and geographic factors that influence the success of RECs in Italy, identifying both the strengths and limitations of this emerging energy-sharing model. The study offers valuable insights for decision-makers and stakeholders, aiming to demonstrate how renewable energy communities can significantly contribute to Italy's energy transition while addressing economic concerns and regulatory compliance.

1. Introduction

The current global energy landscape is marked by unprecedented challenges, not only due to the depletion of fossil fuels but also because of increasing geopolitical instability and the urgent need to mitigate the effects of climate change. In this critical context, the necessity of an energy transition toward more sustainable and decentralized models has never been more apparent.

The decision to dedicate this master thesis to the topic of renewable energy communities stems from the recognition that they offer a tangible and innovative solution to address global energy challenges. Energy communities enable a more democratic and shared management of energy, promoting local renewable energy production and consumption. This approach not only reduces dependence on fossil fuels but also fosters greater involvement of individuals and local communities in the energy transition.

In the current moment, characterized by energy crises, market instability, and an increasingly urgent environmental imperative, renewable energy communities represent a strategic opportunity to enhance the resilience of energy systems and reduce the environmental impact of human activities. This research aims to contribute to a deeper understanding of this model and demonstrate how energy communities can play a pivotal role in shaping a more sustainable, equitable, and resilient energy future.

A review of the existing literature, including scientific articles, reveals that much of the research to date has been primarily centered around understanding the concept of renewable energy communities and exploring how they can be implemented to foster a more sustainable energy system. Until the early months of 2024, energy communities were not fully realized in Italy, and as a result, many studies have focused on their potential benefits, often from a theoretical perspective. Case studies have typically concentrated on specific regions, such as Italy's islands or rural areas, where isolated energy grids could benefit from local energy production. These analyses have also explored how energy communities could improve daily energy usage for private citizens, promoting energy autonomy and efficiency at the household level.

While these insights have been valuable in laying the groundwork for the concept of energy communities, they have often neglected several key dimensions that are crucial for a comprehensive understanding of the topic. One of the main gaps in the existing research is the lack of focus on the technologies currently available in the Italian market. Technological advancements play a pivotal role in the success and scalability of energy communities, and understanding the range, versatility, and potential of these technologies within the context of Italy's unique energy landscape is essential. Italy’s diverse geography, from its densely populated urban centers to its remote rural areas, requires a nuanced approach to technology adoption, with solutions tailored to meet the specific energy needs of different regions.

Furthermore, most past studies have primarily examined the role of residential energy consumers, placing emphasis on the benefits that private citizens might gain from participating in energy communities. While this is an important consideration, it overlooks a critical aspect of the energy equation: the industrial and commercial sectors. Globally, the industrial sector is by far the largest consumer of energy, significantly outpacing residential consumption. In Italy, there is the same situation; the country's vibrant industrial base is a key driver of energy demand. Despite this, the potential for energy communities to integrate industrial players, improve energy efficiency in production processes, and reduce overall emissions in the sector has received relatively little attention in academic and policy discussions.

By failing to fully account for the role of the industrial sector, much of the current research risks missing an opportunity to address one of the most energy-intensive areas of the economy. The industrial sector not only consumes a vast amount of energy but also holds significant potential for innovation in renewable energy adoption. The integration of energy communities into industrial processes could lead to substantial environmental and economic benefits, fostering a transition to more sustainable production methods while enhancing energy security.

This thesis, therefore, seeks to fill these gaps by not only examining the concept of renewable energy communities from a technological standpoint but also by analyzing how these communities can be expanded to include industrial players, thereby maximizing their impact on the energy transition.

The aim of this thesis, therefore, is to develop a highly accurate calculation model designed to simulate the performance of an energy community within the Italian context. This is achieved using Excel software, meticulously programmed to manage such a model in compliance with current regulations on the subject. In collaboration with Altea Green Power S.p.A, the need arose not only for an accurate performance model but also for one that could address the economic concerns of clients interested in participating in this opportunity. The goal is to provide them with a concrete evaluation of the economic value of their potential investment.

Once the model is created, its validity and usability will be tested by simulating the performance of various energy communities, varying both the technology employed and the specific region of Italy where the community is established. This will enable the creation of a database of performance data, useful for quickly assessing opportunities across different scenarios. This analysis is developed on two main fronts: first, a performance assessment of three renewable technologies available on the market: solar photovoltaics, wind, and hydroelectric power, using precise simulation software to estimate the hourly energy production over an entire year in four distinct regions of Italy, which have been simplified into North, Center, South, and Islands.

The initial section of the thesis will explore the underlying motivations for the creation of energy communities, particularly as a response to the global energy crisis. It will also include an analysis of the current Italian regulations, as well as the ongoing shift from a centralized to a more decentralized energy system, highlighting the key concepts driving this transition.

Subsequent chapters will delve into the performance of the three renewable technologies, examining their presence in Italy, supported by national data provided by Terna. In addition, the thesis will provide a broader perspective on industrial consumers, analyzing seven real-world case studies encountered while working in Altea Green Power S.p.A.

The final chapters form the core of this thesis: a detailed explanation of the model’s structure and preparation according to the guidelines established by the current regulatory framework, followed by a thorough economic analysis developed in collaboration with industry experts. The thesis will conclude with the simulation of the model’s performance and a comprehensive analysis of the results.

The ultimate objective is to test the model and produce key insights into the performance, economic viability, and geographic potential of energy communities in Italy, offering valuable tools for decision-makers and stakeholders in the renewable energy sector.

2. Renewable Energy Communities

2.1. Global energy overview and Energy transition

The global energy landscape has undergone significant transformations over the last few decades, shaped by an intricate web of economic growth, technological advancements, geopolitical shifts, and mounting environmental concerns. As the world continues to develop, the demand for energy has seen an unprecedented rise. According to the International Energy Agency (IEA) [1], global energy consumption increased by nearly 25% between 2000 and 2020, driven largely by population growth, rapid urbanization, and the industrialization of emerging economies such as China, India, and Brazil. This surge in energy demand has placed immense pressure on existing energy resources and has highlighted the need for sustainable and efficient energy systems to meet the needs of an ever-growing global population.

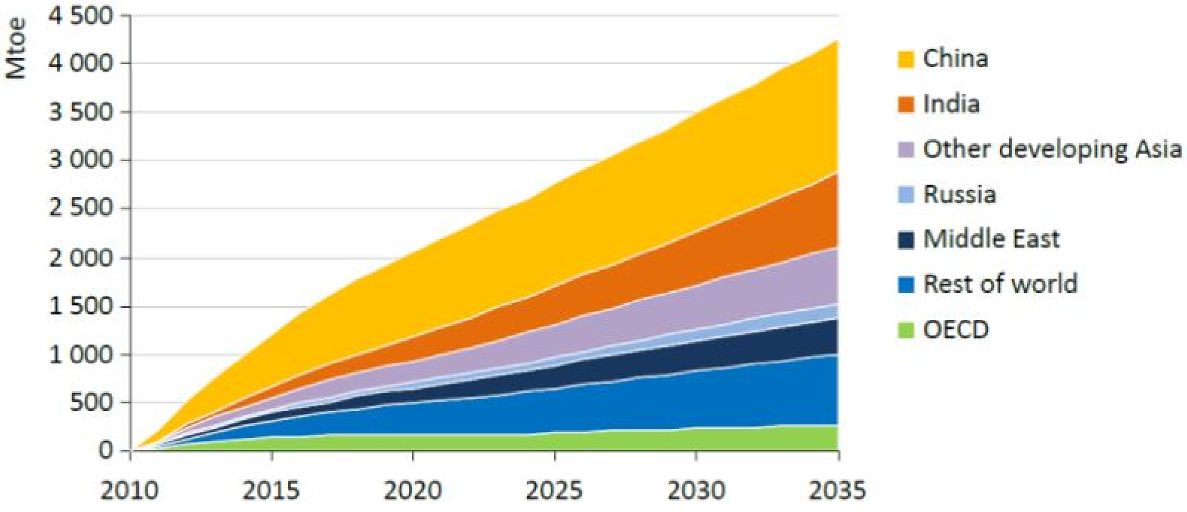


Figure 1 - Global energy consumption IEA [1]

Historically, fossil fuels—namely coal, oil, and natural gas—have been the cornerstone of global energy supply. Throughout the 20th century and well into the 21st, these resources have fueled industrial growth, powered transportation systems, and heated homes. As of 2020, fossil fuels still constituted approximately 80% of the world's primary energy consumption, underscoring their dominant role in the global energy mix. However, the environmental implications of fossil fuel combustion have become increasingly apparent. The burning of these fuels is the largest contributor to greenhouse gas emissions, leading to global warming, climate change, and a host of other environmental issues such as air pollution, acid rain, and biodiversity loss.

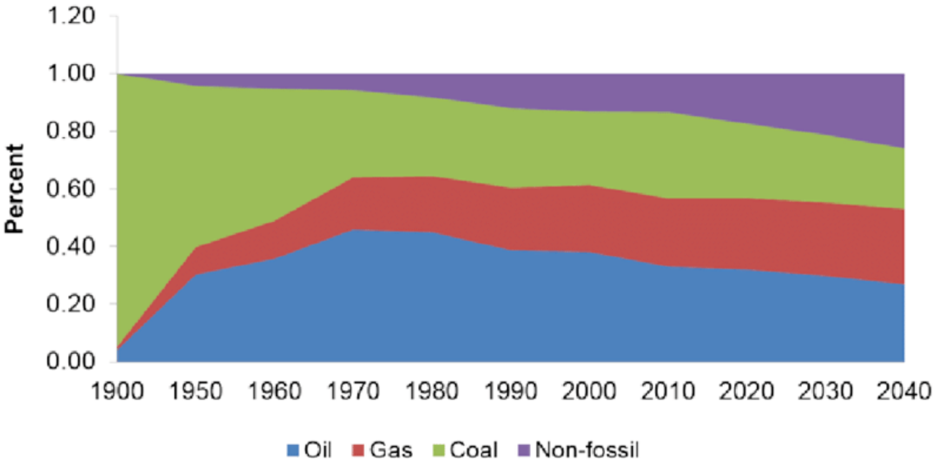


Figure 2 - Shares of Primary Energy Sources (1900-2040, %) [2]

The 1970s marked a turning point in the global energy narrative. The oil crises of 1973 and 1979, triggered by geopolitical tensions in the Middle East, exposed the vulnerabilities of relying heavily on a single energy source. These crises led to soaring oil prices, economic recessions, and a renewed focus on energy security. Western nations, particularly the United States and European countries, began to diversify their energy portfolios by investing in alternative energy sources. This period saw the initial development of nuclear energy, increased use of natural gas, and early research into renewable energy technologies.

Despite these efforts, the transition away from fossil fuels was slow, largely due to the entrenched infrastructure, significant capital investments, and the relatively low cost of fossil fuels. However, the growing recognition of the environmental and social costs of fossil fuel dependence spurred further innovation and policy initiatives aimed at promoting cleaner energy sources. The 1990s and early 2000s saw the advent of more aggressive climate policies, such as the Kyoto Protocol, which sought to curb global greenhouse gas emissions and foster international cooperation on climate action.

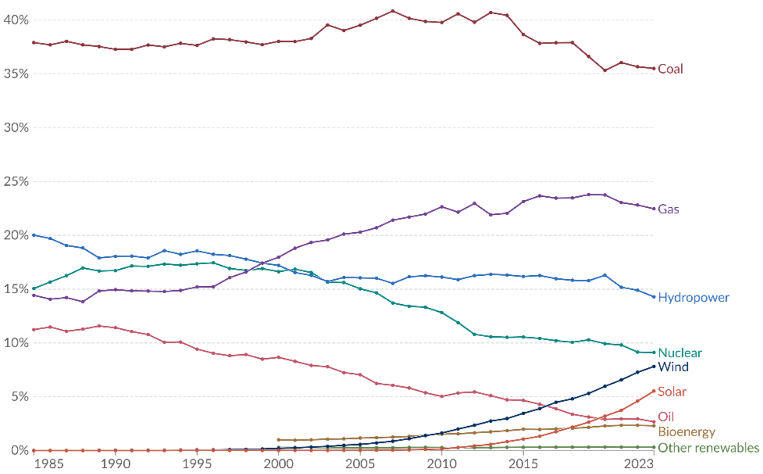
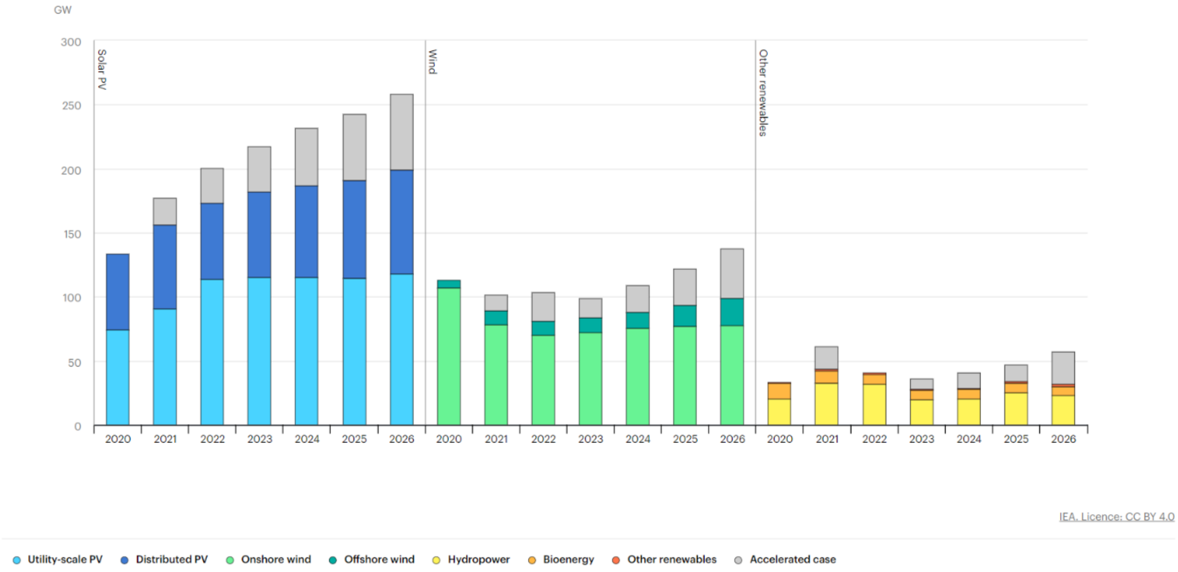


Figure 3 - Share or electricity production by source [3]

In recent years, the global energy landscape has been increasingly shaped by the transition to renewable energy sources. Renewables, including solar, wind, hydro, and biomass, have emerged as vital components of the world's energy systems, offering a sustainable alternative to fossil fuels. The technological advancements in these sectors have been remarkable. The cost of solar photovoltaic (PV) modules, for example, has plummeted by more than 80% since 2010, while the efficiency of wind turbines has continued to improve, making renewable energy more competitive with traditional energy sources. The IEA reports that in 2021, renewable energy accounted for nearly 29% of global electricity generation, with expectations that this share will continue to grow as countries pursue more ambitious climate targets. [4]



IEA. Licence: CC BY 4.0

Figure 4 - Annual capacity additions of solar PV, wind and other renewables 2020-2026 IEA [4]

The growth of renewable energy has been particularly pronounced in regions with strong policy frameworks and favorable natural conditions. Europe has been at the forefront of the renewable energy transition, with countries like Germany, Denmark, and Spain leading the way in wind and solar energy adoption. The European Union's Green Deal, introduced in 2019, aims to make Europe the first climate-neutral continent by 2050, with renewable energy playing a central role in achieving this goal. Similarly, China has become the world's largest producer of renewable energy, driven by its need to reduce air pollution and its commitment to international climate agreements. China's investments in solar and wind energy have not only helped reduce its carbon footprint but have also positioned it as a global leader in renewable energy technology.

Directly quoting from the Treccani Encyclopedia: “*Energy transition refers to a process of transforming the framework for meeting energy needs towards solutions characterized by a reduced environmental impact (with particular reference to greenhouse gases) and, more generally, greater sustainability. Fundamental characteristics of this process are the transition towards a portfolio of energy sources predominantly based on the use of renewable resources, the widespread adoption of efficiency solutions in all energy uses, and, finally, the availability of carbon dioxide (CO2) capture and sequestration solutions that enable the sustainable use of fossil fuels.*” [5]

Hence, energy transition refers to the process of shifting from a reliance on traditional, often non-renewable energy sources (like fossil fuels—coal, oil, and natural gas) to more sustainable and environmentally friendly sources of energy (such as solar, wind, hydro, and geothermal power). This transition aims to address the environmental and economic challenges associated with fossil fuel use, such as greenhouse gas emissions, air pollution, and resource depletion.

The global energy system is facing urgent challenges that threaten both environmental sustainability and human health. The transition to renewable energy sources is a crucial response to these pressing issues. Here are three of the most important problems that the energy transition aims to solve:

Climate Change: By reducing greenhouse gas emissions through the adoption of renewable energy sources, the energy transition helps mitigate global warming and its associated impacts on the environment.

Air Pollution: Shifting away from fossil fuels decreases the emission of harmful pollutants, leading to improved air quality and better public health.

Resource Depletion: Moving towards renewable energy reduces dependence on finite fossil fuels, helping to conserve non-renewable resources and ensure a more sustainable energy future.

In figure 5 there are some milestones indicated by IEA to achieve the complete energy transition by 2050: [6]

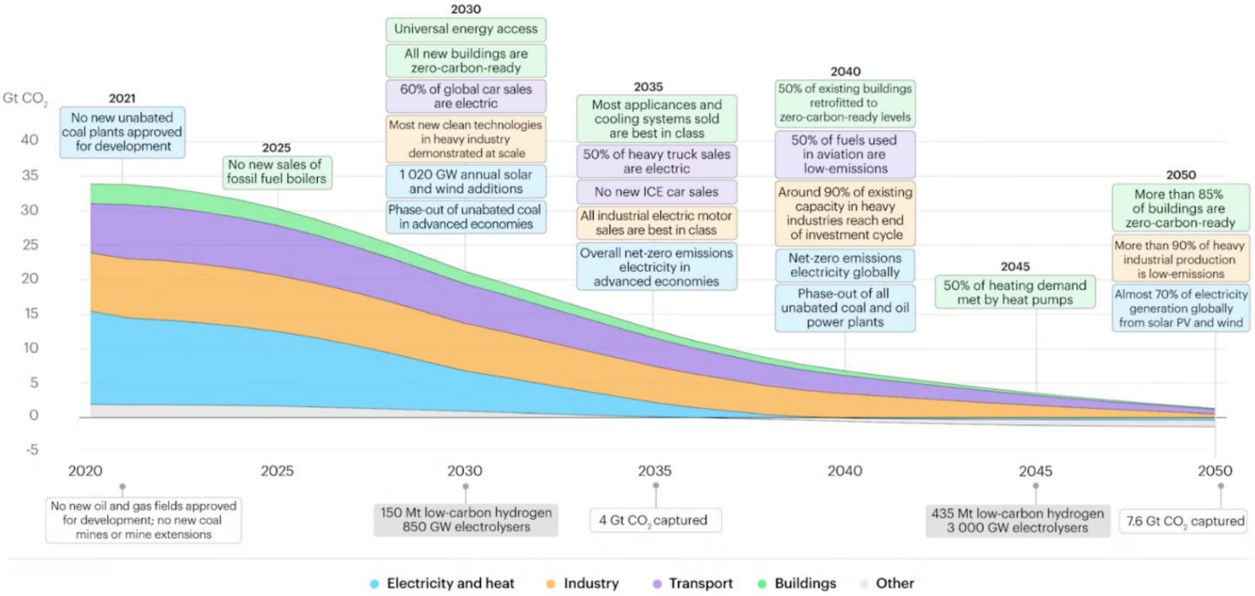


Figure 5 - IEA milestones for 2050 goal [6]

To ensure that the climate clock [7], shown in Figure 6, does not continue to advance unchecked, it is essential that all the milestones analyzed by the International Energy Agency (IEA) are met and successfully implemented. The IEA's milestones provide a comprehensive roadmap for reducing greenhouse gas emissions, advancing renewable energy adoption, and improving energy efficiency. Achieving these targets is crucial for slowing the pace of climate change and avoiding the worst impacts of global warming. Without adhering to and succeeding in these critical milestones, the climate clock will keep ticking, pushing us further towards irreversible environmental consequences. Therefore, committed and effective action on these fronts is vital for mitigating climate change and safeguarding the future of our planet.

Figure 6 - Climate clock in September 2024 [7]

2.2. Italy energy situation

According to the Renewable Energy report by ES and PoliMI [8], Italy is at a critical juncture in its energy transition journey, grappling with both significant achievements and notable challenges as it seeks to meet its 2030 decarbonization targets. The country's efforts in renewable energy development have been marked by a mix of rapid growth in certain areas and stagnation in others, shaped by a complex interplay of policy, market dynamics, and technological advancements.

In recent years, Italy has seen a remarkable increase in its renewable energy capacity, particularly in 2023, where the country added a record 5.7 GW of new capacity. This surge was primarily driven by small-scale photovoltaic installations, which accounted for the vast majority of the new capacity. This trend reflects a broader shift towards decentralized energy production, empowering individual households and small businesses to contribute to the national energy mix. However, this focus on small-scale installations has not been matched by progress in large-scale renewable projects, particularly in the wind energy sector.

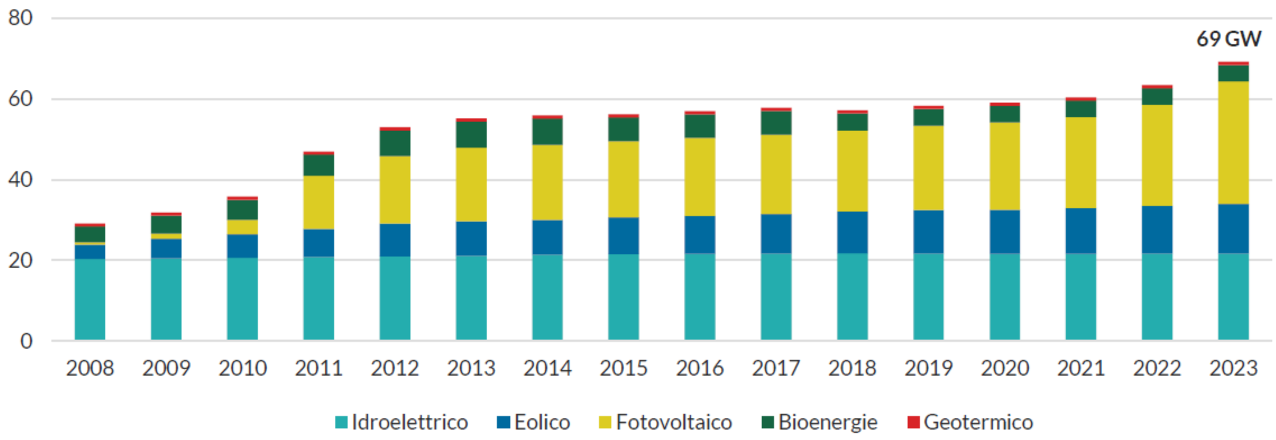


Figure 8 -Evolution of renewable generation capacity in Italy from 2008 onwards. [8]

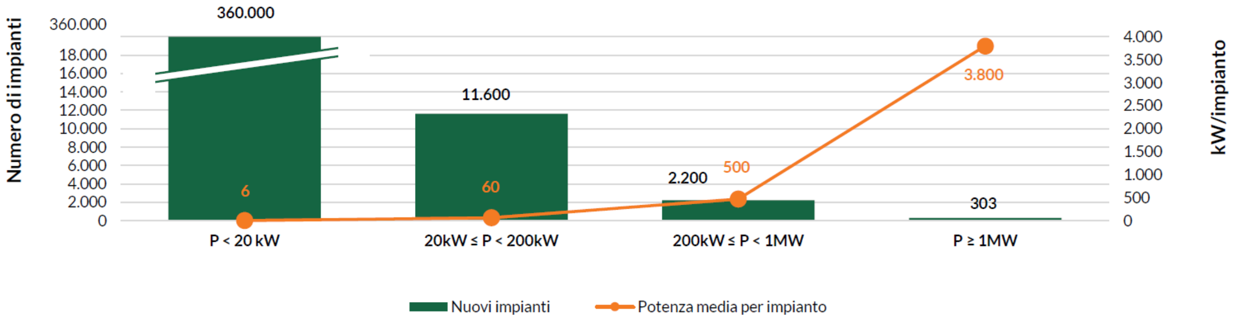


Figure 7 - New plants and mean power plants [8]

The development of large-scale renewable energy projects in Italy has been hampered by a range of challenges, including regulatory hurdles, bureaucratic delays, and local opposition. Legislative measures, such as restrictions on photovoltaic installations on agricultural land and regional moratoria on renewable developments, have slowed the momentum of the energy transition. These obstacles have created a bottleneck in the deployment of large-scale projects, which are crucial for meeting the ambitious targets set by the National Integrated Energy and Climate Plan (PNIEC).

Looking forward, Italy faces the risk of a slowdown in renewable energy installations in the coming years. Projections suggest that annual additions could drop significantly in 2025-2026, potentially falling far short of the levels needed to stay on track with 2030 targets. This anticipated slowdown is largely due to delays in regulatory approvals and the slow rollout of necessary enabling measures. Additionally, the impending end of certain incentive schemes, such as the Scambio Sul Posto (SSP) for medium and small-scale photovoltaic projects, could further dampen the sector's growth.

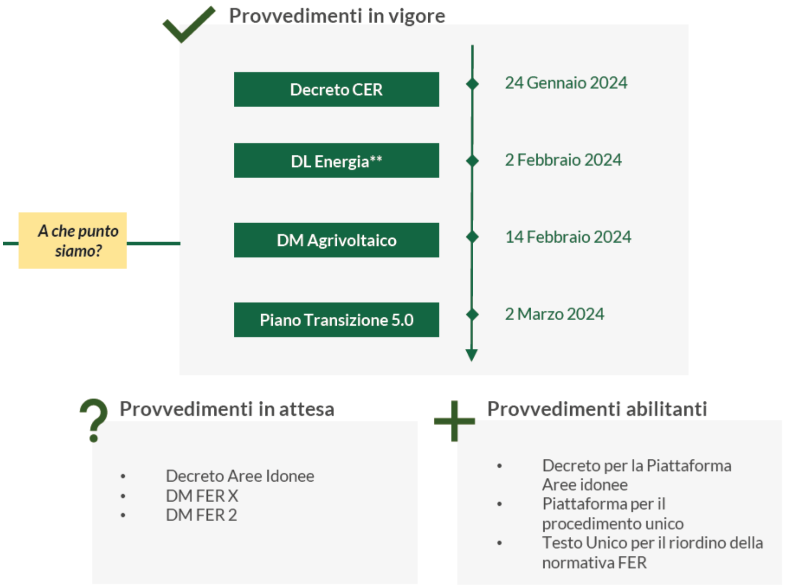


Figure 9 - Italian energy policies overview [8]

Italy's energy policies, as discussed in the 2024 Renewable Energy Report (RER), reflect the country's efforts to transition to a more sustainable and decarbonized energy system, in line with European Union targets and the National Integrated Energy and Climate Plan (PNIEC).

Technological advancements and innovations will play a crucial role in overcoming these challenges. The development of more efficient renewable energy technologies, coupled with improvements in energy storage and grid infrastructure, could help mitigate some of the risks associated with high LCOE and regulatory delays. Moreover, Italy's continued investment in research and development will be essential for maintaining its competitive edge in the global renewable energy market.

In analyzing the future scenario for Italy two different scenarios are considered. The Business-As-Usual (BAU) scenario assumes that Italy continues with current policies and trends without major interventions:

- Slow Renewable Growth: Renewable energy development progresses at a modest pace, hindered by regulatory delays and local opposition.
- Installed Capacity: Italy only reaches around 70 GW of renewable capacity by 2030, well below the targets needed for decarbonization.

In contrast, the Renewable Energy (REN) scenario envisions more aggressive policy actions:

- Accelerated Growth: Enhanced policies and streamlined regulations lead to a faster rollout of renewable energy projects.
- Installed Capacity: Italy successfully reaches around 95-100 GW of renewable capacity by 2030, aligning with its decarbonization and climate goals.

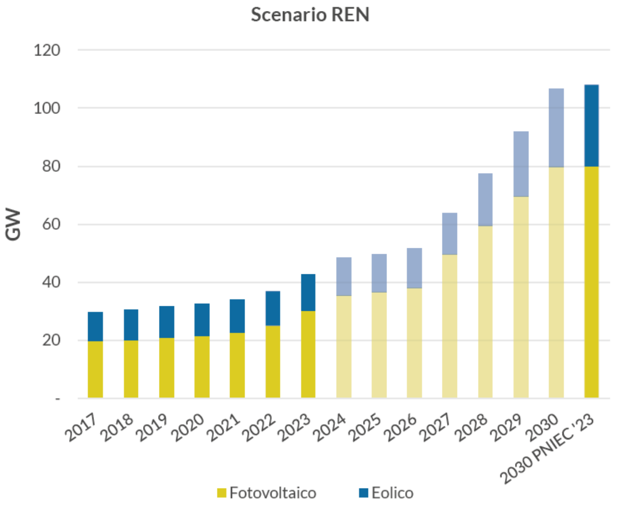


Figure 10 - BAU scenario for future situation in Italy [8]

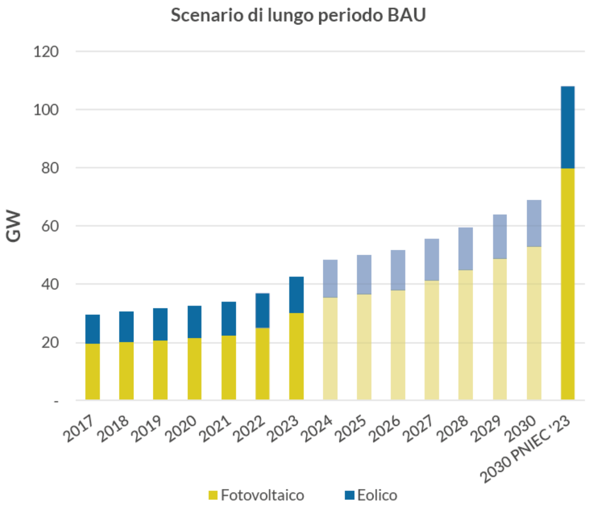


Figure 11 - REN scenario for future situation in Italy [8]

To achieve its 2030 decarbonization goals, Italy must address the current barriers to large-scale renewable energy development and enhance the effectiveness of its policy framework. Streamlining regulatory processes, improving access to financing, and ensuring that incentive schemes are aligned with market realities will be key to accelerating the deployment of renewable energy. Additionally, fostering greater public support through education and transparent communication about the benefits of renewable energy can help mitigate opposition to new projects.

In conclusion, while Italy has made notable progress in expanding its renewable energy capacity, significant challenges remain. The country's ability to meet its 2030 targets will depend on overcoming regulatory and market obstacles, advancing technological innovations, and ensuring that the energy transition is socially and environmentally sustainable. As Italy navigates this complex landscape, strategic planning and strong political will be essential to securing a clean and resilient energy future, the Renewable Energy Community Decree could be an answer to these problems.

2.3. Definitions of RECs and differences with other similar concepts

Directly quoting from the GSE portal for RECs: “*A Renewable Energy Community (REC) is a group of citizens, small and medium-sized enterprises, territorial entities, and local authorities, including municipal administrations, cooperatives, research institutions, religious organizations, third-sector entities, and environmental protection organizations, who share renewable electricity produced by plants managed by one or more members of the community.*” [9]

In an REC, renewable electricity can be shared among the various producers and consumers located within the same geographic area, thanks to the use of the national electricity distribution network, which enables the virtual sharing of this energy.

Hence, Renewable Energy Communities (RECs) are an innovative concept designed to empower local communities by allowing them to produce, consume, share, and manage renewable energy. These communities are formed by a group of individuals, businesses, or local authorities who come together to collaboratively generate and use renewable energy, such as solar, wind, or biomass. The primary goal of RECs is to enhance local energy independence, promote environmental sustainability, and reduce energy costs for community members. By collectively managing energy resources, these communities can ensure that the benefits of renewable energy, such as lower electricity bills and reduced carbon emissions, are distributed equitably among all participants.

In Italy, the concept of Renewable Energy Communities has gained significant traction, particularly as part of the country's broader efforts to transition to a low-carbon economy. The evolution of renewable generation capacity in Italy from 2008 onwards has been marked by a substantial increase in community-driven projects, reflecting a growing recognition of the social and economic advantages of localized energy production. These communities are supported by European Union directives and national policies that encourage decentralized energy systems, aiming to make the energy transition more inclusive and resilient. Through the establishment of RECs, Italy is not only advancing its renewable energy capacity but also fostering greater community involvement and ownership in the energy transition process. This localized approach is critical for meeting national and EU climate goals while ensuring that the shift to renewable energy also delivers tangible benefits at the community level.

2.3.1. RECs differences with CECs

In EU it has always been important to make a distinction between Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs). Even if they both represent local and community-based approaches to energy management, they focus on different aspects and operate under distinct frameworks. RECs are primarily concerned with generating and utilizing renewable energy at a community level. These initiatives aim to harness local renewable resources such as solar, wind, or biomass to enhance sustainability and energy resilience within the community. They often involve stakeholders like residents, businesses, and local governments, working together to install and manage renewable energy systems and sometimes sell excess energy to the grid. RECs are typically regulated by specific national or regional laws that incentivize renewable energy production and consumption.

In contrast, CECs encompass a broader range of activities and focus on empowering citizens and local entities to participate in various aspects of energy management. While CECs do engage in renewable energy projects, they are not limited to them; their activities can also include energy efficiency measures, energy storage solutions, and innovative energy services. The goal of CECs is to democratize energy decision-making and ensure that local communities have control over how energy is produced, consumed, and managed. They are often regulated under comprehensive frameworks, such as the European Union's Clean Energy for All Europeans package, which provides guidelines for community involvement and governance in energy systems. Thus, while RECs have a narrower focus on renewable energy, CECs provide a more inclusive approach to energy management, encompassing a wider array of energy-related activities and emphasizing citizen participation and local control. [10]

1. Focus:
    - RECs: Primarily focused on the production and use of renewable energy.
    - CECs: Broader focus on collective energy activities, including renewable and non-renewable energy, with an emphasis on citizen involvement and local control.

2. Regulatory Framework:
    - RECs: Governed by national or regional regulations specific to renewable energy.
    - CECs: Governed by broader frameworks that promote community involvement in energy systems, such as EU regulations.
3. Activities:
    - RECs: Typically involve generating and using renewable energy.
    - CECs: Can encompass a wider range of energy-related activities, including renewable energy, energy efficiency, and energy storage.

Both concepts aim to enhance local control over energy resources and promote sustainable energy practices, but they differ in their scope and regulatory contexts.

2.3.2. RECs differences with AUCs

In the evolving landscape of renewable energy and collective energy management in Italy, it's crucial to distinguish between Renewable Energy Communities (RECs) and Aggregated Utility Companies (AUCs). While both concepts aim to enhance energy efficiency and sustainability, they operate under different frameworks and serve distinct purposes.

Renewable Energy Communities (RECs) are collaborative networks where a diverse group of participants—including individuals, businesses, and local authorities—come together to generate and share renewable energy. These communities focus on harnessing local renewable resources to achieve broader environmental, economic, and social benefits. The primary goals of RECs include reducing carbon emissions, lowering energy costs for members, and fostering community engagement and resilience. They represent a holistic approach to energy management that emphasizes collective participation and the equitable distribution of benefits.

In contrast, Aggregated Utility Companies (AUCs) are typically organized within the confines of a single building or complex, where residents or businesses aggregate their energy consumption to optimize procurement and management. AUCs aim to leverage the collective energy demand to negotiate better rates or enhance operational efficiencies. Their focus is primarily on achieving cost savings and improving energy management within a specific structure or set of properties. [11]

2.4. New conception of the electrical generation system and decentralization

Historically, the electric power system has been built on a centralized model, characterized by large-scale power plants generating electricity and distributing it through an extensive network of transmission and distribution lines to end-users. This traditional approach, as shown in figure 12, involves a few major facilities—such as coal, natural gas, nuclear, or large hydroelectric plants—supplying electricity to a broad geographic area. While this model has enabled significant economies of scale and reliable energy supply, it also presents several drawbacks. Centralized systems often lead to inefficiencies and high transmission losses due to the long distances electricity must travel. Additionally, they are vulnerable to single points of failure; any disruption at a major power plant or along the transmission network can lead to widespread outages. Environmental impacts are also a concern, as large-scale plants, particularly those burning fossil fuels, contribute significantly to air pollution and greenhouse gas emissions. Furthermore, this model can limit local energy autonomy and innovation, as energy production and consumption are managed remotely, reducing opportunities for communities to engage in and benefit from sustainable energy practices. [12]

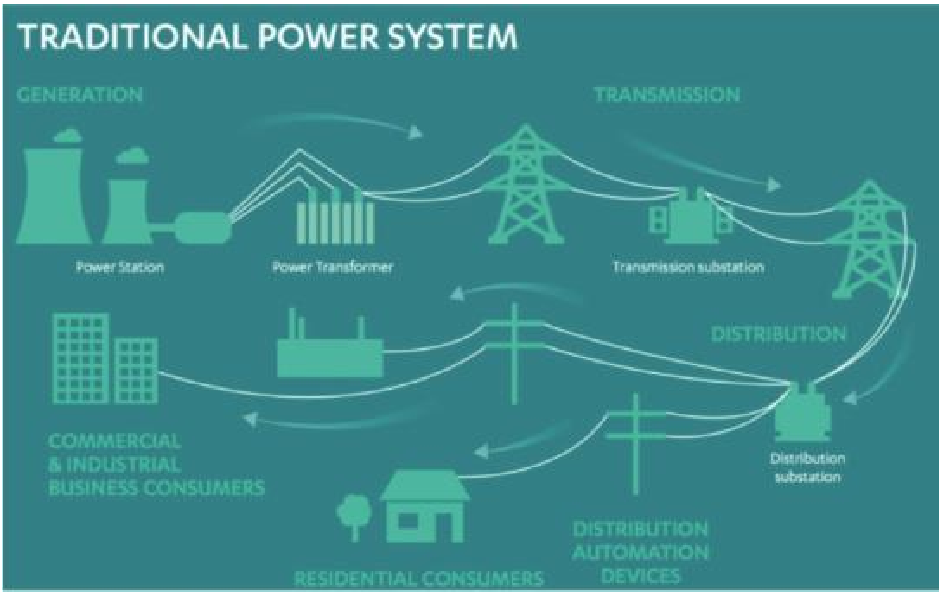


Figure 12 - Traditional centralized power system [12]

The shift from traditional centralized electric power systems to modern smart grids signifies a profound transformation in how electricity is generated, managed, and consumed. In the traditional model, power is produced in large, centralized plants—often fueled by coal, natural gas, nuclear energy, or large-scale hydroelectric projects—and transmitted over long distances to end-users. This setup benefits from economies of scale, but it also has notable drawbacks.

In contrast, smart grids, shown in figure 13, represent a revolutionary shift towards a more decentralized and intelligent energy system. They incorporate a wide range of distributed energy resources, such as residential solar panels, wind turbines, and battery storage systems, alongside traditional power sources. This decentralized approach allows for electricity to be generated closer to where it is used, which can significantly reduce transmission losses and increase overall energy efficiency. Smart grids utilize advanced technologies including real-time monitoring, automated controls, and two-way communication to enhance the reliability and responsiveness of the grid. For instance, real-time data helps quickly identify and address outages or inefficiencies, while automated systems can dynamically adjust energy flows to optimize performance and integrate diverse energy sources seamlessly.

One of the key advantages of smart grids is their capacity to integrate renewable energy sources more effectively. By accommodating intermittent sources like wind and solar, which may vary in output, smart grids help reduce dependence on fossil fuels and decrease carbon emissions. They also empower consumers through smart meters and home energy management systems, giving individuals greater control over their energy usage and fostering energy conservation and cost savings. This increased transparency and control can lead to more informed decision-making and encourage sustainable energy practices.

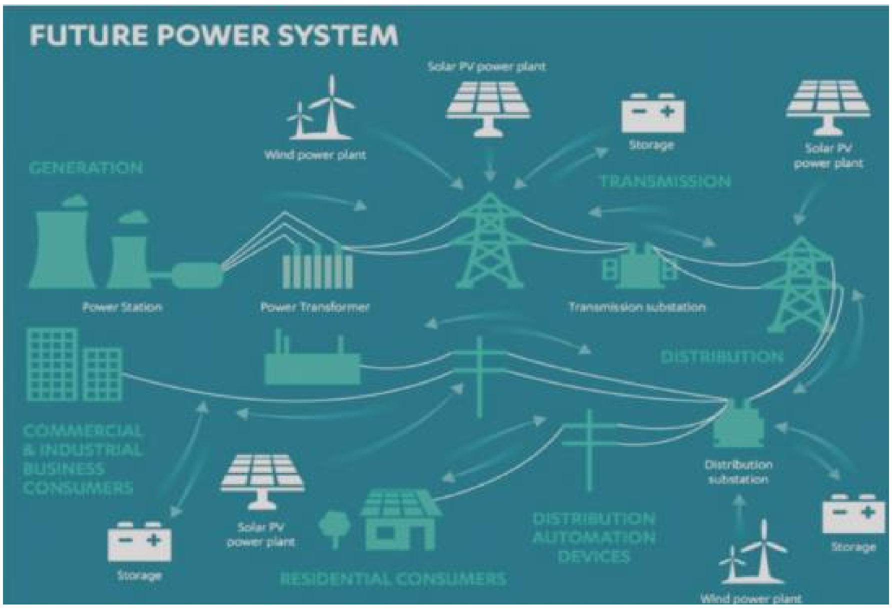


Figure 13 - Future smart grids power systems [12]

However, the transition to smart grids is not without challenges. The initial capital investment required for upgrading infrastructure and implementing advanced technologies can be substantial, posing financial hurdles for utilities and consumers alike. Additionally, the increased connectivity of smart grids introduces potential cybersecurity risks, as more data and control systems become vulnerable to cyberattacks. The complexity of managing a wide array of energy sources, data streams, and system interactions also requires robust maintenance and ongoing adaptation to ensure optimal performance and security.

Despite these challenges, smart grids offer a compelling vision for the future of energy. They promise enhanced resilience and efficiency, better integration of renewable resources, and greater consumer engagement. As the technology continues to evolve and the necessary investments are made, smart grids have the potential to create a more sustainable, reliable, and adaptive energy system that meets the needs of a rapidly changing world.

In a decentralized production system, which underpins Renewable Energy Communities and smart grids, the members involved can be classified as follows:

1. **Consumer:** This is the end user of energy, or the customer who utilizes the electricity produced by the power grid. Consumers can be residential, commercial, or industrial users who purchase energy for their daily needs.
2. **Producer:** This refers to the entity that generates energy, which may include operators of renewable energy generation facilities such as solar panels, wind turbines, cogeneration plants, or even traditional power plants. These producers sell the energy they generate to the power grid for distribution to consumers.
3. **Prosumer:** This term denotes individuals or entities that are both producers and consumers of energy. A prosumer might have a renewable energy generation system installed in their building (such as solar panels) and use the produced energy to meet part or all of their energy needs. Any excess energy can be sold back to the grid or used to offset periods of low production.

The presence of prosumers, particularly those who transition from being mere consumers to also becoming producers, is crucial within a decentralized energy system. It allows for greater flexibility in the electrical system, enabling more efficient management of the energy produced and consumed. In the following chapters, it will be explained how the regulations governing RECs are designed to encourage the emergence of this new role by supporting the installation of photovoltaic systems intended to provide renewable electricity to adjacent communities of consumers.

In the concept of a decentralized electrical system, as seen in RECs and smart grids, the goal is to create a more sustainable and livable city for its inhabitants. This approach aims to ensure that the entire community benefits from energy and economic advantages while minimizing investment costs for members through the use of existing infrastructure. [13]

2.5. User energy system configurations

The decentralization of the energy system and the imperative to decarbonize drive a complex transition from a centralized model, characterized by "one-to-many" or "one-to-one" configurations, to a "many-to-many" architecture.

The "one-to-many" structure involves a single point of generation supplying electricity to multiple points of consumption. This generation point could be an energy production facility like a power plant, typically powered by fossil fuels or a hydroelectric plant, while the points of consumption could include homes, offices, industries, or other establishments.

A "one-to-one" electrical grid refers to a system where a single generation point delivers electricity to a single point of use. For instance, a residential solar panel system may generate electricity that is directly consumed by a single household.

In a "many-to-many" network, multiple energy sources can simultaneously supply multiple loads. This configuration eliminates a fixed hierarchy between energy sources and loads, instead establishing a direct connection between them. This means each energy source can be connected to multiple loads and vice versa, allowing for increased flexibility in energy distribution. Such an organizational structure is particularly suited for generation systems based on intermittent renewable sources, where energy flexibility is crucial. This type of architecture is foundational to renewable energy communities, whose members can be energy consumers, small-scale energy producers, or both, acting as prosumers.

In a many-to-many structure, not only must different generation technologies producing various energy carriers be integrated, but a significant shift in social practices, economic relationships, and the regulatory framework must also occur. The shift towards a decentralized system focused on the electrification of end-uses, where energy demand is met by non-fossil sources, introduces other challenges, such as the current power grid's inadequacy to support a distributed, renewables-based system. A "flexible" energy system provides a viable alternative to traditional electrification. The decentralization of energy production and the distribution network involves the interconnection of socially and geographically diverse entities, which are both autonomous and self-sufficient but also capable of interacting with neighboring communities. As a result, a bottom-up regional reorganization of the energy system is essential. Renewable energy communities are founded on the principle of maximizing self-sufficiency by optimizing the amount of energy produced and consumed within their boundaries, thus increasing the share of self-consumed energy and the savings from reduced reliance on the public grid. The growth of systems based on the self-consumption of locally produced energy will lead to a profound transformation of the grid's structure, evolving it into a system of interconnected subsystems with nested levels of dense connectivity. This transformation can be achieved through a significant increase in the number of prosumers who choose to "form communities and exchange energy among themselves" at the neighborhood and city levels, on a peer-to-peer basis, as shown in figure 14. [14]

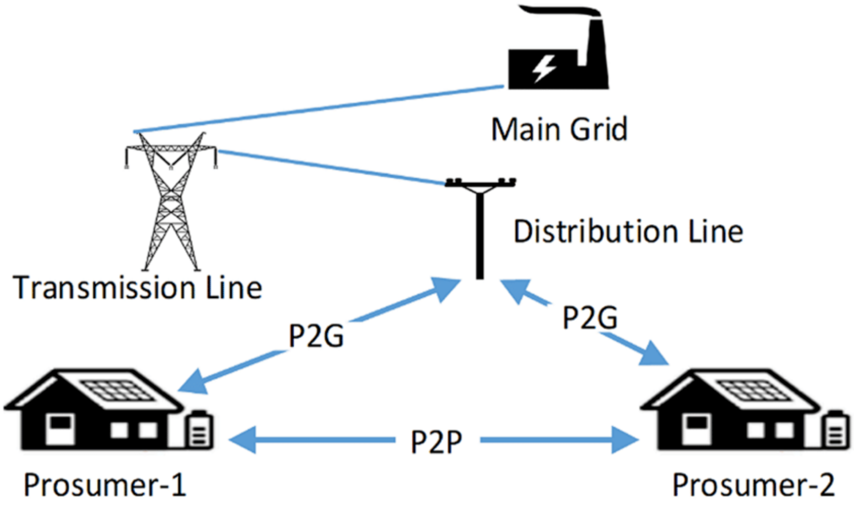


Figure 14 - Graphic explanation of peer-to-grid and peer-to-peer [15]

Peer-to-peer (P2P) energy trading is a transformative concept that redefines how energy is distributed and consumed, marking a significant departure from traditional centralized utility models. In a P2P energy system, individuals or entities can directly buy, sell, or share energy with one another within a decentralized network, bypassing the need for a central authority or large utility companies. This is particularly relevant in communities where prosumers—who both produce and consume energy—are prevalent. Prosumers often generate surplus energy through renewable sources such as solar panels, wind turbines, or small-scale biomass systems. Instead of selling this excess energy back to the grid at a lower price, P2P trading allows these prosumers to directly sell their energy to neighbors or other local consumers at mutually agreed-upon rates, creating a more dynamic and localized energy market.

The implementation of P2P energy trading is facilitated by advanced digital technologies such as blockchain, smart contracts, and Internet of Things (IoT) devices.

One of the most significant advantages of P2P energy trading is its ability to empower consumers, giving them greater control over their energy usage, sources, and costs. Consumers can choose to buy energy from local, renewable sources, supporting sustainable practices and reducing their carbon footprint. This localized energy production and consumption also enhances the resilience of the energy system by reducing dependence on distant, centralized power plants and minimizing transmission losses. By decentralizing energy production and distribution, P2P energy trading helps to create a more flexible and adaptive energy system, capable of responding more effectively to fluctuations in supply and demand.

Moreover, P2P energy trading can drive significant economic benefits. By cutting out the middleman, both producers and consumers can benefit from better pricing. Prosumers can earn a higher return on their surplus energy, while consumers may find more competitive rates than those offered by traditional utilities. This decentralized approach can also stimulate local economies by encouraging investment in renewable energy technologies and infrastructure, creating jobs, and fostering innovation in energy management.

Environmentally, P2P energy trading promotes the wider adoption of renewable energy sources. As more individuals and communities participate in decentralized energy production, reliance on fossil fuels decreases, leading to a reduction in greenhouse gas emissions and contributing to the fight against climate change. The localized nature of P2P trading also supports energy independence, as communities become more self-sufficient and less reliant on external energy supplies.

However, the widespread adoption of P2P energy trading also presents challenges. Regulatory frameworks must evolve to accommodate these new models, ensuring that they integrate smoothly with existing grid infrastructure and market operations. Additionally, the initial cost of implementing the necessary technologies and platforms for P2P trading can be a barrier, particularly in regions where digital infrastructure is underdeveloped.

Despite these challenges, P2P energy trading represents a significant step forward in the transition to a more decentralized, sustainable, and consumer-centric energy system. It aligns with the broader trends of energy democratization and decarbonization, empowering individuals and communities to take an active role in their energy future. As this concept continues to gain traction, it has the potential to reshape the energy landscape, driving innovation and sustainability while enhancing energy security and resilience at the local level. [16]

2.6. Network monitoring

Electric smart meters are advanced devices that play a crucial role in modern energy systems, particularly for prosumers—those who both produce and consume energy. Unlike traditional meters, which only measure energy consumption, smart meters provide a comprehensive, real-time view of both energy usage and production. For prosumers, this dual functionality is essential as it allows for the seamless integration of their renewable energy generation systems, such as solar panels, with the broader electrical grid. Smart meters continuously monitor the flow of electricity into and out of a property, distinguishing between energy drawn from the grid and energy generated on-site. This data is transmitted in real-time to both the prosumer and the utility company, enabling precise billing and energy management.

The smart meter operates through a combination of digital technology and communication systems. It records energy usage in intervals as short as every 15 minutes, allowing for a detailed analysis of consumption patterns. For prosumers, this means they can track when their energy production is highest—typically during daylight hours if using solar power—and align their consumption to maximize the use of their own renewable energy. Additionally, when production exceeds consumption, the smart meter records the excess energy that is exported back to the grid. This exported energy can be credited to the prosumer's account, often through net metering arrangements, where the excess energy offsets future electricity bills. Beyond just measuring energy flow, smart meters provide actionable insights that empower prosumers to optimize their energy use. By accessing data through online portals or apps, prosumers can monitor their real-time energy balance, identify periods of high consumption, and make informed decisions about when to use or store energy. For instance, a prosumer might choose to run high-energy appliances during peak production times to take full advantage of the energy being generated on-site. Some smart meters are also integrated with home energy management systems, which can automatically adjust appliance usage based on energy production levels, further enhancing efficiency and reducing costs. Moreover, smart meters facilitate demand response programs, where prosumers can contribute to grid stability by adjusting their energy consumption during peak demand periods. In some cases, prosumers may receive financial incentives for participating in these programs, which further enhances the economic benefits of being both a producer and consumer of energy.

The communication capabilities of smart meters also extend to the utility providers, enabling more efficient grid management. Utilities can receive instantaneous data on energy flows, which helps in balancing supply and demand across the network, integrating distributed renewable energy sources more effectively, and reducing the likelihood of outages. This real-time data exchange supports the development of smart grids, where electricity distribution becomes more adaptive and responsive to changing conditions. [17]

As seen in figure 15, the difference between 1G (first-generation) and 2G (second-generation) smart meters lies in their capabilities, communication technologies, and the level of control and information they provide to both consumers and utilities. Understanding these differences is crucial, especially when considering their role in energy communities, where managing local energy production, consumption, and distribution efficiently is essential.

1G meters, often referred to as Advanced Metering Infrastructure (AMI) meters, represent the first wave of smart meters. These devices primarily focus on providing remote, automated readings of energy consumption to utilities, eliminating the need for manual meter readings. They communicate usage data to the utility company, typically via a one-way communication system. This enables utilities to generate accurate bills based on real-time consumption data and detect outages more quickly.

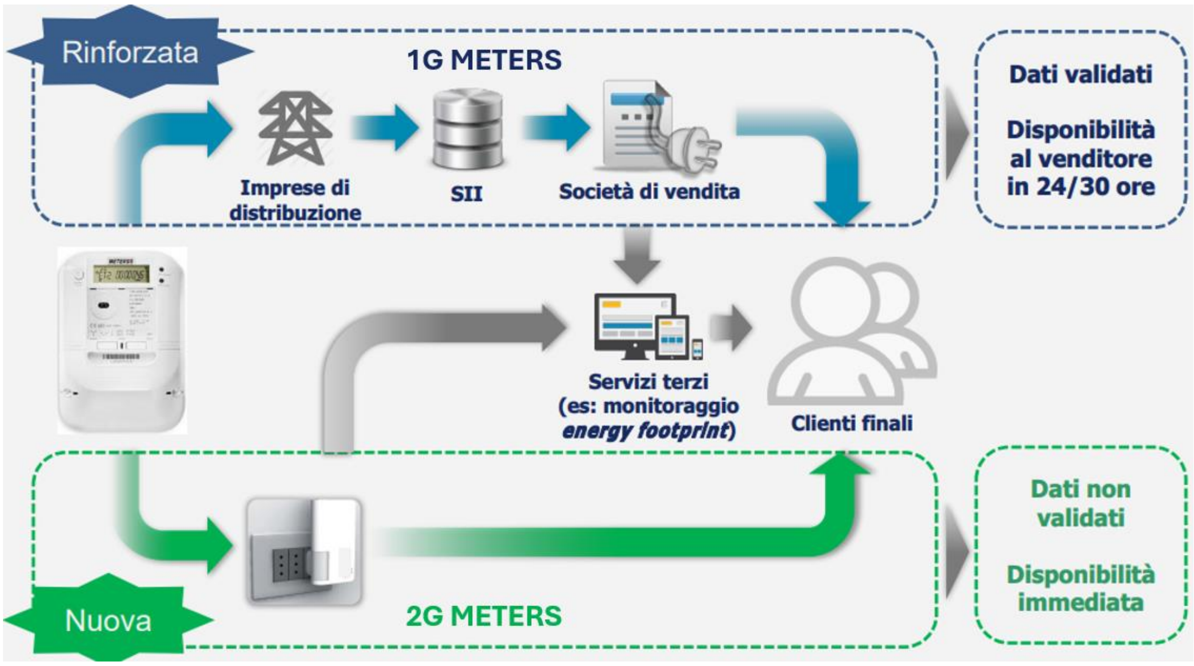


Figure 15 - Differences 1G and 2G meters [18]

However, 1G meters have limitations. They offer limited real-time data to consumers and generally do not support two-way communication. This means consumers have less visibility and control over their energy usage, and the integration of these meters with home energy management systems or renewable energy sources is less sophisticated. For energy communities, which require a high level of interaction between energy producers and consumers, these meters may not be fully adequate.

2G meters, also known as smart meters or advanced smart meters, are more sophisticated and provide two-way communication between the meter and both the utility and the consumer. These meters offer real-time data on energy consumption and production, and they can interact with other smart devices within a home or community. This enables consumers to monitor their energy use in real time, adjust their consumption based on pricing signals or energy availability, and manage energy resources more efficiently.

For energy communities, 2G meters are particularly valuable. They support the dynamic management of local energy resources, such as solar panels or wind turbines, by providing detailed data on when and how much energy is being produced and consumed. This allows energy communities to maximize self-consumption, optimize energy storage, and even participate in peer-to-peer energy trading. The ability to interact with other smart grid technologies also means that 2G meters can help balance supply and demand within the community, reducing reliance on external energy sources and enhancing grid stability.

Moreover, 2G meters enable better integration of renewable energy sources by facilitating demand response and load shifting. For instance, during times of high renewable energy generation, consumers can be incentivized to increase their consumption or store excess energy, ensuring that locally produced energy is used effectively. This is particularly important in energy communities, where the goal is often to achieve greater energy independence and sustainability.

Basically, 2G meters are essential in such a smart grid as Energy Communities for:

- Enhanced Data and Control: 2G meters provide detailed, real-time data that is crucial for managing energy production and consumption within the community. This allows for more efficient energy use and better integration of renewable resources.
- Two-Way Communication: The ability to send and receive data in real time is critical for the dynamic operation of energy communities, where energy flows are often more complex and need to be managed locally.
- Support for Renewable Integration: 2G meters are better equipped to handle the variability of renewable energy sources, providing the necessary data and control to balance production and consumption.
- Enabling Peer-to-Peer Trading: 2G meters facilitate direct energy exchanges between community members, supporting the economic and social goals of energy communities.

Despite these advantages, the implementation of smart meters is not without challenges. Privacy concerns arise from the detailed data collected, which could potentially be used to infer personal habits. Additionally, the initial cost of installing smart meters and integrating them with existing infrastructure can be significant. However, these challenges are outweighed by the benefits, especially for prosumers looking to maximize the efficiency, sustainability, and economic returns of their energy systems.

In summary, smart meters are a key technology for prosumers, offering detailed monitoring, real-time data, and the ability to optimize both energy consumption and production. They not only facilitate the integration of renewable energy into the grid but also empower prosumers to actively participate in energy markets, contributing to a more decentralized, resilient, and efficient energy system. [19]

2.7. Regulation Model: Virtual vs. Physical

Currently in Italy, self-consumption can be conducted under the "one-to-one" model, where a Production Unit (PU) serves a Consumption Unit (CU), such as common utilities in a condominium setting. In transitioning to a "one-to-many" collective self-consumption model (one PU serving multiple CUs), two different configurations can be conceptually considered [20]:

- **Physical self-consumption** scheme, which involves a direct private connection between generation installations and domestic/common utilities, with a single access point (POD – Point Of Delivery) to the public grid (Figure 17).
- **Virtual self-consumption** scheme (also known as "commercial" or "extended perimeter"), which utilizes the public grid for the exchange of energy between generation and consumption units (Figure 16).

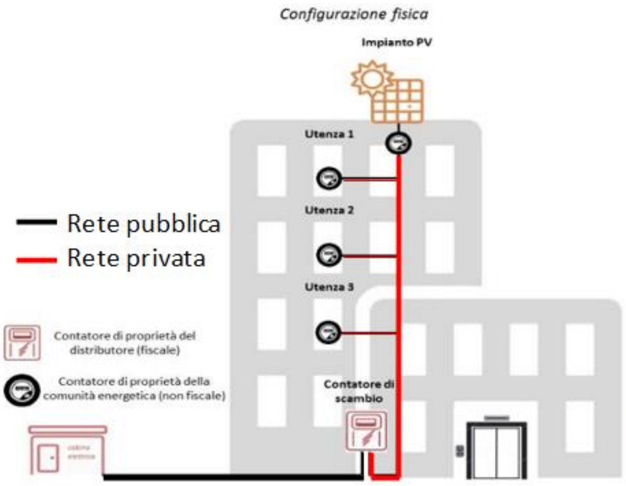


Figure 17 - Physical consumption configuration [20]

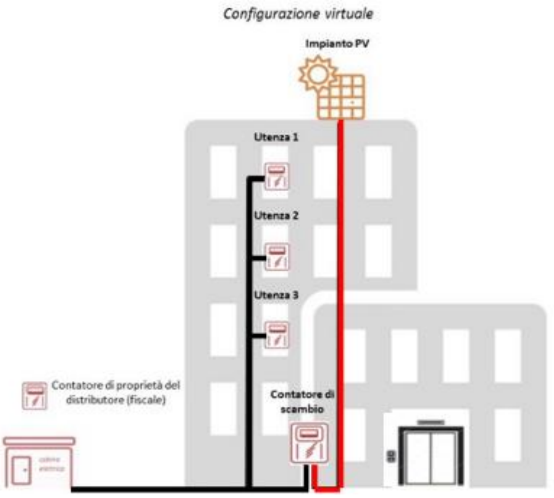


Figure 16 - Virtual consumption configuration [20]

In the physical self-consumption scheme (Figure 17), there is only one POD (Point Of Delivery) for exchange with the grid, and the energy produced and consumed remains effectively within the private network of the building, thus avoiding the application of the variable portion of network and system charges.

The main features of this configuration are:

- A private internal condominium network with a single connection to the public grid through one fiscal meter.
- A single electricity supply contract serving the common and domestic utilities of the condominium.
- A non-fiscal measurement infrastructure for recording the consumption of the utilities.

In the virtual self-consumption scheme (Figure 16), each user is typically connected to the public grid through their own POD (Point Of Delivery), allowing each individual to choose their own energy supplier or exit the scheme at any time. Physical energy exchanges continue to occur over varying portions of the public grid, which might be limited to the BT (low voltage) busbar of the condominium if electricity meters are centralized in a dedicated room.

The main features of the virtual scheme are:

- Unchanged network configuration: The public grid ends at the POD of each individual user (where a fiscal meter is installed).
- Measurement service by the electricity distributor: The distributor is responsible for measuring energy consumption.
- Freedom of choice: Each end customer can select their own energy supplier and can opt out of the scheme at any time.

2.8. On-site exchange and dedicated withdrawal

In the realm of electricity generation and usage, on-site exchange and dedicated withdrawal are two distinct methods related to energy management and distribution.

On-Site Exchange, also referred to as "self-consumption with on-site exchange" or "compensated self-consumption," enables energy producers, such as those with solar panel installations, to use the electricity they generate for their own needs and to transfer any excess to the national grid. When the output from the energy system surpasses the user's consumption, the surplus is delivered to the grid, and the producer receives compensation for the energy contributed.

This system relies on a bidirectional measurement setup, where the user-producer has a meter that tracks both the energy drawn from and the energy supplied to the grid. At the end of the billing period, the amount of energy consumed from the grid and the energy sent to it are compared to establish the energy balance. If there is a positive balance, the producer is granted compensation or energy credits for the surplus energy provided. This approach supports both residential and commercial users, as well as communities with renewable energy systems like solar or wind installations. It promotes self-consumption and the growth of renewable energy by providing financial benefits for producing clean energy. [21]

Dedicated Withdrawal, alternatively, involves a "dedicated withdrawal contract" or "energy sale contract," which is a commercial agreement between an electricity producer and a third party, such as a utility company or grid operator. Unlike on-site exchange, in dedicated withdrawal, producers do not use the energy directly but transfer it entirely to the GSE (Gestore dei Servizi Energetici). Rather than negotiating sales through bilateral agreements or selling on the wholesale market, producers receive guaranteed minimum prices, or for larger facilities, the average monthly price of their zonal wholesale market. Terms and conditions for the sale of energy are set out in the dedicated withdrawal contract.

This approach is commonly used by large-scale power plants, such as those fueled by coal, gas, or nuclear energy, which produce significant quantities of electricity for market distribution. However, it is also applicable to large renewable energy installations, like solar farms or wind farms, where the energy generated is sold to a single buyer, such as an electricity distribution company, through a long-term contract. [22]

In conclusion, on-site exchange and dedicated withdrawal offer two different strategies for energy producers to monetize their output. On-site exchange supports the use of self-generated energy with the option to trade excess energy with the grid, while dedicated withdrawal involves selling generated energy to a specific buyer through a contractual arrangement. Both methods play a role in advancing the use of renewable energy and supporting the transition toward a more sustainable energy system.

Renewable Energy Communities (RECs) can access the economic contributions available by applying for the distributed self-consumption service with the GSE (Gestore dei Servizi Energetici). Additionally, producers can monetize all the energy fed into the grid by either selling it on the market or requesting its withdrawal from the GSE through the Dedicated Withdrawal Service (RID).

2.9. Normative framework of Renewable Energy Communities

Up to the present, the EU has regularly issued directives, funding, and planning documents related to energy policies. This emphasis on the energy sector is somewhat unique and a key focus of the EU Commission, both to meet the obligations set by global organizations to promote sustainable development and to lessen dependence on third-party countries for energy (especially fossil fuels) in order to avoid situations of energy instability. Figure 18 illustrates the legislative and regulatory process for Renewable Energy Communities in Italy. The key points and updates introduced by each regulation are analyzed below.

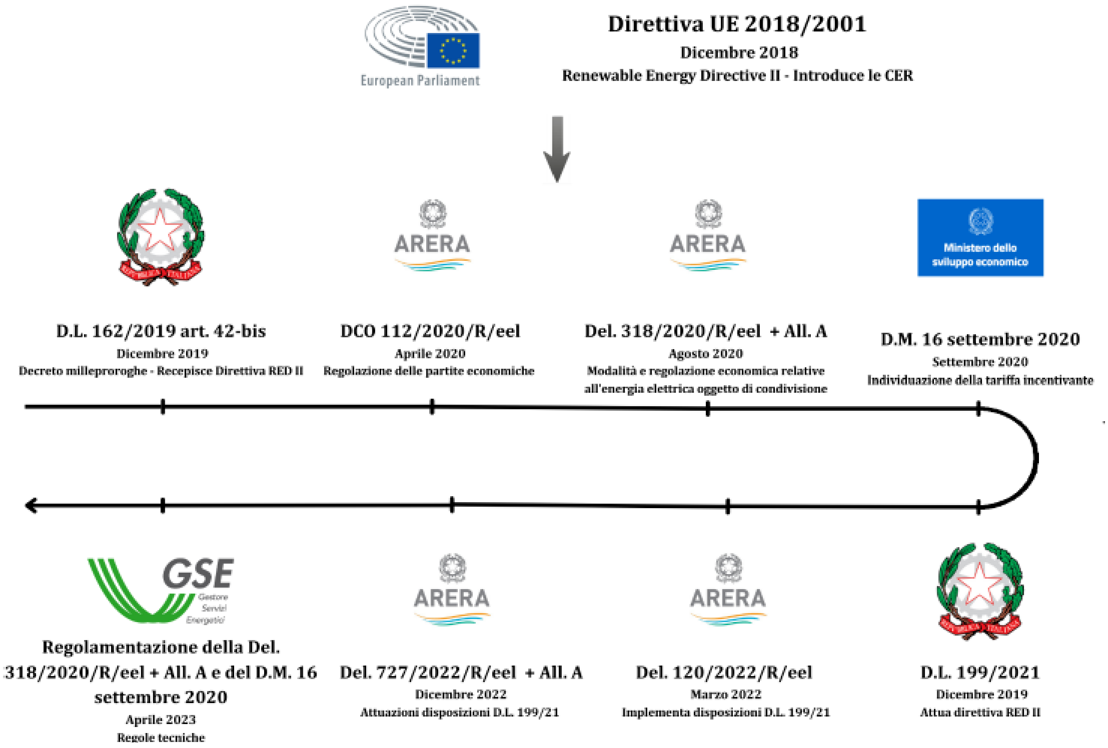


Figure 18 - process of the regulatory framework for RECs in Italy [23]

2.9.1. European Directive

The EU Directive 2018/2001, also known by the acronym RED II (Renewable Energy Directive II), is part of the Clean Energy for All Europeans Package. This package comprises a set of legislative proposals and policy initiatives aimed at promoting the transition towards cleaner and more sustainable energy in Europe. The primary goal is to achieve the ambitious targets of the European Union concerning clean energy and the reduction of CO2 emissions. The overarching objective of the Clean Energy Package is to ensure a transition to a clean, secure, and efficient energy sector in Europe by reducing greenhouse gas emissions, increasing the use of renewable energy sources, and promoting energy efficiency. It also specifies several social principles, such as the inclusion of citizens and communities in national climate planning strategies, the principle of a just and fair transition for all, with particular attention to the most vulnerable groups, and the principle of capacity-building at the local authority level to acquire skills at the local level to continue supporting community energy projects.

RED II, an integral part of this package, specifically focuses on promoting the use of renewable energy sources within the European Union. The regulation sets a series of binding targets for the share of renewables in the transport sector, provides support mechanisms and incentives for the production and consumption of advanced biofuels, promotes sustainable biomass production, and introduces measures to ensure that energy production from biomass is sustainable and meets certain environmental criteria. Among the various directives that make up the Clean Energy for All Europeans Package, RED II, which concerns the promotion of energy from renewable sources, amends Directives 2009/125/EC and 2010/30/EU, and is of fundamental importance because it introduced and defined Renewable Energy Communities for the first time. The directive provides for the establishment of such communities with the aim of facilitating active citizen participation in the energy transition. A renewable energy community can consist of one or more participants who decide to cooperate to manage and share energy produced from renewable sources. The directive also sets out the necessary conditions for local renewable energy production and the promotion of self-consumption at the community level. In this context, renewable energy communities can also provide energy services to national electricity grids, thus contributing to a more efficient and flexible use of energy. Other important aspects of the directive include the simplification of procedures for the installation of renewable energy production plants and the increase of national renewable energy production targets by 2030. The directive aims to promote broader adoption of renewable technologies, with particular attention to the decentralization of the energy system and active citizen participation.

RED II was followed by a second European regulation, IEM 2019/944, published in June 2019, also aimed at promoting the creation of renewable energy communities. This directive aims to establish a regulatory framework enabling end-users to produce, consume, store, and share renewable energy within local communities.

With the National Integrated Energy and Climate Plan (PNIEC), submitted to the European Community in December 2019, the Italian Government outlined its contributions and the related measures to help achieve the EU's 2030 energy and climate goals. In this context, significant importance is given to self-consumption, including collective self-consumption and renewable energy communities. [23]

2.9.2. Implementation in Italy

Directive 2018/2001 was implemented in Italy on December 30, 2019, by Decree-Law 162/19, also known as the Milleproroghe Decree. Although it was followed by additional regulations that clarify and define it more comprehensively, it introduces Renewable Energy Communities (RECs) in Chapter 42-bis, specifying that 'shareholders or members are individuals, small and medium-sized enterprises, territorial entities or local authorities, including municipal administrations, and participation in the renewable energy community cannot constitute the main commercial and industrial activity.' It is also specified that 'the primary goal of the association is to provide environmental, economic, or social benefits to its shareholders or members or to the local areas where the community operates, rather than financial profits,' and that 'participation in renewable energy communities must be open to all final customers, especially domestic customers, located within the specified perimeter, including those from low-income or vulnerable households.'

The maximum capacity of a renewable energy production plant serving members of the REC is 200 kW, and the produced energy is shared through the existing public distribution network and self-consumed according to well-defined methods described below, or it can be stored using storage systems. It is also specified that the commissioning date of such plants must be after the effective date of the conversion law of Decree-Law 162/19, that is, from March 1, 2020. The perimeter, or the territorial limit within which a member is part of the same energy community, is defined 'by the points of withdrawal of consumers and the points of injection of production plants, which are located on low-voltage electrical networks connected, as of the creation of the association, to the same medium-voltage/low-voltage transformation cabin.' This is the main characteristic that differentiates a REC from a group of renewable energy self-consumers acting collectively, as the latter are part of the same building or condominium. Each member of the community retains their rights and obligations (including billing) as a final customer and regulates their relationships with the same configuration through a private law contract that governs the possibility of withdrawal and the parties responsible for the configuration.

The following article also specifies 'that self-consumed electricity be quantified on an hourly basis' and that there be 'coincidence between the concepts of "shared energy," "self-consumed electricity," and "incentivized electricity for self-consumption,"' defining shared electricity as 'the minimum, in each hourly period, between the electricity produced and injected into the grid by renewable energy plants and the electricity withdrawn by the group of associated final customers.' Within the amount of shared electricity for instantaneous self-consumption, any energy stored in accumulators may be considered. [24]

2.10. The RECs Decree

The decree that encourages the establishment and development of Renewable Energy Communities and widespread self-consumption in Italy has been published on the website of the Ministry of Environment and Energy Security on the 23rd of January 2024. As of January 24th, the decree will officially come into force, following its registration by the Court of Auditors and the prior approval of the European Commission.

As stipulated by the decree, within the next thirty days, the Ministry will approve the operational rules that will govern the methods and timing for recognizing incentives, after verification by ARERA and based on a proposal by the Energy Services Manager (GSE). The GSE, which is responsible for managing the measure, will activate the portals through which applications can be submitted within 45 days of the approval of the rules. [25][26]

2.10.1. Purpose

Support for the construction of plants for the production of renewable energy and the expansion of existing ones with a capacity of up to 1 MW.

Renewable energy is intended as the energy derived from non-fossil renewable sources, namely wind, solar, thermal, photovoltaic, and geothermal energy, ambient energy, tidal energy, wave energy, and other forms of marine energy, as well as hydraulic energy, biomass, landfill gas, sewage treatment gas, and biogas.

2.10.2. Eligible interventions/expenses

There are 2 types of incentives provided:

Incentives for energy sharing

Renewable energy plants, including upgrades, within CACER configurations with the following requirements:

- The maximum nominal capacity of each plant, or the upgrade intervention, must not exceed 1 MW.
- Renewable Energy Communities must be properly established at the time of application submission.

- The production plants and withdrawal points within the CACER are connected to the distribution network through connection points within the area served by the same primary substation.
- The plants must meet the performance and environmental protection requirements necessary to comply with the DNSH principle and the construction requirements outlined in the operational rules.
- The CACER must ensure, through explicit statutory provisions, private agreements, or, in the case of individual self-consumption, a self-declared statement:
    - That any excess premium tariff amount, relative to the threshold value of the shared energy quota, is allocated only to non-business consumers and/or used for social purposes that benefit the territories where the sharing plants are located.
    - Complete, adequate, and prior information to all final consumers about the benefits they derive from access to the tariff.
    - An annual report on the benefits resulting from the application of the premium tariff, optionally in advance with the GSE if the project may be eligible for the incentive.

Incentive tariff (fixed part + variable part) is fixed for 20 years, starting from the date of commercial operation of the plant, and is recognized on the share of electricity shared within the CACER.

- The fixed part varies based on the size of the plant, while the variable part depends on the market price of energy (Pz).
- The incentive tariff increases as the power of the plants decreases and as the market price of energy (Pz) decreases.
- An additional tariff increase is also provided for plants located in the Central and Northern Regions of Italy.

Table 1 - Incentive tariff fixed part + variable part

Plant Power	Incentive tariff
P < 200 kW	80 €/MWh + 0/40 €/MWh
200 kW < P < 600 kW	70 €/MWh + 0/40 €/MWh
P > 600 kW	60 €/MWh + 0/40 €/MWh

Table 2 -Geographic tariff increase

Geographic zone	Tariff increase
South regions	-
Centre regions	+ 4 €/MWh
North regions	+ 10 €/MWh

Granting of PNRR benefits

Non-repayable grant on investments up to 40% of eligible costs on renewable energy plants, including upgrades, within REC configurations and collective self-consumption systems from renewable sources located in municipalities with a population of less than 5,000 inhabitants, with the following requirements:

- The maximum nominal capacity of each plant, or the upgrade intervention, must not exceed 1 MW.
- Renewable Energy Communities must be properly established at the time of application submission.
- The production plants and withdrawal points within the CACER are connected to the distribution network through connection points within the area served by the same primary substation.
- The plants must meet the performance and environmental protection requirements necessary to comply with the DNSH principle and the construction requirements outlined in the operational rules.

- The CACER must ensure, through explicit statutory provisions, private agreements, or, in the case of individual self-consumption, a self-declared statement:
    - That any excess premium tariff amount, relative to the threshold value of the shared energy quota, is allocated only to non-business consumers and/or used for social purposes that benefit the territories where the sharing plants are located.
    - Complete, adequate, and prior information to all final consumers about the benefits they derive from access to the tariff.
    - An annual report on the benefits resulting from the application of the premium tariff, optionally in advance with the GSE if the project may be eligible for the incentive.
- The start of works must be after the application submission date.
- Possession of the authorization for the construction and operation of the plant, where required.
- Possession of the definitive accepted connection offer to the electrical grid, where required.
- Entry into operation within 18 months from the date of approval of the contribution and in any case no later than June 30, 2026.

Eligible expenses are within the limit of the maximum reference investment cost equal to:

Table 3 - Maximum expense for PNRR benefits

Plant Power	Admissible expense
P < 20 kW	1500 €/kW
20 kW < P < 200 kW	1200 €/kW
200 kW < P < 600 kW	1100 €/kW
P > 600 kW	1050 €/kW

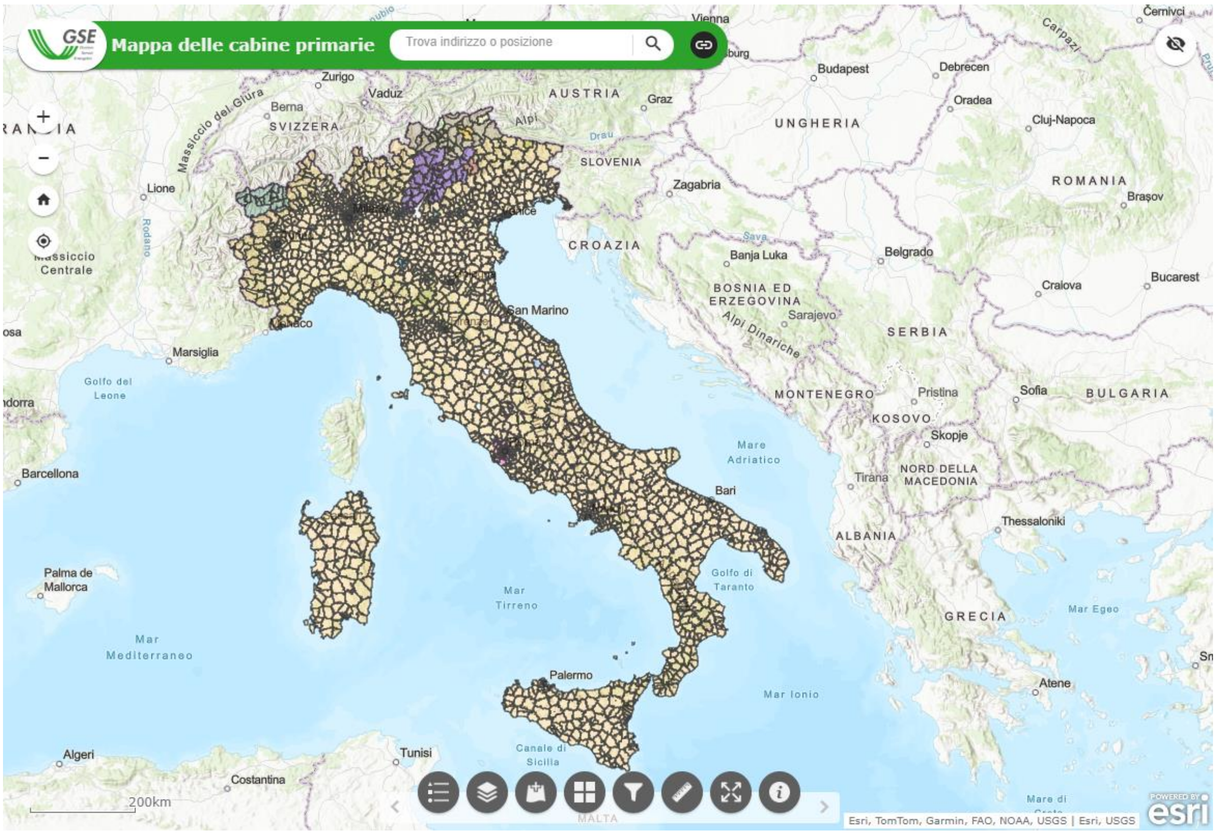


Figure 19 - Map of primary substations GSE [27]

2.10.3. Allocation

€ 5,700,000,000 allocated as follows:

- Incentive tariff: € 3,500,000,000
- PNRR non-repayable grants: € 2,200,000,000

2.10.4. Beneficiaries

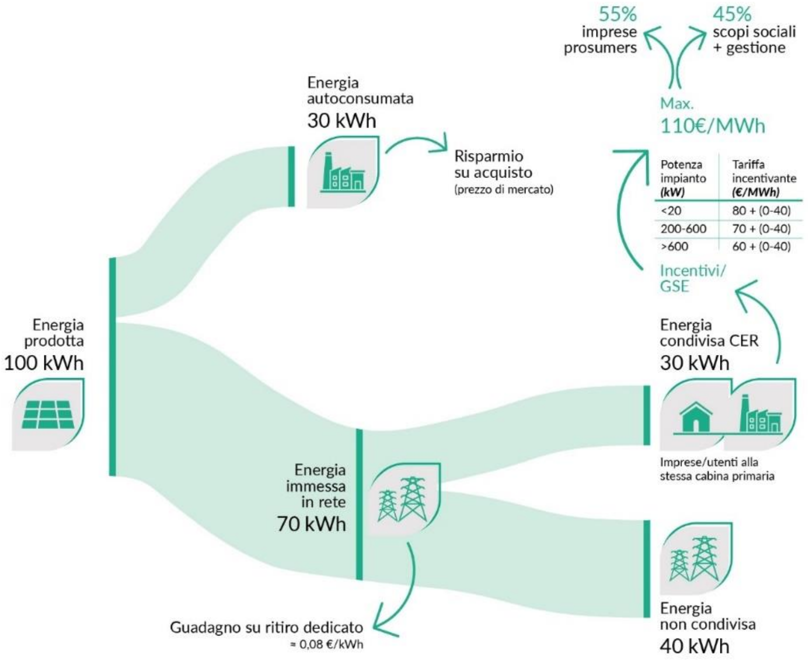
The Renewable Energy Community (REC) can be established by:

- SMEs (Small and Medium-sized Enterprises)
- Citizens
- Local authorities
- Associations
- Condominiums
- Third sector organizations
- Cooperatives
- Religious entities

2.11. Benefits of RECs

[28] Renewable Energy Communities offer a multitude of benefits that span environmental, economic, social, and resilience aspects. Here's a comprehensive look at these advantages:

1. **Environmental Benefits:**
    - Reduction in Carbon Emissions: RECs contribute significantly to lowering greenhouse gas emissions by replacing fossil fuels with clean, renewable energy sources such as wind, solar, and hydro power.
    - Promotion of Clean Energy: By prioritizing the use of renewable energy, RECs foster a shift away from non-renewable energy sources, thereby supporting efforts to combat climate change and reduce environmental pollution.
    - Conservation of Resources: Renewable energy sources are inherently more sustainable and have a lower environmental impact compared to traditional energy sources, aiding in the conservation of natural resources.
2. **Social Benefits:**
    - Strengthened Community Ties: RECs foster a sense of community by bringing together local citizens, businesses, and organizations to work collaboratively towards common energy goals, thereby enhancing social cohesion.
    - Empowerment and Ownership: By participating in RECs, community members gain a sense of ownership and control over their energy resources, which can enhance their overall sense of empowerment and engagement.
    - Equitable Distribution of Benefits: RECs ensure that the advantages of renewable energy, such as cost savings and environmental improvements, are distributed fairly among all members, promoting social equity.



Potenza impianto *(kW)*	Tariffa incentivante *(€/MWh)*
<20	80 + (0-40)
200-600	70 + (0-40)
>600	60 + (0-40)

Figure 20 - Economic benefits on produced energy

3. **Economic Benefits (figure 20):**

    - Lower Energy Costs: Members of RECs can benefit from reduced electricity bills through self-consumption of locally generated renewable energy, which often leads to substantial savings.

    - Job Creation: The establishment and maintenance of renewable energy projects within RECs create various job opportunities, ranging from installation and maintenance to project management and administration.

    - Local Investment: RECs can stimulate local economies by attracting investments in renewable energy infrastructure and technology, which can lead to further economic development and growth.

4. **Energy Resilience Benefits:**

    - Decentralization of Energy Production: By decentralizing energy generation, RECs reduce reliance on large, centralized power grids, which can make communities less vulnerable to disruptions and outages.

    - Enhanced Energy Security: The local production of renewable energy can improve a community's energy security, providing a more reliable and stable energy supply that is less susceptible to external shocks.

5. **Overall Sustainable Development:**

    - Promotion of Sustainable Practices: RECs support the broader goal of sustainable development by integrating renewable energy into daily life and encouraging environmentally responsible behaviors and practices.
    - Long-Term Environmental Impact: By advancing renewable energy adoption, RECs contribute to long-term environmental health and sustainability, benefiting future generations.
    - Model for Other Communities: Successful RECs can serve as models for other communities, demonstrating the feasibility and benefits of renewable energy initiatives and encouraging widespread adoption.

3. Electricity Production from Renewable Sources

The global energy landscape is undergoing a profound transformation, driven by the pressing need to mitigate climate change and reduce dependency on fossil fuels. Central to this transformation is the shift towards renewable energy sources, which offer sustainable, low-carbon alternatives to conventional energy generation. Among these renewable sources, solar photovoltaics (PV), wind, and hydroelectric power stand out as the most significant contributors to electricity production.

Solar energy, harnessed through photovoltaic (PV) systems, has emerged as one of the fastest-growing sources of electricity worldwide. The advancement in PV technology, coupled with a substantial decrease in the cost of solar panels, has led to widespread adoption. Solar PV systems convert sunlight directly into electricity, providing a clean, abundant, and inexhaustible energy source. Their scalability—from small rooftop installations to large utility-scale solar farms—makes them a versatile option for diverse energy needs. Moreover, the ability of PV systems to be integrated into existing infrastructure, such as buildings and transportation networks, further enhances their appeal in urban and rural settings alike.

Wind energy, another cornerstone of renewable electricity production, has seen remarkable growth over the past few decades. Wind turbines convert the kinetic energy of wind into electrical power, offering a highly efficient and increasingly cost-effective means of electricity generation. The expansion of wind farms, both onshore and offshore, has been a key driver in the renewable energy sector, contributing significantly to the decarbonization of the energy grid. Offshore wind, in particular, is poised for exponential growth, benefiting from stronger and more consistent wind resources compared to onshore locations. The development of larger and more efficient turbines continues to enhance the viability of wind energy, positioning it as a critical component of a sustainable energy future.

Hydropower, the oldest and most established form of renewable energy, remains a major contributor to global electricity production. Utilizing the energy of flowing water, hydroelectric plants generate electricity in a reliable and controllable manner. Unlike solar and wind, which are variable by nature, hydropower provides a stable and continuous power supply, often serving as a backbone for many national grids. Furthermore, hydropower plants can offer significant flexibility in electricity production, capable of rapidly adjusting output to meet demand fluctuations. In addition to conventional large-scale dams, the development of small-scale hydro projects and pumped storage systems is expanding the role of hydropower in modern energy systems, enabling greater integration with other renewable sources.

As the world transitions towards a more sustainable energy system, the integration of solar, wind, and hydro power into the electricity grid presents both opportunities and challenges. These technologies, while inherently renewable, are also intermittent and weather-dependent, necessitating advancements in energy storage, grid management, and regulatory frameworks to ensure a stable and reliable energy supply. The synergy between these renewable sources and emerging technologies, such as smart grids and energy storage systems, will be crucial in overcoming these challenges and realizing the full potential of a renewable-powered future.

This chapter delves deeper into the mechanisms behind electricity production from solar PV, wind, and hydroelectric power, offering an examination of how these technologies function. We will explore the principles of each technology, shedding light on their unique advantages and challenges. Additionally, this chapter outlines the methodologies used to collect and analyze the data that form the basis of the findings presented later in this thesis. By understanding the technical foundations and the analytical approaches employed, we aim to provide a clear context for the subsequent discussions and conclusions drawn in the following chapters.

3.1. Photovoltaic Energy

The increasing urgency to address climate change and reduce greenhouse gas emissions has driven significant advancements in renewable energy technologies. Among these, photovoltaic (PV) energy has emerged as a pivotal player in the global shift towards sustainable energy sources. As societies worldwide strive to transition from fossil fuels to cleaner alternatives, the integration of photovoltaic systems into Renewable Energy Communities (RECs) offers a promising pathway to achieving both environmental and economic sustainability.

Photovoltaic energy production harnesses the power of sunlight, converting it directly into electricity through the use of solar cells, the process can be represented by this equation:

$$E = G \times A \times \eta \times H \quad (1)$$

Where:

E = Energy produced [kWh]

G = Solar irradiance [kW/m^2]

A = Area of the photovoltaic panels [m^2]

η = Efficiency of the photovoltaic panels (in decimal form)

H = Hours of efficient operation [h]

These cells, typically made of semiconductor materials like silicon, operate on the principle of the photovoltaic effect, where sunlight induces the generation of electrical current within the material, as illustrated in figure 21. PV systems can be deployed at various scales, from small rooftop installations on individual homes to large solar farms that feed electricity into the grid. Their versatility and relatively low maintenance make them an attractive option for decentralized energy production, particularly in the context of RECs. Photovoltaic energy is particularly well-suited for these communities due to its scalability, modularity, and the declining cost of solar technology.

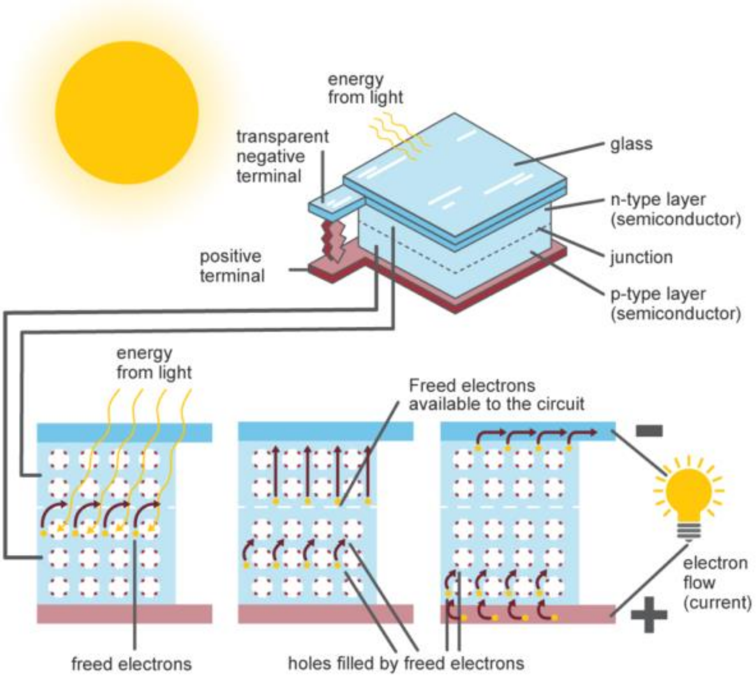


Figure 21 - Inside a photovoltaic cell [29]

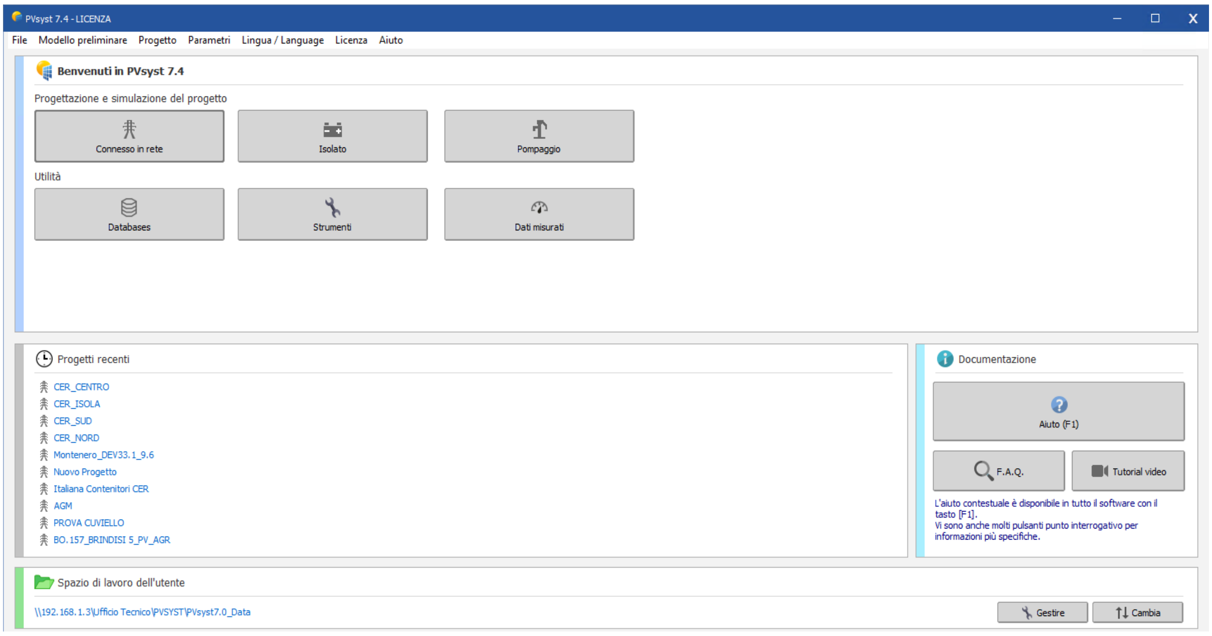
However, while the benefits of photovoltaic energy are substantial, it is also important to consider the challenges and limitations associated with this technology. One of the primary advantages of PV energy is its ability to generate electricity without emitting greenhouse gases, making it a crucial tool in the fight against climate change. Additionally, the declining cost of solar panels and improvements in efficiency have made PV systems more accessible and economically viable for a broader range of consumers.

On the other hand, photovoltaic energy production is not without its disadvantages. The intermittent nature of solar energy—dependent on weather conditions and daylight hours—poses a significant challenge for consistent energy supply. This variability necessitates the integration of energy storage systems or complementary energy sources to ensure a reliable power supply. Furthermore, the production of solar panels involves the use of raw materials and energy, which raises concerns about the environmental impact of manufacturing and disposal processes.

In this chapter, we will delve into a comprehensive analysis of photovoltaic energy, focusing on both its technical and practical aspects. First, we will explore one of the most powerful software tools available for PV simulation, providing insights into how it can be utilized to model and optimize solar energy systems. Following this, we will analyze national data sourced from annual reports to gain a clearer understanding of the current landscape of photovoltaic energy in Italy. This analysis will help us assess the penetration and utilization of PV technology across the country. Finally, we will describe the specific data sets that will be incorporated into our model, setting the stage for a detailed examination of photovoltaic energy's role within Renewable Energy Communities. This approach will not only highlight the practical applications of PV technology but also underscore its significance in the broader context of Italy's renewable energy strategy. [30]

3.1.1. PVsyst software for photovoltaic simulation

PVsyst is one of the leading software tools designed specifically for the simulation, sizing, and analysis of photovoltaic (PV) systems. Developed by André Mermoud at the University of Geneva, PVsyst is widely used by engineers, researchers, and professionals in the solar energy industry to design and optimize PV installations, ranging from small residential setups to large-scale solar farms.



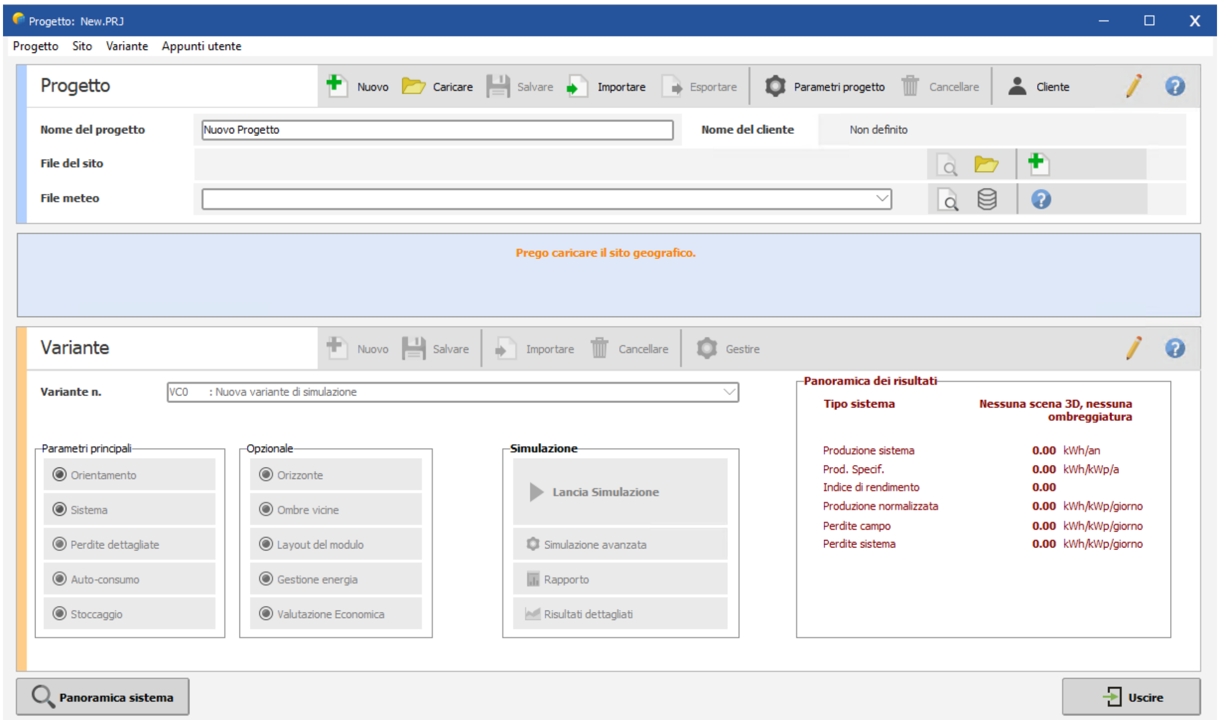
L'aiuto contestuale è disponibile in tutto il software con il tasto [F1].
Vi sono anche molti pulsanti punto interrogativo per informazioni più specifiche.

\\192.168.1.3\Ufficio Tecnico\PVSYST\PVsyst7.0_Data

Figure 22 - Main menu of PVsyst software

PVsyst operates as a comprehensive tool for the simulation, sizing, and analysis of photovoltaic systems, guiding users through the entire process of PV project development, from initial feasibility studies to detailed design and performance evaluation.

The process begins with project setup (figure 23), where users define the specific location of the PV installation. This step is crucial, as the geographical location (figure 25) significantly impacts the system's performance due to varying solar irradiance and weather conditions. PVsyst provides access to an extensive database of meteorological data (figure 24), which includes parameters such as global horizontal irradiance (GHI), temperature, and wind speed—key factors that influence the accuracy of the simulation and energy production estimates.



Nome del progetto Nuovo Progetto

Nome del cliente Non definito

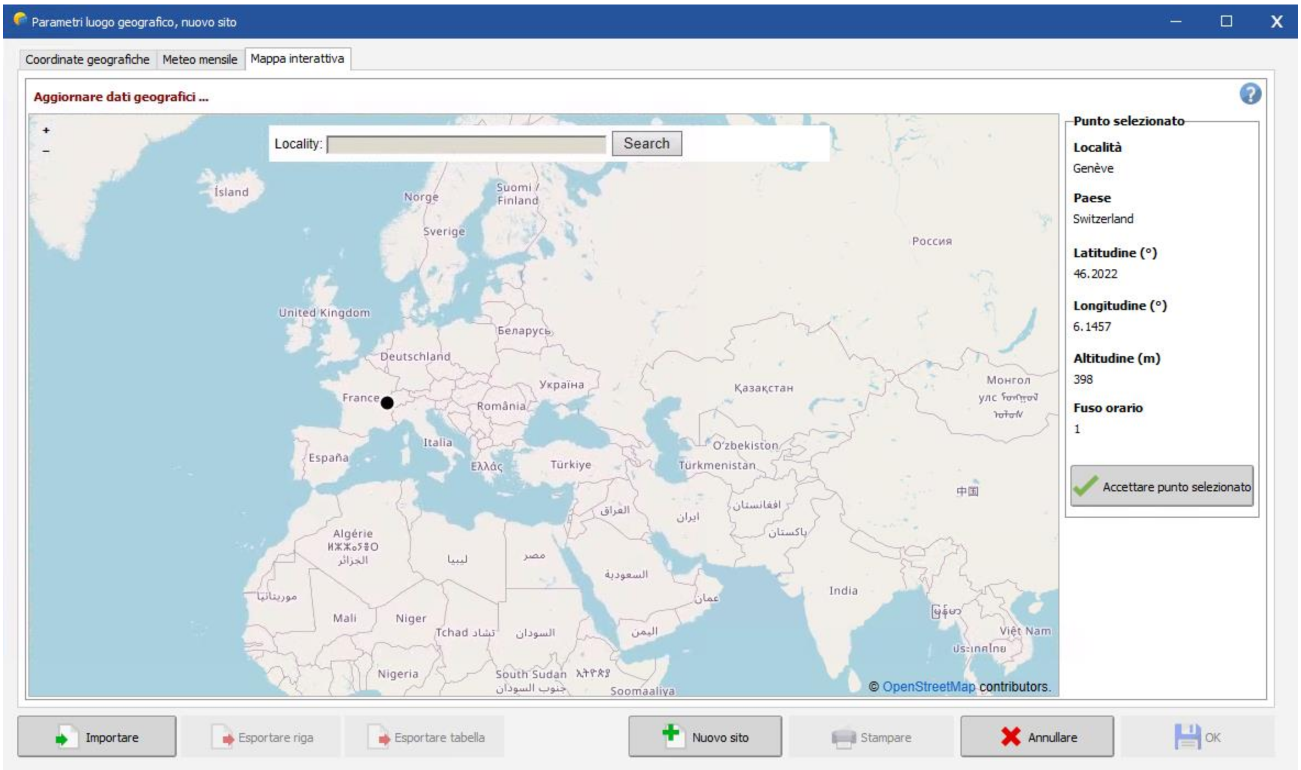
Prego caricare il sito geografico.

Variante n. VC0 : Nuova variante di simulazione

Panoramica dei risultati

Tipo sistema	**Nessuna scena 3D, nessuna ombreggiatura**	
Produzione sistema	**0.00**	kWh/an
Prod. Specif.	**0.00**	kWh/kWp/a
Indice di rendimento	**0.00**	
Produzione normalizzata	**0.00**	kWh/kWp/giorno
Perdite campo	**0.00**	kWh/kWp/giorno
Perdite sistema	**0.00**	kWh/kWp/giorno

Figure 23 -Project setup window



Località
Genève

Paese
Switzerland

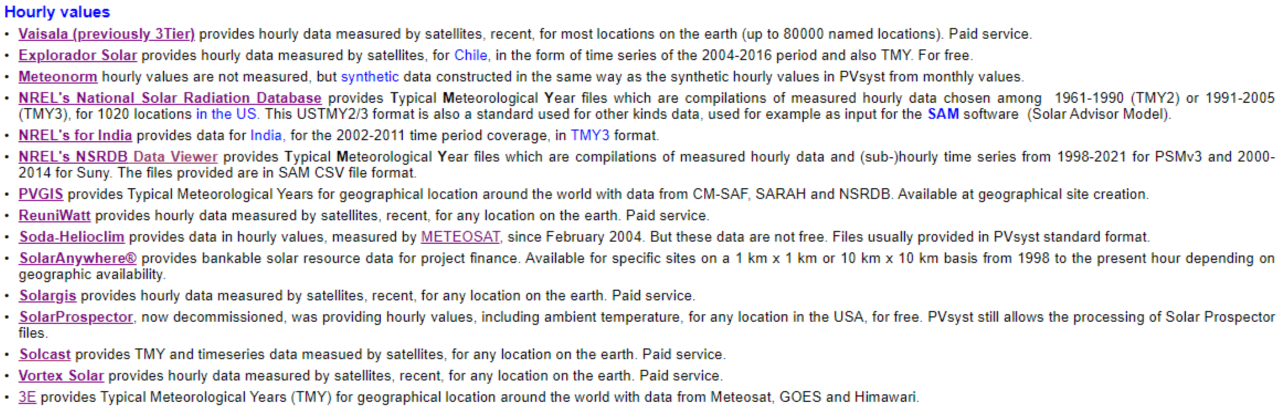
Latitudine (°)
46.2022

Longitudine (°)
6.1457

Altitudine (m)
398

Fuso orario
1

Figure 25 - New geographic site setup window



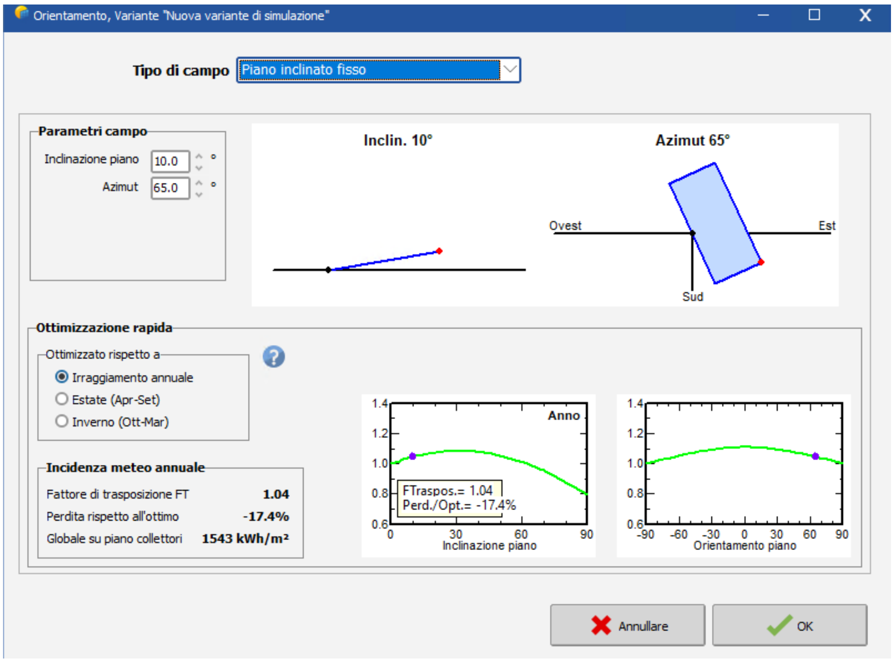
Hourly values

- Vaisala (previously 3Tier) provides hourly data measured by satellites, recent, for most locations on the earth (up to 80000 named locations). Paid service.
- Explorador Solar provides hourly data measured by satellites, for Chile, in the form of time series of the 2004-2016 period and also TMY. For free.
- Meteonorm hourly values are not measured, but synthetic data constructed in the same way as the synthetic hourly values in PVsyst from monthly values.
- NREL's National Solar Radiation Database provides Typical Meteorological Year files which are compilations of measured hourly data chosen among 1961-1990 (TMY2) or 1991-2005 (TMY3), for 1020 locations in the US. This USTMY2/3 format is also a standard used for other kinds data, used for example as input for the **SAM** software (Solar Advisor Model).
- NREL's for India provides data for India, for the 2002-2011 time period coverage, in TMY3 format.
- NREL's NSRDB Data Viewer provides Typical Meteorological Year files which are compilations of measured hourly data and (sub-)hourly time series from 1998-2021 for PSMv3 and 2000-2014 for Suny. The files provided are in SAM CSV file format.
- PVGIS provides Typical Meteorological Years for geographical location around the world with data from CM-SAF, SARAH and NSRDB. Available at geographical site creation.
- ReuniWatt provides hourly data measured by satellites, recent, for any location on the earth. Paid service.
- Soda-Helioclim provides data in hourly values, measured by METEOSAT, since February 2004. But these data are not free. Files usually provided in PVsyst standard format.
- SolarAnywhere® provides bankable solar resource data for project finance. Available for specific sites on a 1 km x 1 km or 10 km x 10 km basis from 1998 to the present hour depending on geographic availability.
- Solargis provides hourly data measured by satellites, recent, for any location on the earth. Paid service.
- SolarProspector, now decommissioned, was providing hourly values, including ambient temperature, for any location in the USA, for free. PVsyst still allows the processing of Solar Prospector files.
- Solcast provides TMY and timeseries data measued by satellites, for any location on the earth. Paid service.
- Vortex Solar provides hourly data measured by satellites, recent, for any location on the earth. Paid service.
- 3E provides Typical Meteorological Years (TMY) for geographical location around the world with data from Meteosat, GOES and Himawari.

Figure 24 - List of sources for accurate weather data by PVsyst

Once the location is set, users proceed to configure the PV system. PVsyst allows for the specification of various components, including PV modules, inverters, and other essential system elements. The software supports a variety of system topologies, catering to grid-connected, stand-alone, and hybrid systems. This flexibility ensures that the design can be tailored to the specific needs and constraints of the project.

The next stage involves the detailed design and sizing of the PV system. Users can design the array layout by selecting the orientation and tilt angle of the modules, as well as the spacing between them. PVsyst includes advanced tools for shading analysis, enabling users to optimize the placement of panels to minimize energy losses due to shading from nearby objects or terrain features. The software also assists in sizing the system components, ensuring compatibility and optimal performance of inverters, cables, and any storage systems involved.



Orientamento, Variante "Nuova variante di simulazione"

Tipo di campo: Piano inclinato fisso

Parametri campo

Inclinazione piano: 10.0 °

Azimut: 65.0 °

Ottimizzazione rapida

Ottimizzato rispetto a

● Irraggiamento annuale

○ Estate (Apr-Set)

○ Inverno (Ott-Mar)

Incidenza meteo annuale

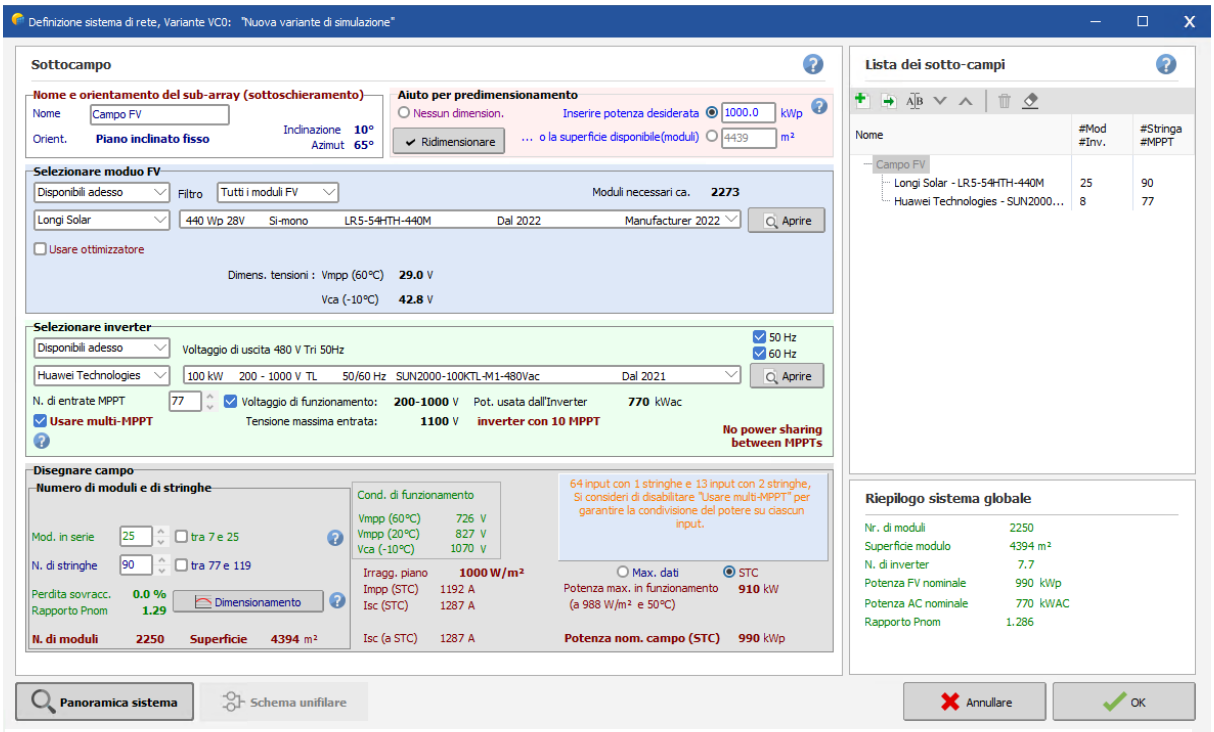
Fattore di trasposizione FT	**1.04**
Perdita rispetto all'ottimo	**-17.4%**
Globale su piano collettori	**1543 kWh/m²**

FTraspos.= 1.04

Perd./Opt.= -17.4%

Figure 26 - Orientation and inclination of new PV plant

The parameters I considered for the analysis include a tilt angle of 10° and an azimuth of 65°, simulating less-than-ideal conditions for a photovoltaic system. This approach reflects the reality that, in actual installations, it is rare to achieve perfect construction conditions for optimal system performance. Therefore, it seemed more appropriate to conduct simulations that closely resemble real-world scenarios rather than idealized ones. Additionally, PVsyst offers the capability to select from a vast database of technologies. Currently, at AGP SpA, we frequently utilize Longi Solar technology, with module power outputs ranging from 440W to 660W, and HUAWEI or SOLAREDGE inverter technologies, which are among the best available. For this analysis, I selected Longi 440 modules, which are particularly well-suited for rooftop installations, and a HUAWEI 100 kW inverter. All other settings, such as the optimal number of modules in series and parallel, the number of Maximum Power Point Trackers (MPPTs), and the optimal number of inverters, are automatically calculated by PVsyst.



Definizione sistema di rete, Variante VC0: "Nuova variante di simulazione"

Sottocampo

Nome e orientamento del sub-array (sottoschieramento)
Nome: Campo FV
Orient.: **Piano inclinato fisso**
Inclinazione **10°**
Azimut **65°**

Aiuto per predimensionamento
○ Nessun dimension.
Inserire potenza desiderata ● 1000.0 kWp
… o la superficie disponibile(moduli) ○ 4439 m²

Selezionare moduo FV
Disponibili adesso
Filtro: Tutti i moduli FV
Moduli necessari ca. **2273**
Longi Solar
440 Wp 28V Si-mono LR5-54HTH-440M Dal 2022 Manufacturer 2022
☐ Usare ottimizzatore
Dimens. tensioni : Vmpp (60°C) **29.0** V
Vca (-10°C) **42.8** V

Selezionare inverter
Disponibili adesso
Voltaggio di uscita 480 V Tri 50Hz
☑ 50 Hz
☑ 60 Hz
Huawei Technologies
100 kW 200 - 1000 V TL 50/60 Hz SUN2000-100KTL-M1-480Vac Dal 2021
N. di entrate MPPT: 77
☑ Voltaggio di funzionamento: **200-1000** V
Pot. usata dall'Inverter **770** kWac
☑ **Usare multi-MPPT**
Tensione massima entrata: **1100** V
inverter con 10 MPPT
No power sharing between MPPTs

Disegnare campo

Numero di moduli e di stringhe
Mod. in serie: 25 ☐ tra 7 e 25
N. di stringhe: 90 ☐ tra 77 e 119
Perdita sovracc. **0.0 %**
Rapporto Pnom **1.29**
N. di moduli **2250** **Superficie** **4394** m²

Cond. di funzionamento
Vmpp (60°C) 726 V
Vmpp (20°C) 827 V
Vca (-10°C) 1070 V
Irragg. piano **1000 W/m²**
Impp (STC) 1192 A
Isc (STC) 1287 A
Isc (a STC) 1287 A

64 input con 1 stringhe e 13 input con 2 stringhe, Si consideri di disabilitare "Usare multi-MPPT" per garantire la condivisione del potere su ciascun input.

○ Max. dati ● STC
Potenza max. in funzionamento (a 988 W/m² e 50°C) **910** kW
Potenza nom. campo (STC) **990** kWp

Lista dei sotto-campi

Nome	#Mod #Inv.	#Stringa #MPPT
Campo FV		
Longi Solar - LR5-54HTH-440M	25	90
Huawei Technologies - SUN2000…	8	77

Riepilogo sistema globale

Nr. di moduli	2250
Superficie modulo	4394 m²
N. di inverter	7.7
Potenza FV nominale	990 kWp
Potenza AC nominale	770 kWAC
Rapporto Pnom	1.286

Figure 27 - Selection of PV panels and inverter characteristics

The next step involves analyzing the detailed losses of the photovoltaic system to simulate its performance with high accuracy. Among the most critical factors to adjust are:

- Module quality section
    - Module efficiency loss = -0.8%
    - LID (Light Induced Deegradation) = 2%
    - Module mismatch losses = 2 %
    - Power Losses at MPP = 0.1 %
- Thermal parameters
    - Uc (constant loss factor) = $29\,\frac{W}{m^2K}$
    - Uv (wind loss factor) = 0
- Soling losses (reduction in energy output caused by the accumulation of dirt, dust, pollen, leaves, bird droppings, and other debris on the surface of solar panels)

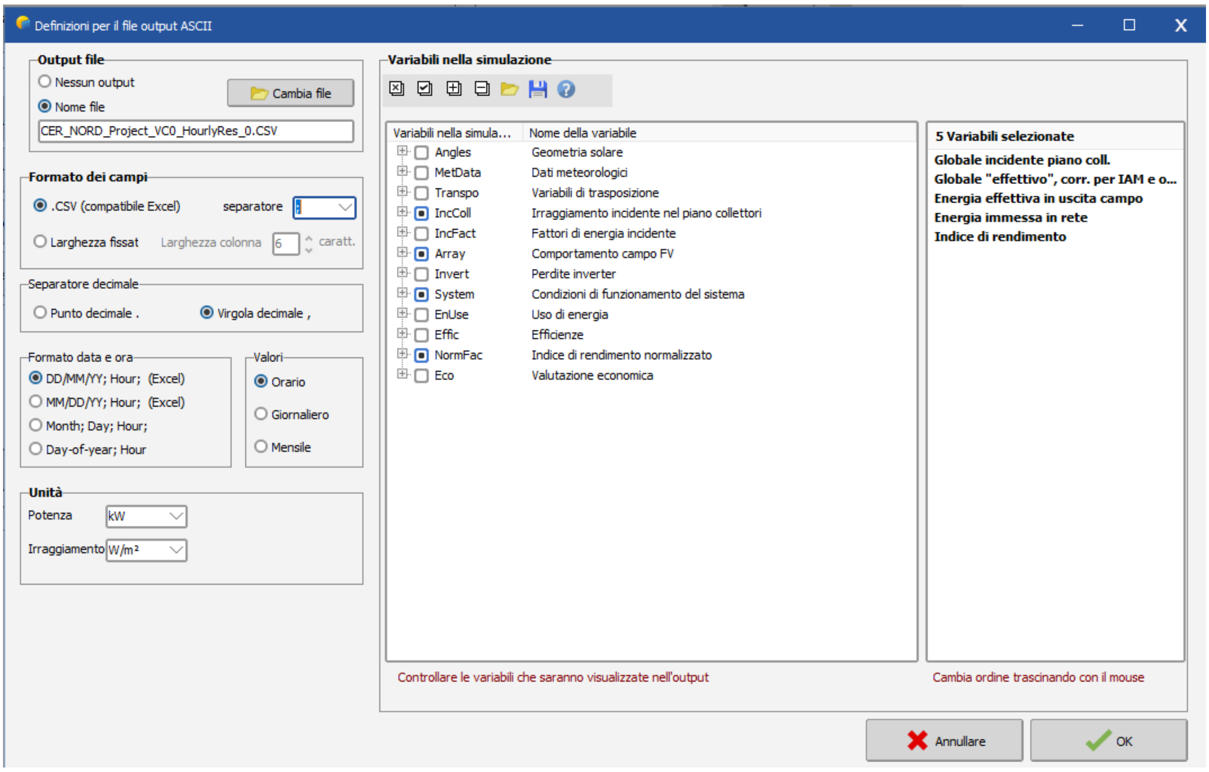
Table 4 - Soiling losses values

Location	Soiling value (%)
Regular rain regions	2
Heavy agricultural regions	4
Desert regions	5
Regions with significant bird populations	5
Desert regions with sandstorms	7

- Unavailabilty (the percentage of time that the system is not operational or unable to produce electricity) = 1%

All the values are taken from instructions by engineers on this field.

With the system configuration in place, PVsyst runs simulations to estimate energy production over a specified period, typically a year. The simulation engine in PVsyst uses sophisticated algorithms to model how the PV system will perform under various conditions, considering factors such as irradiance, temperature fluctuations, shading effects, and system losses like inverter efficiency and wiring resistance. The result is a detailed report that includes key performance indicators such as the Performance Ratio (PR), specific yield (kWh/kWp), and capacity factor, all of which are essential for evaluating the system's efficiency and viability.



Output file
○ Nessun output
● Nome file
CER_NORD_Project_VC0_HourlyRes_0.CSV

Formato dei campi
● .CSV (compatibile Excel) separatore ;
○ Larghezza fissat Larghezza colonna 6 caratt.

Separatore decimale
○ Punto decimale .
● Virgola decimale ,

Formato data e ora
● DD/MM/YY; Hour; (Excel)
○ MM/DD/YY; Hour; (Excel)
○ Month; Day; Hour;
○ Day-of-year; Hour

Valori
● Orario
○ Giornaliero
○ Mensile

Unità
Potenza kW
Irraggiamento W/m²

Variabili nella simulazione

Variabili nella simula...	Nome della variabile
☐ Angles	Geometria solare
☐ MetData	Dati meteorologici
☐ Transpo	Variabili di trasposizione
■ IncColl	Irraggiamento incidente nel piano collettori
☐ IncFact	Fattori di energia incidente
■ Array	Comportamento campo FV
☐ Invert	Perdite inverter
■ System	Condizioni di funzionamento del sistema
☐ EnUse	Uso di energia
☐ Effic	Efficienze
■ NormFac	Indice di rendimento normalizzato
☐ Eco	Valutazione economica

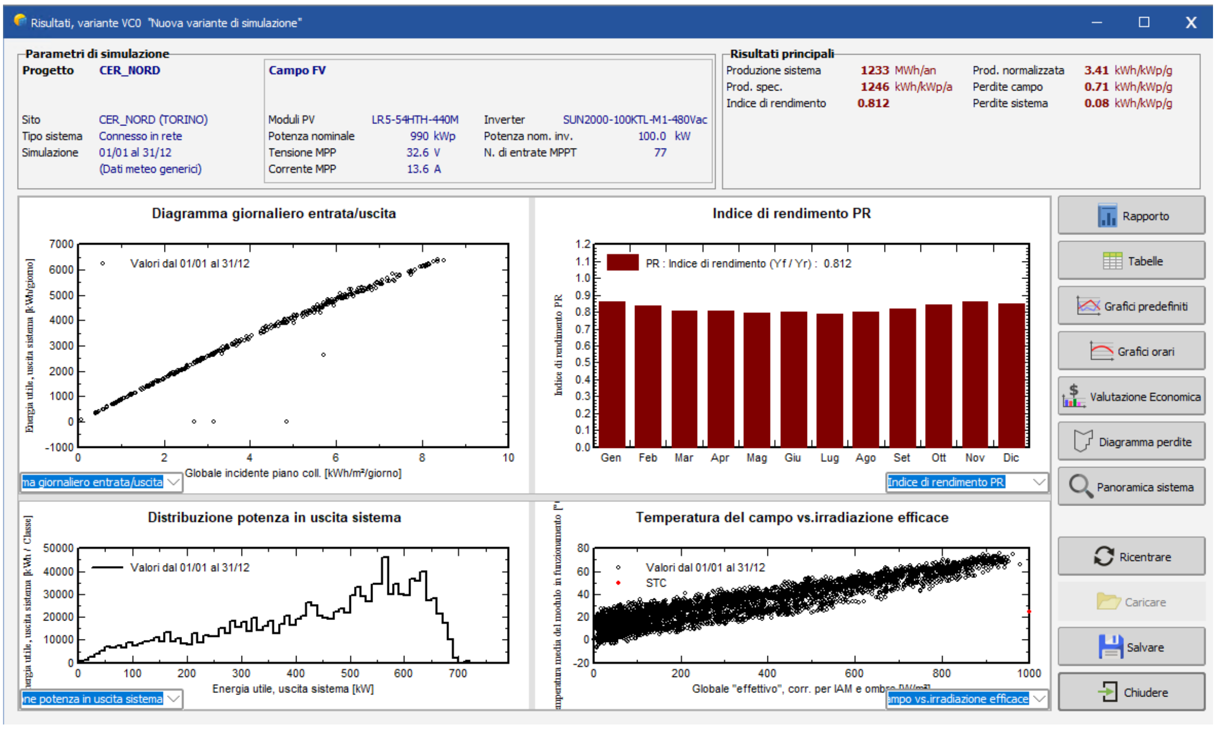
5 Variabili selezionate
Globale incidente piano coll.
Globale "effettivo", corr. per IAM e o...
Energia effettiva in uscita campo
Energia immessa in rete
Indice di rendimento

Controllare le variabili che saranno visualizzate nell'output

Cambia ordine trascinando con il mouse

Figure 28 - Selection of output parameters

Finally, PVsyst generates detailed reports and visualizations. These reports can be customized and exported in various formats, making them useful for project proposals, regulatory submissions, and client presentations.



Parametri di simulazione

Progetto CER_NORD

Sito CER_NORD (TORINO)
Tipo sistema Connesso in rete
Simulazione 01/01 al 31/12
(Dati meteo generici)

Campo FV

Moduli PV LR5-54HTH-440M
Potenza nominale 990 kWp
Tensione MPP 32.6 V
Corrente MPP 13.6 A
Inverter SUN2000-100KTL-M1-480Vac
Potenza nom. inv. 100.0 kW
N. di entrate MPPT 77

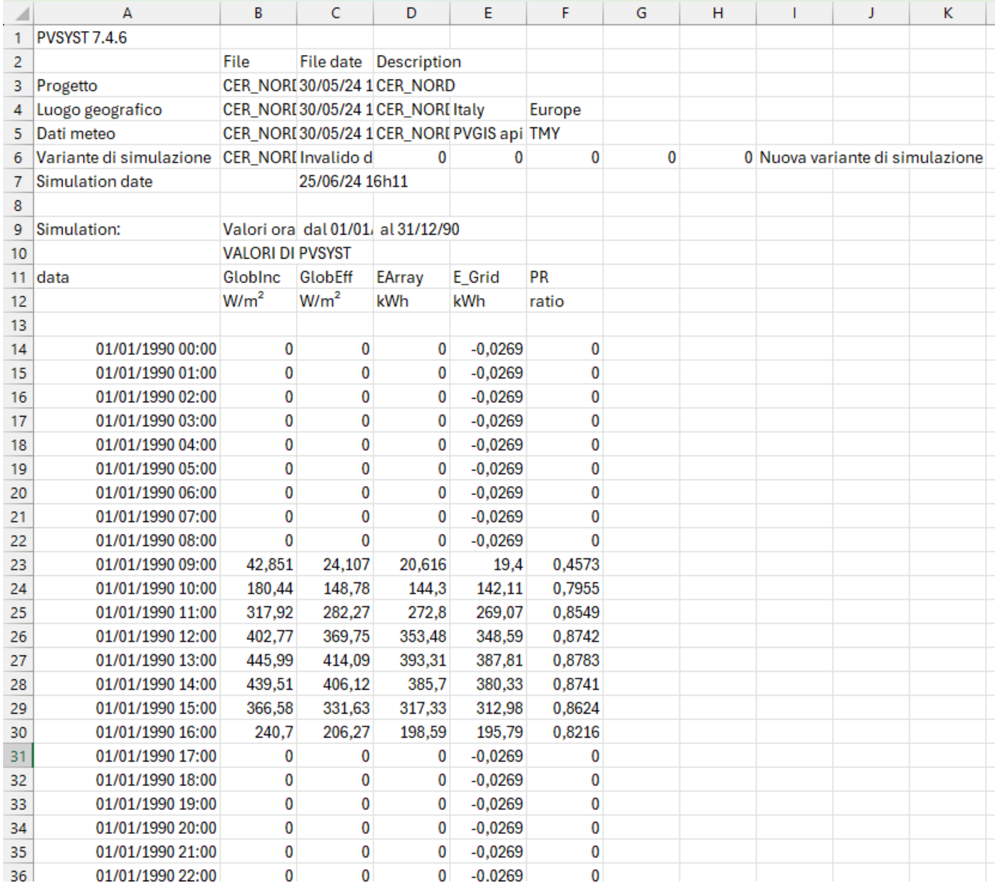
Risultati principali

Produzione sistema 1233 MWh/an
Prod. spec. 1246 kWh/kWp/a
Indice di rendimento 0.812
Prod. normalizzata 3.41 kWh/kWp/g
Perdite campo 0.71 kWh/kWp/g
Perdite sistema 0.08 kWh/kWp/g

Figure 29 - Basic results summary window

The data necessary for this analysis report, to be exported in Excel sheets, includes:

- **Global Incident Irradiance**: The amount of solar radiation received on the surface of the photovoltaic panels, measured in kilowatt-hours per square meter (kWh/m²).
- **Actual Global Irradiance**: The effective solar irradiance that reaches the photovoltaic panels after accounting for atmospheric conditions, shading, and other factors.
- **Actual Energy Output from the PV Array**: The total energy generated by the photovoltaic system, measured in kilowatt-hours (kWh), reflecting the system's real performance.
- **Energy Fed into the Grid**: The amount of energy produced by the PV system that is transferred to the electrical grid, measured in kilowatt-hours (kWh).
- **Performance Ratio (PR)**: A key performance indicator that represents the ratio of the actual energy output of the PV system to the theoretical maximum possible output, taking into account losses due to inefficiencies and other factors.



	A	B	C	D	E	F	G	H	I	J	K
1	PVSYST 7.4.6										
2		File	File date	Description							
3	Progetto	CER_NOR	30/05/24 1	CER_NORD							
4	Luogo geografico	CER_NOR	30/05/24 1	CER_NOR	Italy	Europe					
5	Dati meteo	CER_NOR	30/05/24 1	CER_NOR	PVGIS api	TMY					
6	Variante di simulazione	CER_NOR	Invalido d	0	0	0	0	0	Nuova variante di simulazione		
7	Simulation date		25/06/24 16h11								
8											
9	Simulation:	Valori ora	dal 01/01,	al 31/12/90							
10		VALORI DI	PVSYST								
11	data	GlobInc	GlobEff	EArray	E_Grid	PR					
12		W/m^2	W/m^2	kWh	kWh	ratio					
13											
14	01/01/1990 00:00	0	0	0	-0,0269	0					
15	01/01/1990 01:00	0	0	0	-0,0269	0					
16	01/01/1990 02:00	0	0	0	-0,0269	0					
17	01/01/1990 03:00	0	0	0	-0,0269	0					
18	01/01/1990 04:00	0	0	0	-0,0269	0					
19	01/01/1990 05:00	0	0	0	-0,0269	0					
20	01/01/1990 06:00	0	0	0	-0,0269	0					
21	01/01/1990 07:00	0	0	0	-0,0269	0					
22	01/01/1990 08:00	0	0	0	-0,0269	0					
23	01/01/1990 09:00	42,851	24,107	20,616	19,4	0,4573					
24	01/01/1990 10:00	180,44	148,78	144,3	142,11	0,7955					
25	01/01/1990 11:00	317,92	282,27	272,8	269,07	0,8549					
26	01/01/1990 12:00	402,77	369,75	353,48	348,59	0,8742					
27	01/01/1990 13:00	445,99	414,09	393,31	387,81	0,8783					
28	01/01/1990 14:00	439,51	406,12	385,7	380,33	0,8741					
29	01/01/1990 15:00	366,58	331,63	317,33	312,98	0,8624					
30	01/01/1990 16:00	240,7	206,27	198,59	195,79	0,8216					
31	01/01/1990 17:00	0	0	0	-0,0269	0					
32	01/01/1990 18:00	0	0	0	-0,0269	0					
33	01/01/1990 19:00	0	0	0	-0,0269	0					
34	01/01/1990 20:00	0	0	0	-0,0269	0					
35	01/01/1990 21:00	0	0	0	-0,0269	0					
36	01/01/1990 22:00	0	0	0	-0,0269	0					

Figure 30 - Excel output example

As illustrated in Figure 30, we have values for each day of the year and each hour of the day, which are precisely the data needed for input into the model. These values will form the foundation of our analysis, providing detailed temporal granularity necessary for accurate simulations.

Subsequent to data collection, the output values will require processing and extraction. This step involves aggregating, analyzing, and interpreting the raw data to derive meaningful insights and performance metrics. The processed data will be used to evaluate the system's efficiency, reliability, and overall performance.

In the following chapter, we will delve into the methodologies for data processing, including techniques for aggregating hourly and daily figures into actionable insights. By understanding and applying these data extraction techniques, we can ensure a comprehensive and accurate assessment of the photovoltaic system's performance.

3.1.2. Italian database analysis

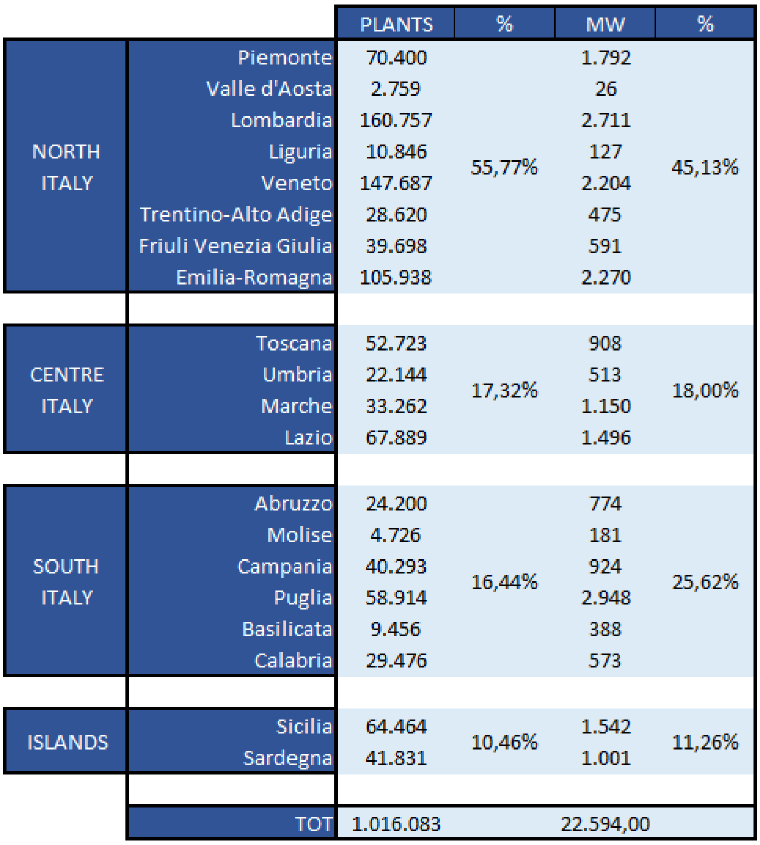
In this chapter, and in general for all three technologies I am analyzing, data from the "Rapporto Statistico GSE - FER 2021" [31] are used to provide an in-depth analysis of Italy's renewable energy landscape. This comprehensive report, published by GSE, offers valuable insights into the performance of various renewable energy sources, including solar, wind, hydroelectric, and bioenergy, during the year 2021. By leveraging this data, I aim to assess the contribution of these energy sources to Italy's overall energy production, with a focus on their role in meeting sustainability targets. The accuracy and detail provided by the GSE report make it an indispensable resource for understanding the current state and potential of renewable energy in Italy.

The initial data extracted from the database for photovoltaic energy in Italy pertain to the number of installations and the installed capacity for each region, as shown in figure …

These data are of crucial importance for all three technologies under consideration, as they provide insights into the presence and distribution of various types of installations across the territory. This understanding underscores three key factors:

1. The existence of high-quality energy resources in specific regions;
2. The suitability of local environments and terrain for particular energy technologies;
3. The strategic significance of these investments, possibly driven by substantial regional incentives or targeted funding programs.

Figure 31 presents a detailed analysis of photovoltaic energy distribution across various regions of Italy, emphasizing significant regional disparities. In Northern Italy, regions such as Lombardy and Veneto demonstrate a high concentration of PV plants and installed capacity, primarily driven by advanced economic development and substantial government incentives. Although solar conditions are less optimal, the region’s industrial capacity and available land have enabled extensive installations.



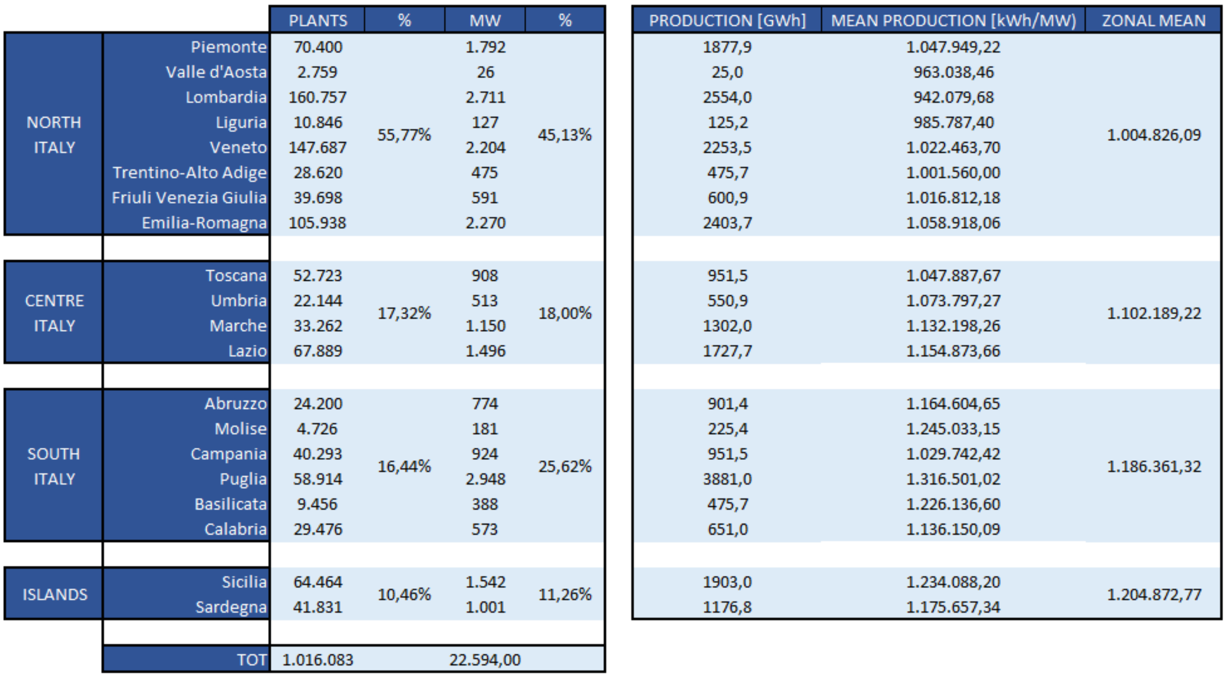
		PLANTS	%	MW	%
NORTH ITALY	Piemonte	70.400	55,77%	1.792	45,13%
	Valle d'Aosta	2.759		26	
	Lombardia	160.757		2.711	
	Liguria	10.846		127	
	Veneto	147.687		2.204	
	Trentino-Alto Adige	28.620		475	
	Friuli Venezia Giulia	39.698		591	
	Emilia-Romagna	105.938		2.270	
CENTRE ITALY	Toscana	52.723	17,32%	908	18,00%
	Umbria	22.144		513	
	Marche	33.262		1.150	
	Lazio	67.889		1.496	
SOUTH ITALY	Abruzzo	24.200	16,44%	774	25,62%
	Molise	4.726		181	
	Campania	40.293		924	
	Puglia	58.914		2.948	
	Basilicata	9.456		388	
	Calabria	29.476		573	
ISLANDS	Sicilia	64.464	10,46%	1.542	11,26%
	Sardegna	41.831		1.001	
	TOT	1.016.083		22.594,00	

Figure 31 - Excel representation of Terna data analysis

Conversely, Southern Italy and the Islands, despite having fewer installations, exhibit higher installed capacity attributed to superior solar irradiance. Regions like Puglia and Sicily capitalize on abundant sunlight, making them prime locations for high-capacity photovoltaic systems. The figures for Central Italy suggest a balanced scenario, where economic factors and geographical conditions both contribute to PV deployment.

These observed differences are underpinned by a complex interplay of solar irradiance levels, economic policies, and geographical constraints, all of which are crucial in shaping the photovoltaic energy landscape across Italy. This analysis underscores the importance of region-specific strategies in optimizing PV energy deployment across the nation.

Additionally, the total energy production of the installations across various regions was extracted and used to calculate the average kWh production per region for a 1 MW photovoltaic plant installation.



		PLANTS	%	MW	%	PRODUCTION [GWh]	MEAN PRODUCTION [kWh/MW]	ZONAL MEAN
NORTH ITALY	Piemonte	70.400	55,77%	1.792	45,13%	1877,9	1.047.949,22	1.004.826,09
	Valle d'Aosta	2.759		26		25,0	963.038,46	
	Lombardia	160.757		2.711		2554,0	942.079,68	
	Liguria	10.846		127		125,2	985.787,40	
	Veneto	147.687		2.204		2253,5	1.022.463,70	
	Trentino-Alto Adige	28.620		475		475,7	1.001.560,00	
	Friuli Venezia Giulia	39.698		591		600,9	1.016.812,18	
	Emilia-Romagna	105.938		2.270		2403,7	1.058.918,06	
CENTRE ITALY	Toscana	52.723	17,32%	908	18,00%	951,5	1.047.887,67	1.102.189,22
	Umbria	22.144		513		550,9	1.073.797,27	
	Marche	33.262		1.150		1302,0	1.132.198,26	
	Lazio	67.889		1.496		1727,7	1.154.873,66	
SOUTH ITALY	Abruzzo	24.200	16,44%	774	25,62%	901,4	1.164.604,65	1.186.361,32
	Molise	4.726		181		225,4	1.245.033,15	
	Campania	40.293		924		951,5	1.029.742,42	
	Puglia	58.914		2.948		3881,0	1.316.501,02	
	Basilicata	9.456		388		475,7	1.226.136,60	
	Calabria	29.476		573		651,0	1.136.150,09	
ISLANDS	Sicilia	64.464	10,46%	1.542	11,26%	1903,0	1.234.088,20	1.204.872,77
	Sardegna	41.831		1.001		1176,8	1.175.657,34	
	TOT	1.016.083		22.594,00				

Figure 32 - Yearly production analysis by Terna data

As illustrated in Figure 33, energy production is predominantly concentrated in Northern Italy, with significant outputs from regions like Lombardia, Veneto, and Emilia-Romagna. An important analytical aspect is the calculation of regional average production by dividing the total energy output by the installed capacity (MW). The resulting average is lower in Northern regions, as expected, due to their reduced solar irradiance caused by their greater distance from the equator. This correlation highlights the geographic influence on photovoltaic efficiency and energy yield.

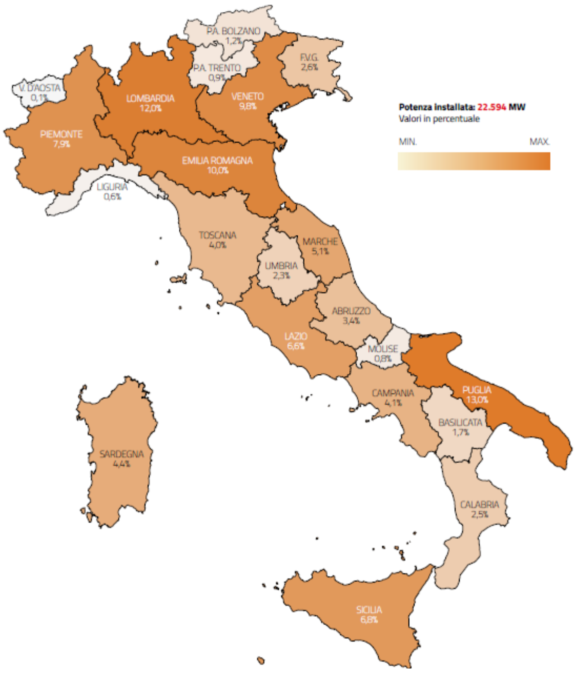
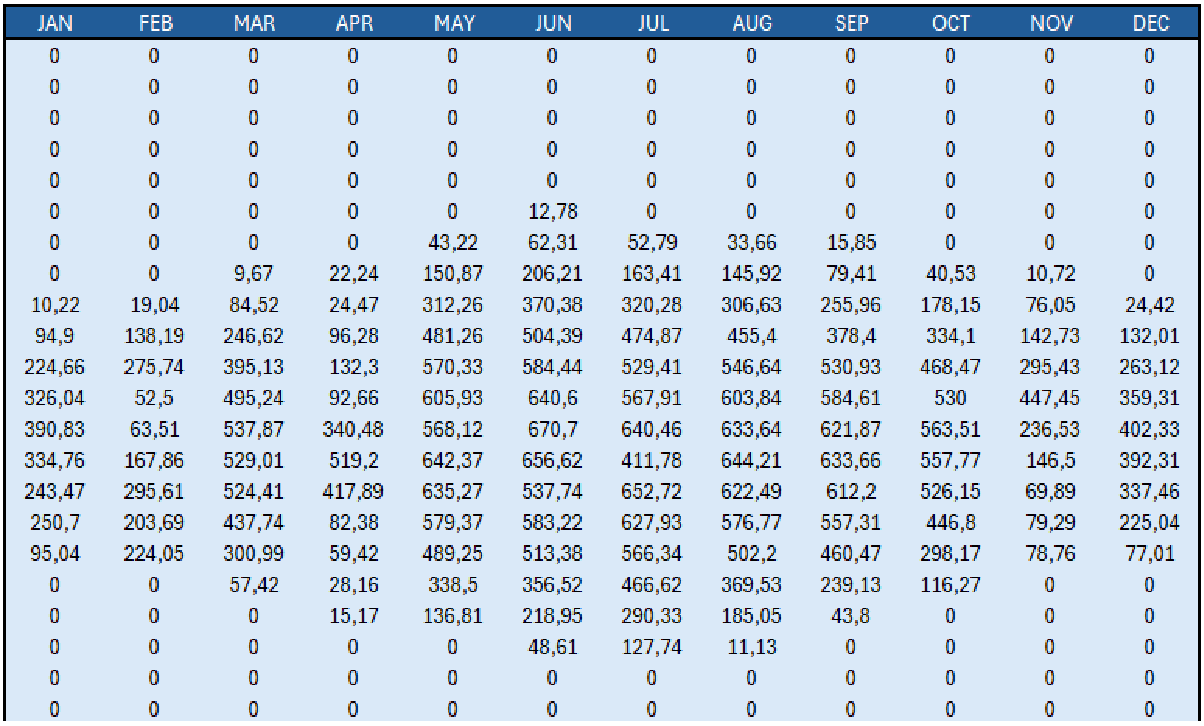


Figure 33 - Photovoltaic power percentage distribution in Italy

3.1.3. Photovoltaic simulation and data analysis

This chapter presents the results of the data analysis on photovoltaic energy, obtained by following the comprehensive procedure outlined in the previous chapter. Utilizing PVsyst and adhering to the parameters and methodologies specified earlier, I conducted simulations to generate the data for this analysis. This section provides a detailed display of the outcomes derived from these simulations, showcasing the performance and efficiency metrics of the photovoltaic systems studied.

In figure 34 an example of extracted and organized data is shown.



JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	12,78	0	0	0	0	0	0
0	0	0	0	43,22	62,31	52,79	33,66	15,85	0	0	0
0	0	9,67	22,24	150,87	206,21	163,41	145,92	79,41	40,53	10,72	0
10,22	19,04	84,52	24,47	312,26	370,38	320,28	306,63	255,96	178,15	76,05	24,42
94,9	138,19	246,62	96,28	481,26	504,39	474,87	455,4	378,4	334,1	142,73	132,01
224,66	275,74	395,13	132,3	570,33	584,44	529,41	546,64	530,93	468,47	295,43	263,12
326,04	52,5	495,24	92,66	605,93	640,6	567,91	603,84	584,61	530	447,45	359,31
390,83	63,51	537,87	340,48	568,12	670,7	640,46	633,64	621,87	563,51	236,53	402,33
334,76	167,86	529,01	519,2	642,37	656,62	411,78	644,21	633,66	557,77	146,5	392,31
243,47	295,61	524,41	417,89	635,27	537,74	652,72	622,49	612,2	526,15	69,89	337,46
250,7	203,69	437,74	82,38	579,37	583,22	627,93	576,77	557,31	446,8	79,29	225,04
95,04	224,05	300,99	59,42	489,25	513,38	566,34	502,2	460,47	298,17	78,76	77,01
0	0	57,42	28,16	338,5	356,52	466,62	369,53	239,13	116,27	0	0
0	0	0	15,17	136,81	218,95	290,33	185,05	43,8	0	0	0
0	0	0	0	0	48,61	127,74	11,13	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0

Figure 34 - Organized PV production data

The data will be subsequently integrated into the REC analysis model. The following are representative graphs illustrating the production trends across various zones, comparing the four zones during a typical day in both a winter and a summer month.

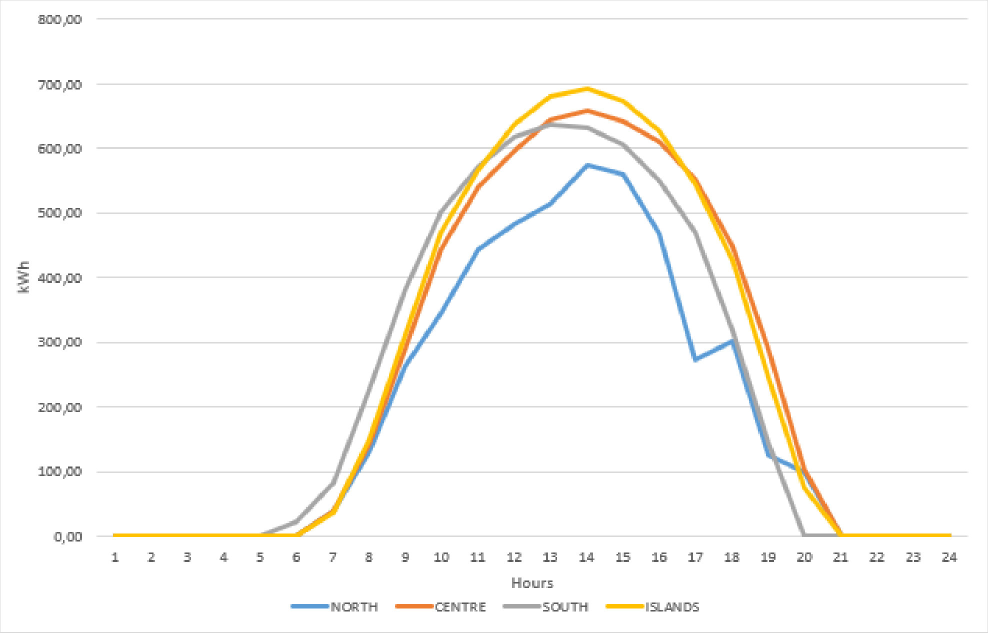


Figure 35 - Daily production of PV plant in a summer day

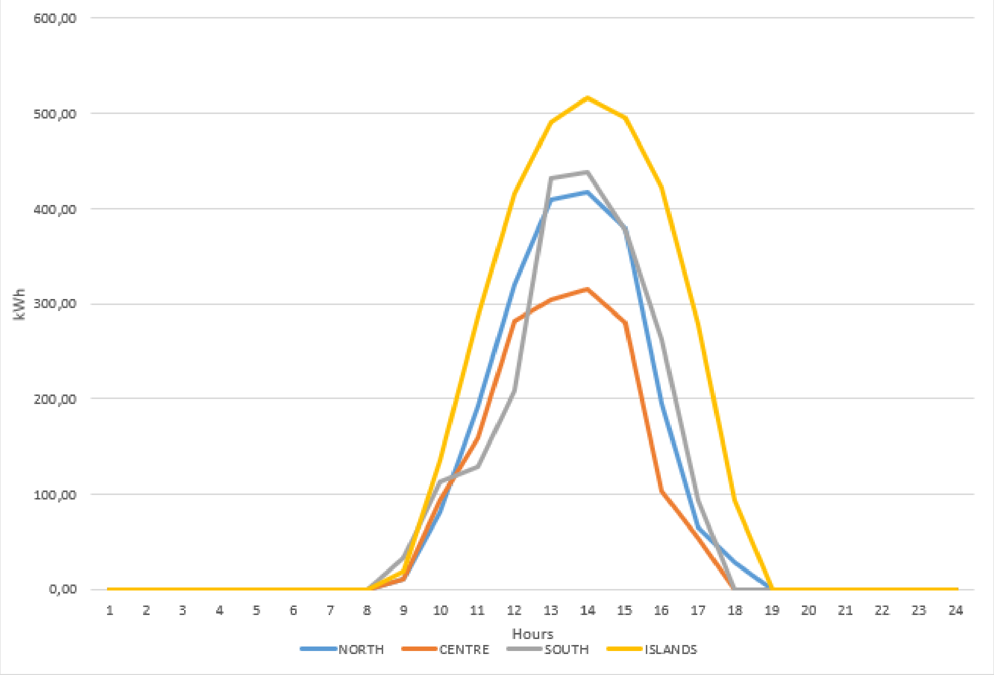


Figure 36 - Daily production of PV plant in a winter day

As illustrated in Figures 35 and 36, during the summer season, the islands and the southern region are prominent in terms of energy production. Specifically, the islands lead in maximum production, reaching up to 700 kWh in an hour, while the southern region stands out for the breadth of the production window observed.

In the winter months, the production trends exhibit a similar pattern but with a reduced production curve. This reduction aligns with the lower solar irradiation hours available during this period. The decreased production levels in winter are expected due to the shorter daylight hours and less intense solar radiation, which naturally limits the energy output compared to the summer season.

The data underscores the significant seasonal variability in photovoltaic energy production, highlighting how geographical factors and seasonal changes influence overall performance. This analysis provides critical insights into optimizing energy production strategies across different times of the year.

3.2. Wind Energy

Wind energy has emerged as a vital component in the quest for sustainable and clean energy solutions. As concerns over climate change intensify and the need for reducing carbon emissions becomes more pressing, wind power offers a promising alternative to traditional fossil fuels. This chapter explores the intricacies of wind energy technology, its benefits, and the challenges it faces, providing a comprehensive understanding of its role in the contemporary energy landscape.

Wind energy harnesses the power of the wind to generate electricity through a series of sophisticated processes and components. At the heart of this technology is the wind turbine, which converts the kinetic energy of wind into mechanical energy.

$$E = \frac{1}{2} \times \rho \times A \times v^3 \times \eta \times t \quad (2)$$

Where:

E = Energy produced [kWh]

ρ = Air density [kg/m³]

A = Rotor swept area [m²]

v = Wind speed [m/s]

η = Efficiency of the wind turbine (dimensionless, typically as a fraction)

t = Time period [h]

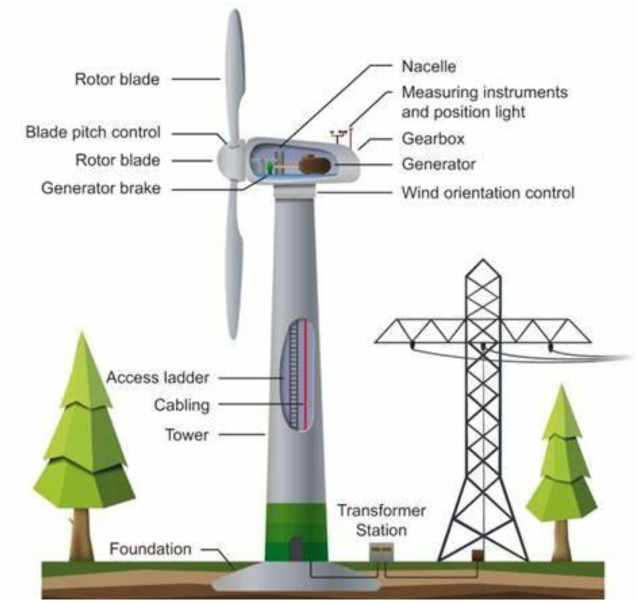


Figure 37 - Main components of a wind turbine [32]

As shown in figure 37, wind turbines typically consist of large blades mounted on a rotor. As wind flows over these blades, it generates lift and drag forces that cause the rotor to spin. This rotational motion is transferred to a gearbox located within the nacelle, which is the housing at the top of the turbine tower. The gearbox increases the rotational speed of the shaft connected to the generator. The generator then converts this mechanical energy into electrical energy. The electricity produced is transmitted via cables to a substation, where it is stepped up in voltage for distribution across the power grid.

Wind energy offers several significant advantages that make it an attractive option for sustainable power generation. One of its most notable benefits is its minimal environmental impact. Unlike fossil fuel-based power generation, wind turbines produce electricity without emitting greenhouse gases, thereby contributing to a reduction in the overall carbon footprint. Additionally, wind is a renewable resource, meaning it is abundant and can be harnessed continuously without depleting natural resources. Economically, wind energy has become increasingly cost-effective. Technological advancements and economies of scale have dramatically reduced the cost of wind power, making it one of the most competitive sources of new electricity generation. This reduction in cost is complemented by the job creation opportunities within the wind energy sector, which spans manufacturing, installation, maintenance, and operation, thereby stimulating local economies and promoting economic growth. Wind energy also enhances energy security by diversifying the energy mix and reducing reliance on imported fossil fuels. The ability to generate power locally, particularly in rural or remote areas, minimizes transmission losses and contributes to a more resilient and self-sufficient energy system. Moreover, wind energy is scalable and versatile. It can be deployed across various scales, from small residential turbines to large offshore wind farms, allowing for adaptation to different energy needs and geographic conditions.

Despite its many advantages, wind energy faces several challenges that must be addressed to maximize its potential. One of the primary issues is the intermittency and variability of wind resources. Wind speeds fluctuate throughout the day and across seasons, leading to variability in energy production. This intermittency requires effective integration with the power grid and the development of energy storage solutions to ensure a stable and reliable power supply. Another challenge is the impact of wind turbines on wildlife. Birds and bats can collide with turbine blades, leading to mortality. Efforts to mitigate these impacts include careful site selection, technological improvements in turbine design, and ongoing research to understand and minimize these effects. The visual and noise impacts of wind turbines can also be a concern. Some communities may find the presence of turbines visually intrusive, and operational noise can be bothersome to nearby residents. Addressing these concerns involves thoughtful siting, community engagement, and advancements in turbine design to reduce noise levels. Additionally, the land use requirements for wind farms can be significant. Large-scale wind installations require considerable land area, which can affect agricultural or other land uses. However, it is often possible to use the land between turbines for agricultural or grazing activities, thereby mitigating land use conflicts. Finally, the infrastructure and maintenance requirements for wind farms, particularly those located offshore or in remote areas, can pose logistical and cost challenges. Developing and maintaining such infrastructure requires careful planning and investment. [33]

3.2.1. Online softwares for wind simulation

Wind resource assessment tools play a critical role in the planning, development, and optimization of wind energy projects. These tools provide essential data that helps developers, policymakers, and engineers understand the wind potential of specific locations, ensuring that wind farms are both technically and economically viable.

Wind resource assessment tools, like the Global Wind Atlas and Atlante Eolico Italiano, are designed to offer detailed insights into wind patterns and energy potential across different regions. By leveraging advanced meteorological data and computational models, these platforms provide high-resolution maps and data that allow users to evaluate the wind energy potential with great precision. This data is crucial for various stages of wind project development, from initial site selection to detailed energy yield assessments.

The Global Wind Atlas (GWA) is an advanced online platform that offers detailed wind resource data for regions around the world. Developed by the Technical University of Denmark (DTU) in collaboration with the World Bank, this tool is designed to aid in the assessment and development of wind energy projects by providing high-resolution wind data.

The GWA stands out for its ability to deliver comprehensive wind resource information at a high spatial resolution, typically down to 250 meters. This allows users to conduct precise evaluations of wind potential at specific locations, enhancing the accuracy of energy yield predictions. The platform covers nearly all global regions, making it a crucial resource for wind energy planning on an international scale.

Its interactive maps and data visualization tools enable users to explore various wind parameters, including wind speeds and directions, across different heights. This capability is instrumental for assessing wind energy potential at typical turbine hub heights. The atlas also offers historical and predictive wind data, providing insights into both past wind patterns and future trends. Accessibility is another key feature, as the Global Wind Atlas is available online, allowing users from around the world to easily access and utilize its resources. [34]

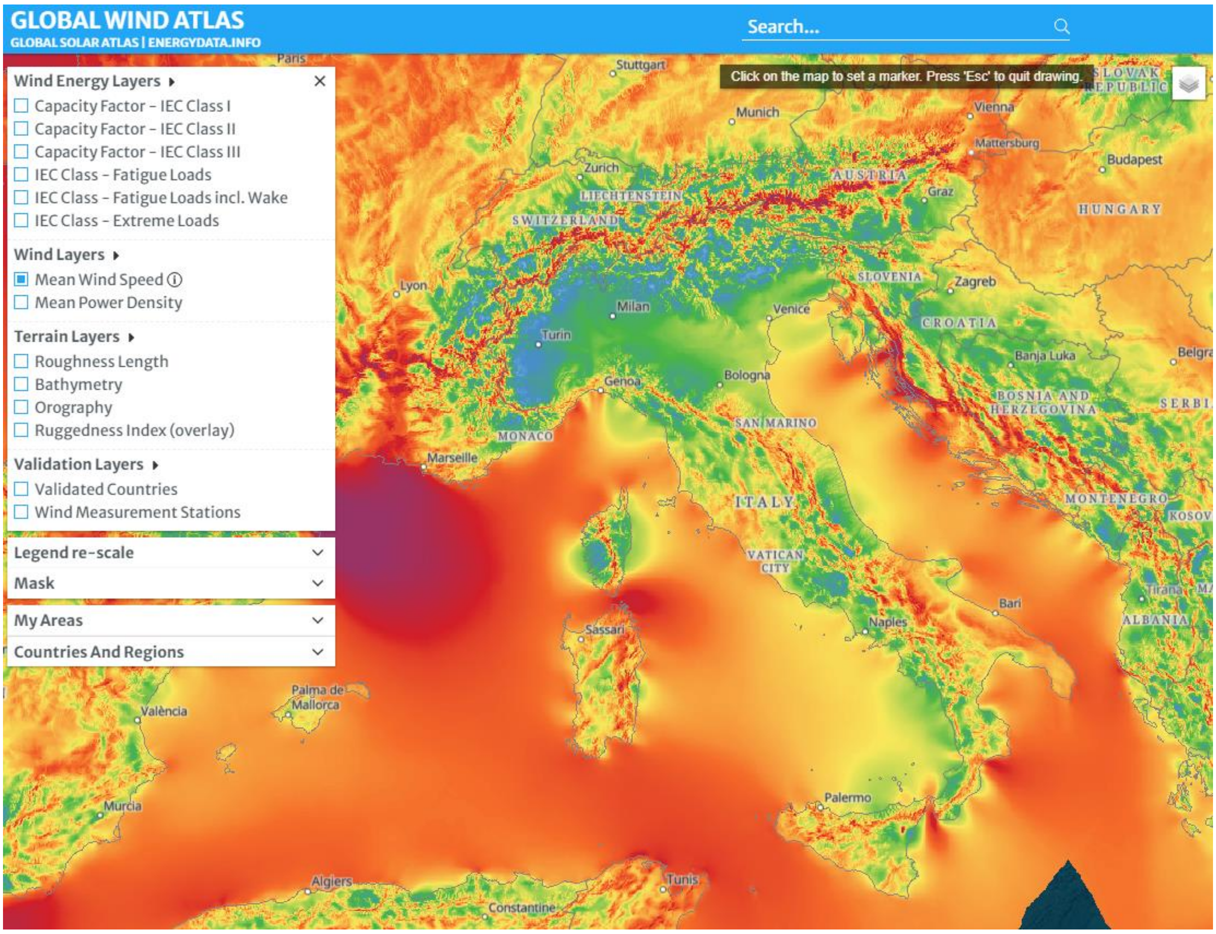


Figure 38 - Basic window of GWA [34]

The Atlante Eolico Italiano (AEI), or Italian Wind Atlas, is a specialized tool that provides detailed wind resource data specifically for Italy. Developed by the Italian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA), this atlas offers localized wind information essential for evaluating wind energy potential across the Italian territory.

The AEI delivers high-resolution wind data similar to the GWA, but with a focus on the unique climatic and geographic conditions of Italy. It allows users to access interactive wind maps and tools tailored to Italian regions, facilitating detailed assessments of wind resources at specific sites. This localized approach ensures that the data is highly relevant for stakeholders involved in wind energy projects within Italy.

Integration with local meteorological data enhances the accuracy of the wind resource information provided. The atlas supports wind energy planning by offering precise data and analysis tools that are crucial for decision-making. Its online availability ensures that users throughout Italy can easily access and navigate the platform, making it a valuable resource for policymakers, developers, and researchers engaged in the development of wind energy projects. [35]

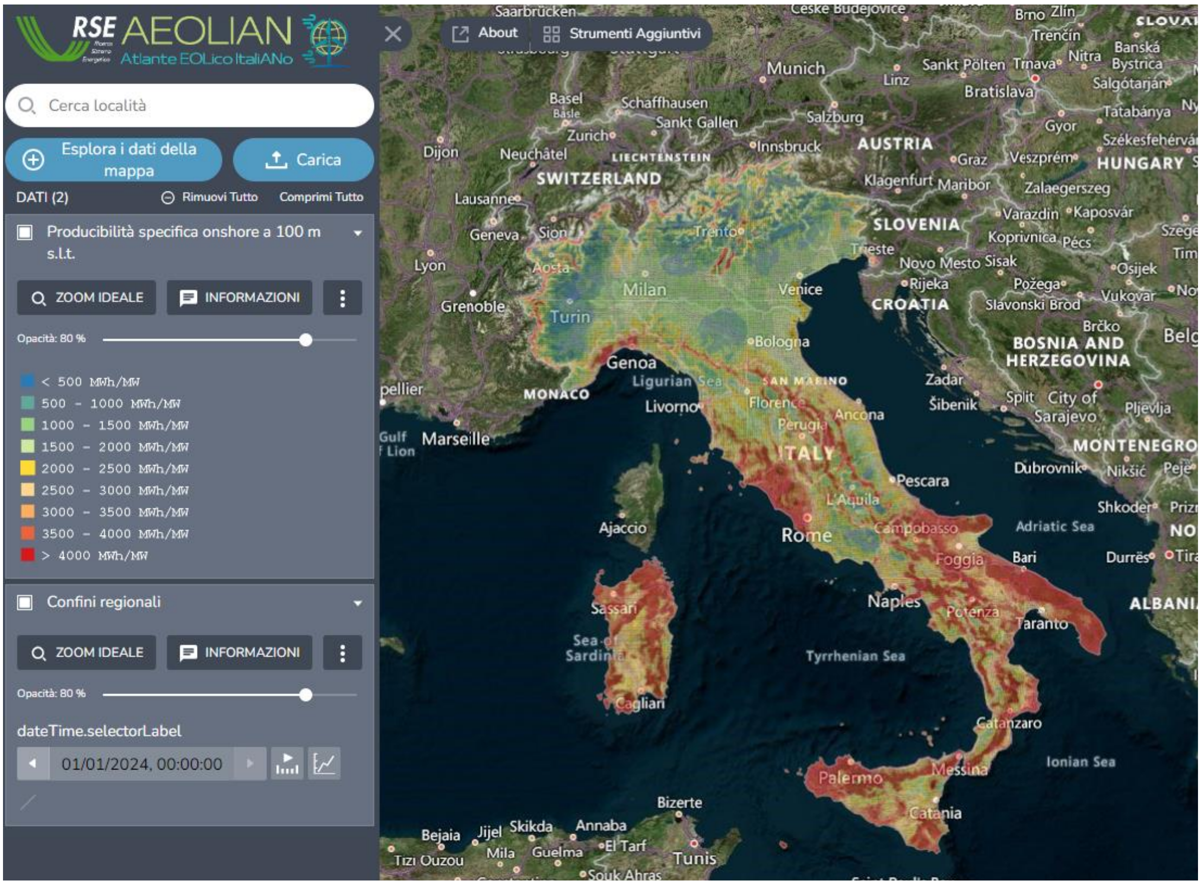


Figure 39 - Basic window of AEI online [35]

The data extracted from these simulators for this analysis primarily focused on the annual energy production of a 1 MW wind turbine in four different regions of Italy, along with the corresponding wind distributions.

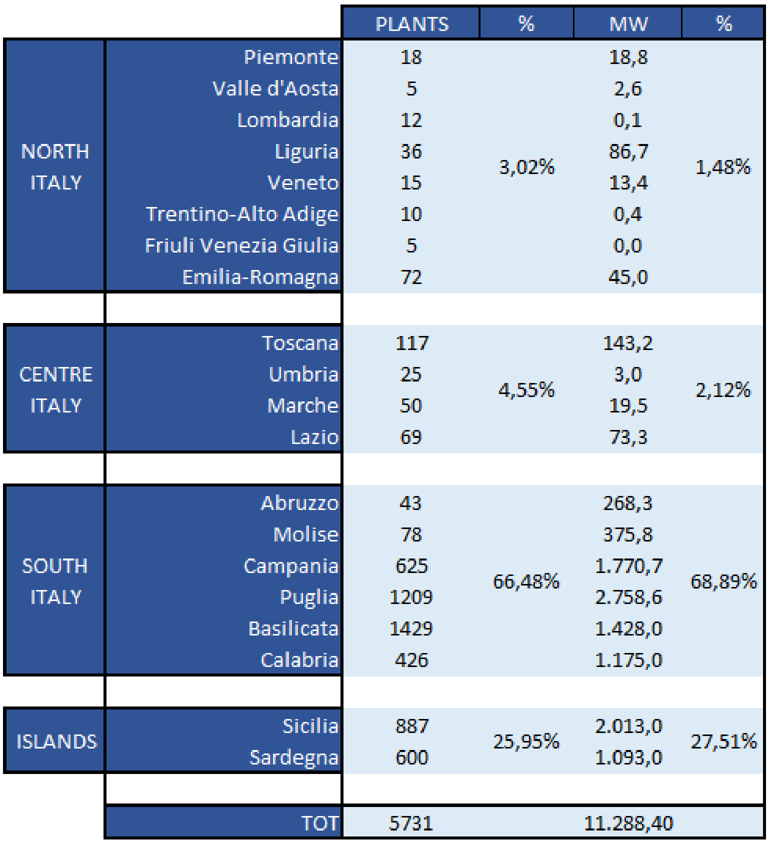
By simulating the performance of a 1 MW wind turbine in these distinct regions, I was able to evaluate the differences in energy output, which are largely influenced by local wind patterns and topographical features. Each region's wind distribution was carefully analyzed to assess its suitability for wind energy generation. The simulations provided valuable insights into how these variables affect the turbine's performance over a year, allowing for a detailed comparison of potential energy yields across the selected sites.

This analysis not only highlights the regional disparities in wind energy potential within Italy but also underscores the importance of site-specific assessments when planning and developing wind energy projects.

3.2.2. Italian database analysis

As for photovoltaic energy, in this section, I will conduct an in-depth analysis using data from TERNA to thoroughly examine the influence of wind energy in Italy. The objective is to assess the current landscape of wind energy production, with a particular emphasis on distinguishing the production capacities across different Italian regions. By utilizing TERNA's data [31], I aim to provide a detailed understanding of wind energy's contribution to the national energy mix, highlighting regional variations in both potential and actual production. This approach will offer a refined perspective on the geographical distribution and efficiency of wind energy utilization in Italy.

The initial data extracted from the database pertain to the number of installations and the installed capacity for each region, as shown in figure 40.



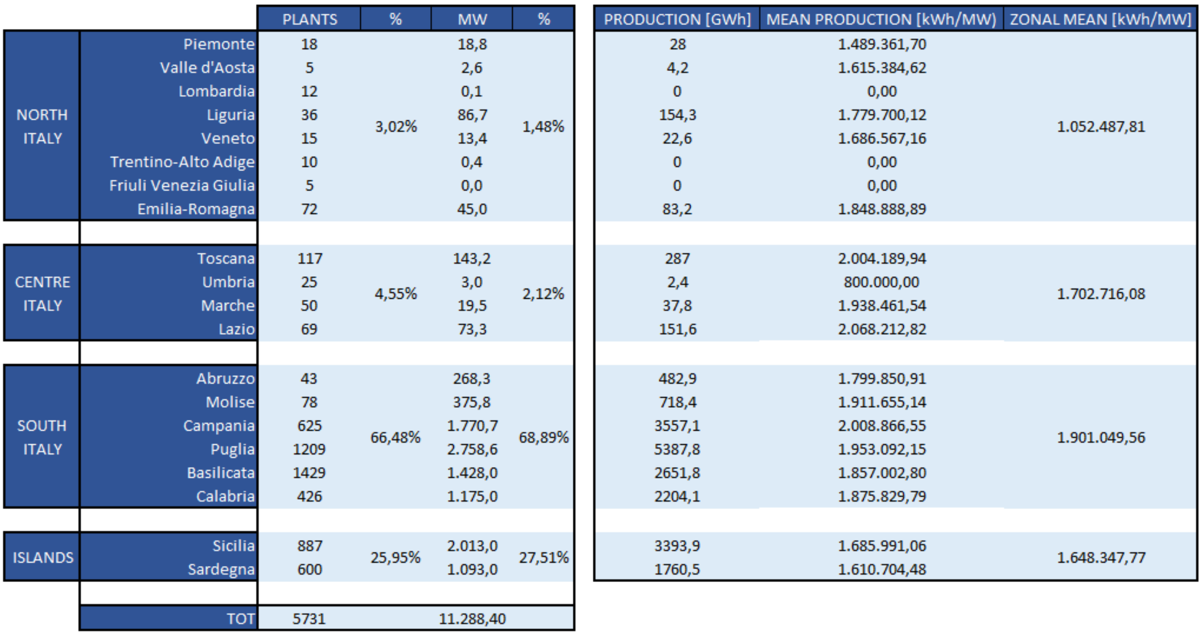
		PLANTS	%	MW	%
NORTH ITALY	Piemonte	18	3,02%	18,8	1,48%
	Valle d'Aosta	5		2,6	
	Lombardia	12		0,1	
	Liguria	36		86,7	
	Veneto	15		13,4	
	Trentino-Alto Adige	10		0,4	
	Friuli Venezia Giulia	5		0,0	
	Emilia-Romagna	72		45,0	
CENTRE ITALY	Toscana	117	4,55%	143,2	2,12%
	Umbria	25		3,0	
	Marche	50		19,5	
	Lazio	69		73,3	
SOUTH ITALY	Abruzzo	43	66,48%	268,3	68,89%
	Molise	78		375,8	
	Campania	625		1.770,7	
	Puglia	1209		2.758,6	
	Basilicata	1429		1.428,0	
	Calabria	426		1.175,0	
ISLANDS	Sicilia	887	25,95%	2.013,0	27,51%
	Sardegna	600		1.093,0	
	TOT	5731		11.288,40	

Figure 40 - Excel representation of Terna data

Figure 40 presents an analysis of wind energy distribution across Italy, revealing notable regional disparities in both the number of wind plants and installed capacity. In Southern Italy and the Islands, regions such as Puglia, Basilicata, and Sicily dominate with a significant share of both installations and capacity. These areas benefit from favorable wind conditions and supportive policies, making them ideal for large-scale wind farms. Central Italy shows moderate development, with Lazio and Tuscany having a notable presence. In contrast, Northern Italy, with regions like Liguria and Emilia-Romagna, has a relatively modest contribution to the nation's wind energy capacity, likely due to less favorable wind resources and geographical constraints.

These regional differences can be attributed to a combination of environmental factors, such as wind speed and consistency, as well as the availability of suitable land and regional policy incentives. The concentration of wind energy infrastructure in the South and Islands highlights the strategic importance of these areas in Italy's overall renewable energy strategy, leveraging their natural advantages to maximize wind energy production.

Additionally, the total energy production of the installations across various regions was extracted and used to calculate the average kWh production per region for a 1 MW installation.



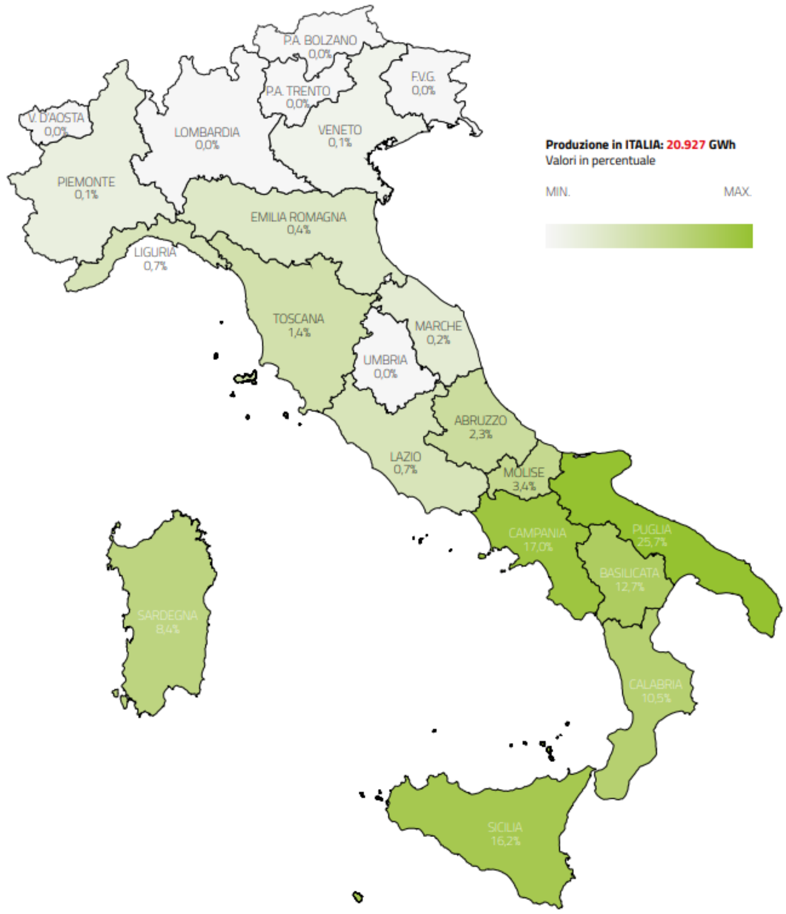
		PLANTS	%	MW	%	PRODUCTION [GWh]	MEAN PRODUCTION [kWh/MW)	ZONAL MEAN [kWh/MW]
NORTH ITALY	Piemonte	18	3,02%	18,8	1,48%	28	1.489.361,70	1.052.487,81
	Valle d'Aosta	5		2,6		4,2	1.615.384,62	
	Lombardia	12		0,1		0	0,00	
	Liguria	36		86,7		154,3	1.779.700,12	
	Veneto	15		13,4		22,6	1.686.567,16	
	Trentino-Alto Adige	10		0,4		0	0,00	
	Friuli Venezia Giulia	5		0,0		0	0,00	
	Emilia-Romagna	72		45,0		83,2	1.848.888,89	
CENTRE ITALY	Toscana	117	4,55%	143,2	2,12%	287	2.004.189,94	1.702.716,08
	Umbria	25		3,0		2,4	800.000,00	
	Marche	50		19,5		37,8	1.938.461,54	
	Lazio	69		73,3		151,6	2.068.212,82	
SOUTH ITALY	Abruzzo	43	66,48%	268,3	68,89%	482,9	1.799.850,91	1.901.049,56
	Molise	78		375,8		718,4	1.911.655,14	
	Campania	625		1.770,7		3557,1	2.008.866,55	
	Puglia	1209		2.758,6		5387,8	1.953.092,15	
	Basilicata	1429		1.428,0		2651,8	1.857.002,80	
	Calabria	426		1.175,0		2204,1	1.875.829,79	
ISLANDS	Sicilia	887	25,95%	2.013,0	27,51%	3393,9	1.685.991,06	1.648.347,77
	Sardegna	600		1.093,0		1760,5	1.610.704,48	
	TOT	5731		11.288,40				

Figure 41 - Analysed data for wind production in Italy

The analysis of national data reveals that the highest concentration of facilities, and consequently the greatest production, is located in southern Italy and the islands. An intriguing finding is the average productivity across different regions, which shows minimal variation. This contrasts with what will be observed from simulator data, where productivity differences between northern and southern Italy are more pronounced.

This discrepancy arises because the limited number of facilities in northern Italy are strategically placed in optimal locations, leading to high production values that are comparable to those in southern Italy. However, southern Italy benefits from a greater number of facilities, resulting in more frequent high production values.

Therefore, for the purpose of this analysis, simulator data, which represents more "representative" zones across entire regions, is considered more reliable. This approach ensures a more accurate reflection of regional productivity potential and addresses the variability in facility distribution.

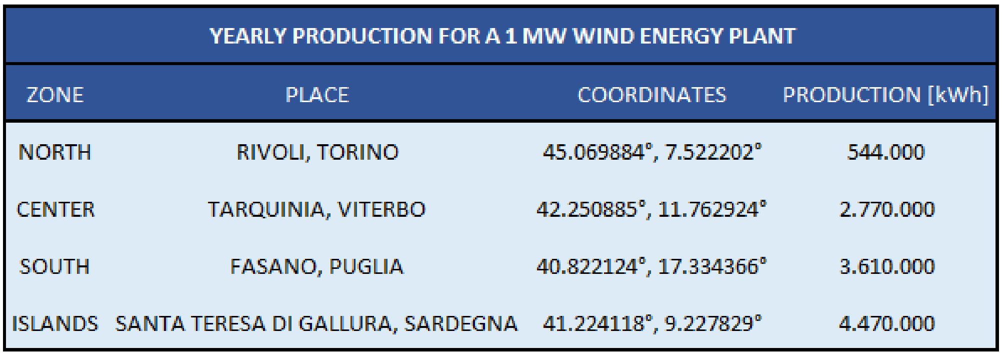


Fonte: elaborazioni GSE su dati Terna

Figure 42 - Regional distribution of wind energy production [31]

3.2.3. Simulated data analysis

After a thorough analysis of the national average data, we proceed with defining the hourly productivity for a 1 MW wind turbine. Annual productivity data are extrapolated from online atlases, which indicate a significant difference in productivity between northern and southern regions, as expected.



YEARLY PRODUCTION FOR A 1 MW WIND ENERGY PLANT			
ZONE	PLACE	COORDINATES	PRODUCTION [kWh]
NORTH	RIVOLI, TORINO	45.069884°, 7.522202°	544.000
CENTER	TARQUINIA, VITERBO	42.250885°, 11.762924°	2.770.000
SOUTH	FASANO, PUGLIA	40.822124°, 17.334366°	3.610.000
ISLANDS	SANTA TERESA DI GALLURA, SARDEGNA	41.224118°, 9.227829°	4.470.000

Figure 43 - Summary producibility wind energy

This difference is further highlighted by Figures 44, 45, 46, and 47, which use varying shades of color—blue and green in northern regions, progressively transitioning to red towards the south and the islands.

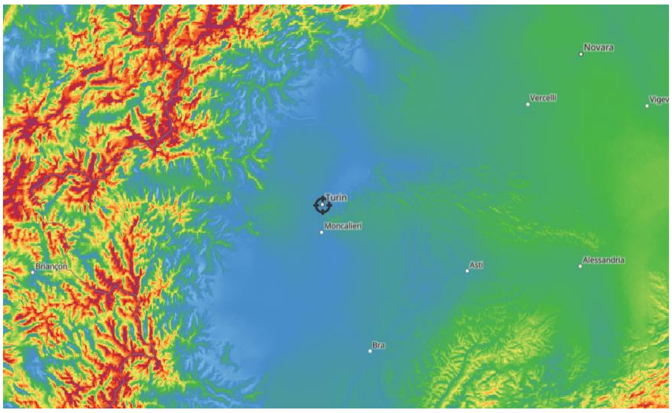


Figure 47 - Rivoli zoom GWA [34]

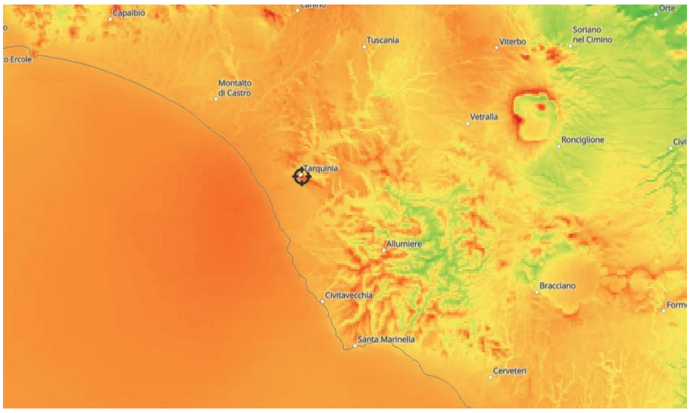


Figure 46 - Tarquinia zoom GWA [34]

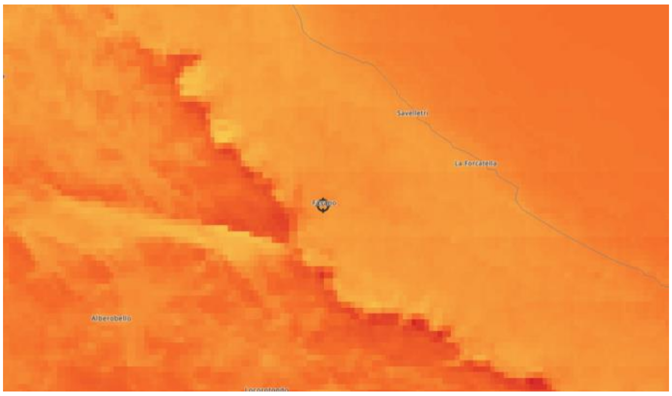


Figure 45 - Fasano zoom GWA [34]

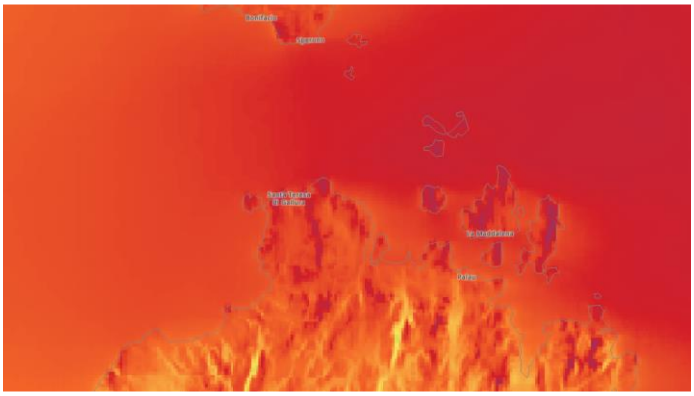
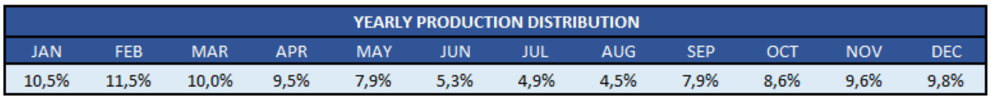


Figure 44 - Santa Teresa zoom GWA [34]

From the annual productivity data, the analysis needs to be extended to a monthly and daily level. Distribution data have been extracted from the European Union database [36], as shown in figure 48 and 49, wind energy production has peaks in winter months, as well as peaks during night hours. This aspect is of crucial importance due to the complementary nature of wind energy with solar energy.



YEARLY PRODUCTION DISTRIBUTION											
JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
10,5%	11,5%	10,0%	9,5%	7,9%	5,3%	4,9%	4,5%	7,9%	8,6%	9,6%	9,8%

Figure 48 - Production distribution in months from Excel

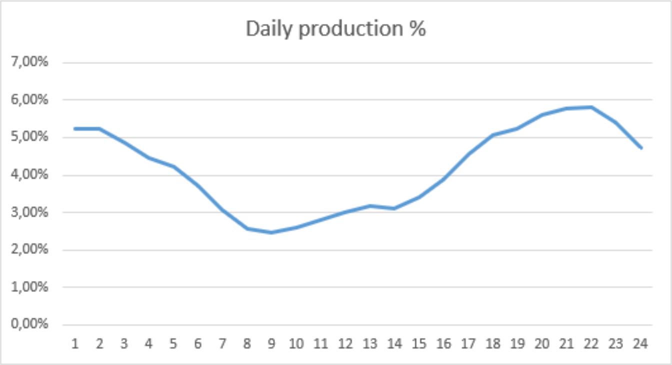


Figure 49 - Hourly distribution of energy production

The results of the wind production analysis are presented in Figure 50. The data reveal similar overall patterns across regions; however, the islands demonstrate an hourly production exceeding 1000 kWh, whereas northern Italy shows significantly lower performance, with hourly production not exceeding 150 kWh. These findings indicate that wind energy may not be a highly effective solution for northern Italy, while it could prove more advantageous in other regions.

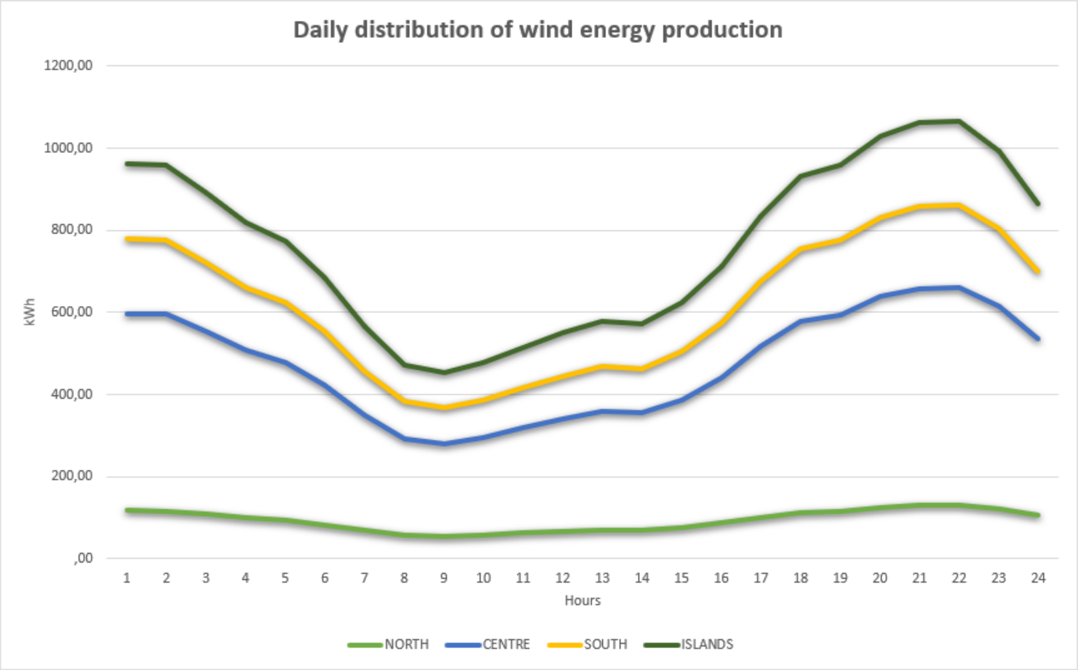


Figure 50 - Summary diagram for wind energy production

3.3. Hydroelectric Energy

Hydropower, or hydroelectric power, is a renewable energy technology that converts the kinetic energy of flowing or falling water into electricity. This process involves transforming the potential energy stored in elevated water into mechanical energy as the water descends, which is then converted into electrical energy by turbines connected to generators.

The core principle of hydropower is to harness the potential energy of water at a height and convert it into kinetic energy as it flows downward. This kinetic energy drives turbines that generate mechanical energy, which is subsequently transformed into electrical energy. The efficiency of this conversion depends on factors such as the height of the water drop (head) and the water flow rate, as shown in equation:

$$E = \eta \times \rho \times g \times H \times Q \times t \quad (3)$$

Where:

E = Energy produced [kWh]

η = Efficiency of the hydroelectric system (dimensionless, typically as a fraction)

ρ = Water density (1000 kg/m³ for freshwater)

g = Acceleration due to gravity (approximately 9.81 m/s²)

h = Height of the water head [m]

Q = Flow rate of water [m³/s]

t = Time period [h]

Among various types of hydropower plants are:

- Run-of-River Plants: These plants utilize the natural flow of rivers without significant water storage. They are typically smaller in scale and dependent on river flow variability.
- Reservoir (Storage) Plants: These facilities create large reservoirs through dam construction to store water. The stored water can be released as needed to generate electricity, allowing for a more consistent and controlled power supply.
- Pumped Storage Plants: These systems store energy by pumping water from a lower reservoir to an upper one during periods of low electricity demand. The stored water is then released to generate electricity during peak demand periods.

A hydropower plant is composed of several key components that work together to generate electricity. The process begins with a dam, which creates a reservoir to store water at a higher elevation. Water from this reservoir is then channeled through a penstock, a pipeline that directs the flow of water to the turbines. The turbines convert the kinetic energy of the flowing water into mechanical energy. This mechanical energy is subsequently transformed into electrical energy by a generator. Finally, a transformer increases the voltage of the generated electricity to facilitate its transmission over power lines.

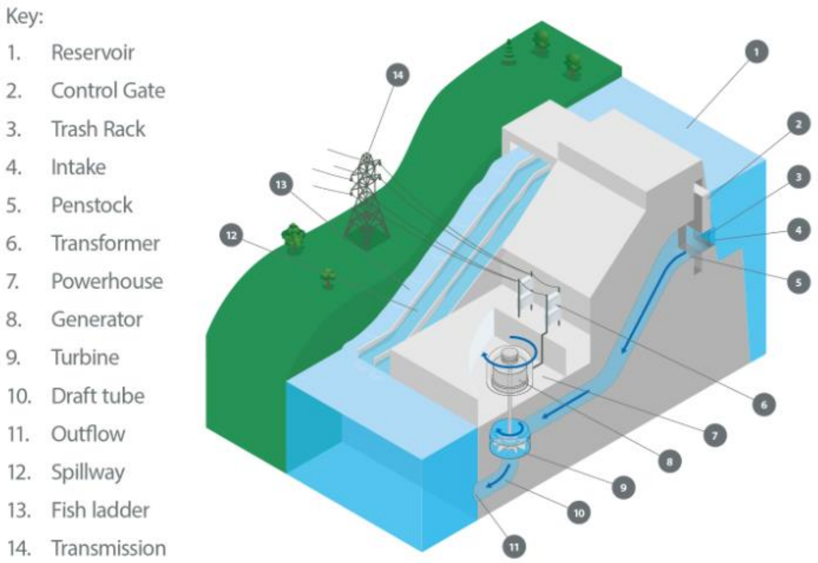


Figure 51 - Hydropower plant components [37]

Hydropower offers several notable advantages as a renewable energy source. It is inherently renewable because it relies on the natural water cycle, which is continuously replenished by precipitation. This method of energy generation produces minimal greenhouse gas emissions compared to fossil fuels, making it a cleaner alternative for power production. Additionally, hydropower plants provide a reliable and controllable power supply, as they can generate electricity consistently and adjust output according to demand.

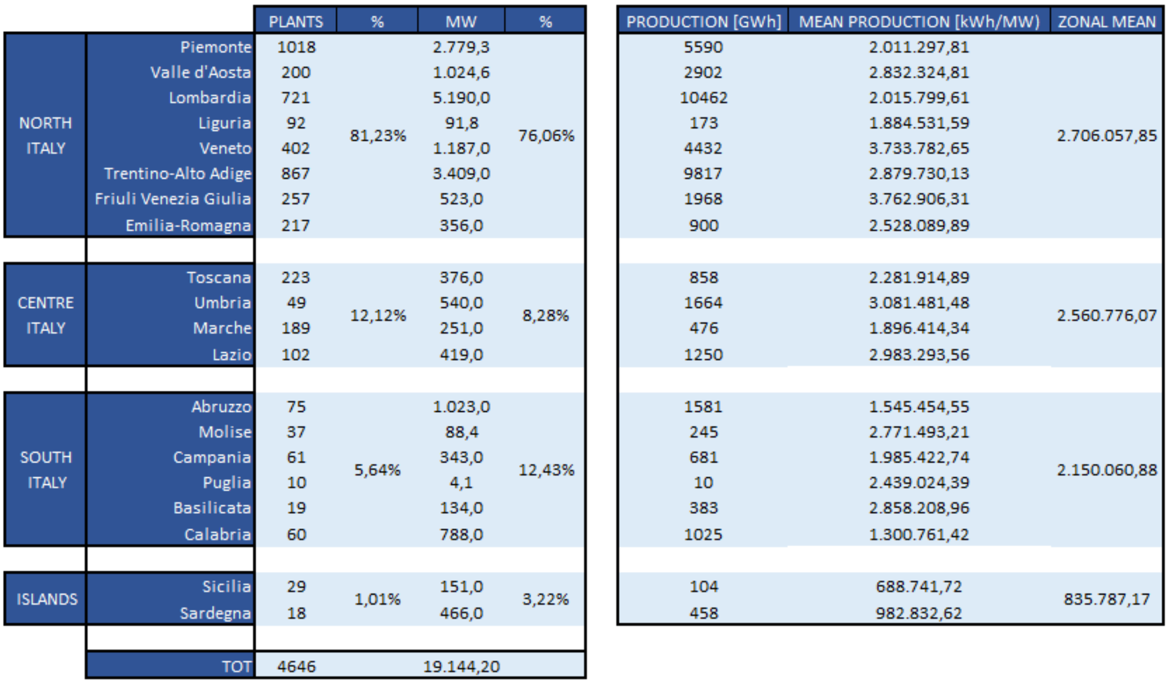
However, hydropower also presents some challenges. The construction of dams and reservoirs can have significant environmental impacts, including the disruption of local ecosystems and the displacement of communities. Moreover, the initial costs for building hydropower infrastructure are substantial, requiring significant investment. Despite these challenges, hydropower remains a crucial and sustainable component of the global renewable energy mix, balancing its benefits with its environmental and economic considerations.

Natural factors play a significant role in determining the producibility of hydropower. The water flow rate is fundamental, as the volume of water available in rivers or reservoirs varies due to rainfall, snowmelt, and seasonal changes, directly impacting energy generation. The head, or the vertical distance between the water source and the turbine, is also crucial; a greater head translates into more potential energy. Additionally, precipitation patterns, including rainfall and snowfall, influence flow rates and reservoir levels, affecting overall production. In regions with heavy snowfall, the timing and volume of snowmelt can further impact water flow. Due to these factors, only certain regions in Italy are ideally suited for hydropower plants, with many areas lacking the necessary conditions to support such infrastructure effectively. [38]

3.3.1. Italian database analysis

As for previous chapters, in this section, I will conduct an in-depth analysis using data from TERNA [31] to thoroughly examine the presence of hydropower energy in Italy. The objective is to assess the current landscape of this type of energy production, with a particular emphasis on distinguishing the production capacities across different Italian regions.

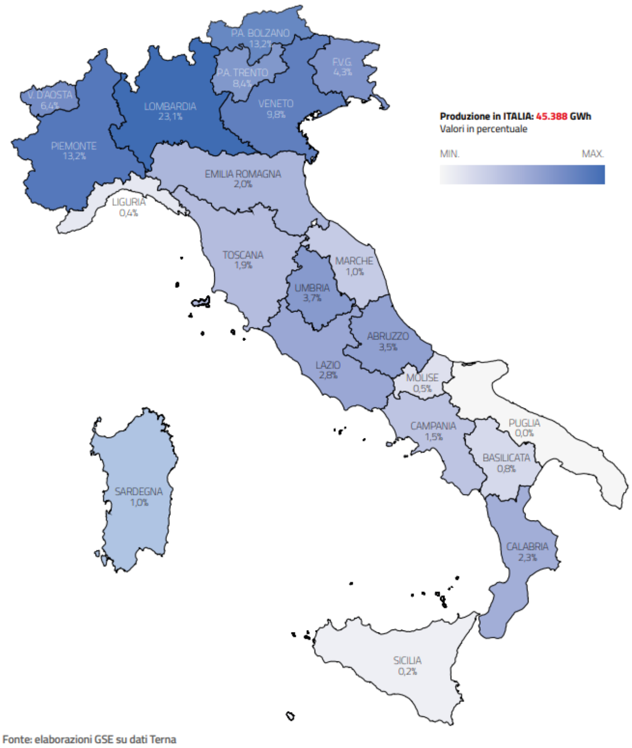
Figure 52 provides a detailed breakdown of hydropower generation across Italy, highlighting significant regional variations in both the number of plants and the installed capacity (MW). In Northern Italy, regions like Lombardy, Veneto, and Trentino-Alto Adige dominate in terms of both the number of plants and installed capacity, reflecting the region's advantageous topography and abundant water resources. In contrast, Central and Southern Italy, as well as the Islands, show markedly lower values in both plant numbers and capacity, leading to less hydropower production. This is largely due to less favorable geographical conditions, such as fewer mountainous areas and less consistent water flow, which limits hydropower potential in these regions.



		PLANTS	%	MW	%	PRODUCTION [GWh]	MEAN PRODUCTION [kWh/MW]	ZONAL MEAN
NORTH ITALY	Piemonte	1018	81,23%	2.779,3	76,06%	5590	2.011.297,81	2.706.057,85
	Valle d'Aosta	200		1.024,6		2902	2.832.324,81	
	Lombardia	721		5.190,0		10462	2.015.799,61	
	Liguria	92		91,8		173	1.884.531,59	
	Veneto	402		1.187,0		4432	3.733.782,65	
	Trentino-Alto Adige	867		3.409,0		9817	2.879.730,13	
	Friuli Venezia Giulia	257		523,0		1968	3.762.906,31	
	Emilia-Romagna	217		356,0		900	2.528.089,89	
CENTRE ITALY	Toscana	223	12,12%	376,0	8,28%	858	2.281.914,89	2.560.776,07
	Umbria	49		540,0		1664	3.081.481,48	
	Marche	189		251,0		476	1.896.414,34	
	Lazio	102		419,0		1250	2.983.293,56	
SOUTH ITALY	Abruzzo	75	5,64%	1.023,0	12,43%	1581	1.545.454,55	2.150.060,88
	Molise	37		88,4		245	2.771.493,21	
	Campania	61		343,0		681	1.985.422,74	
	Puglia	10		4,1		10	2.439.024,39	
	Basilicata	19		134,0		383	2.858.208,96	
	Calabria	60		788,0		1025	1.300.761,42	
ISLANDS	Sicilia	29	1,01%	151,0	3,22%	104	688.741,72	835.787,17
	Sardegna	18		466,0		458	982.832,62	
	TOT	4646		19.144,20				

Figure 52 - Analysed data for hydro production and presence in Italy

The average production across different regions, in this case, is not significantly different, indicating that when conditions are favorable, a hydropower plant performs similarly across various areas. However, it is crucial to consider the substantial number of existing plants in northern Italy, which underscores the challenge of establishing new facilities in other regions.



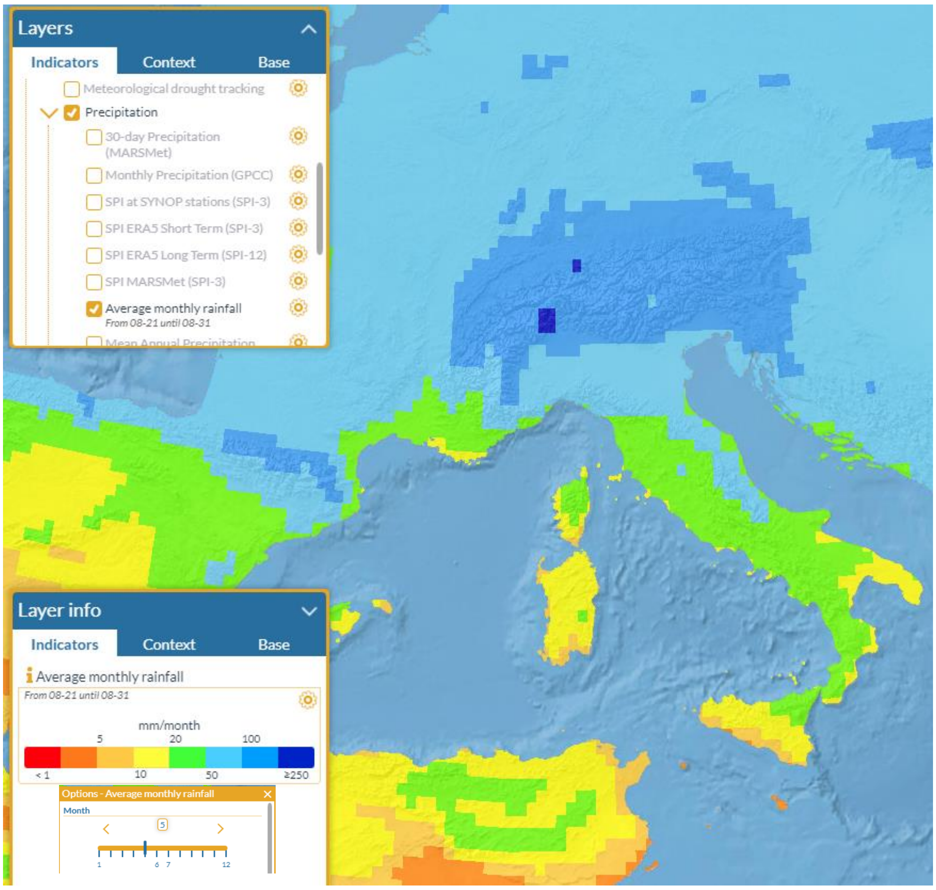
Fonte: elaborazioni GSE su dati Terna

Figure 53 -Regional distribution of hydropower energy production [31]

3.3.2. Simulated data analysis

The objective of this chapter is to analyze simulated data for the relevant technology and derive hourly production figures for integration into the subsequently described model. In the case of hydropower, there are no available free simulators for plant performance. Indeed, the principle is that if the conditions for installing a hydropower plant are met, its production will be relatively consistent across different regions.

Nevertheless, as noted in the introductory chapter, hydropower systems are substantially influenced by precipitation. Therefore, a more precise analysis that incorporates this factor is essential. As depicted in figure 54, the European Drought Observatory [39] provides data to estimate average precipitation for each region, which can vary monthly throughout the year based on historical averages. This tool has facilitated the development of an annual precipitation profile, shown in figure 55, which is used to determine monthly production distribution in relation to the proportion of total annual precipitation occurring each month.



☐ Meteorological drought tracking
☑ Precipitation
  ☐ 30-day Precipitation (MARSMet)
  ☐ Monthly Precipitation (GPCC)
  ☐ SPI at SYNOP stations (SPI-3)
  ☐ SPI ERA5 Short Term (SPI-3)
  ☐ SPI ERA5 Long Term (SPI-12)
  ☐ SPI MARSMet (SPI-3)
  ☑ Average monthly rainfall
  From 08-21 until 08-31
  ☐ Mean Annual Precipitation

Average monthly rainfall
From 08-21 until 08-31

Options - Average monthly rainfall
Month: 5

Figure 54 - EDO precipitation analysis [39]

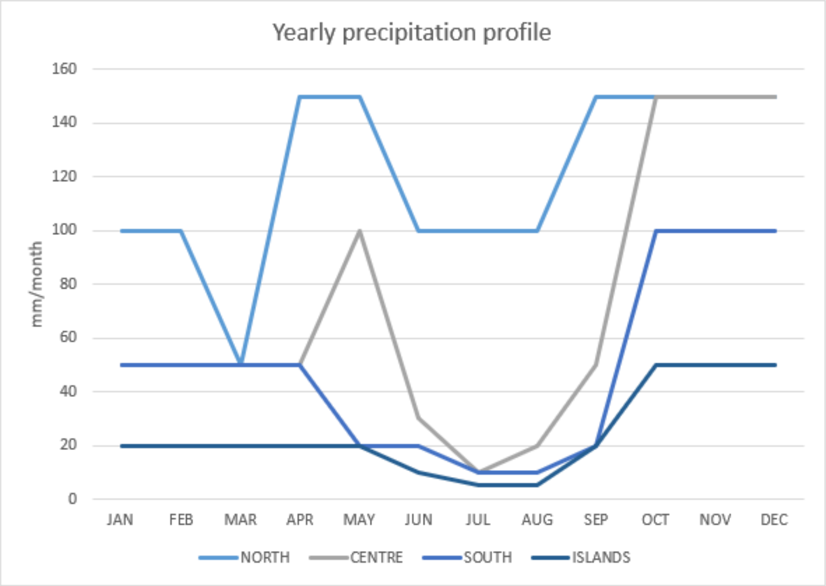


Figure 55 - Precipitation profile of different regions

As observed in Figure 55, northern Italy exhibits the highest levels of precipitation, maintaining very high rainfall values compared to southern Italy and the islands, which show lower levels. The central region achieves precipitation values comparable to those of the north. This precipitation profile not only aids in defining the distribution but also helps to corroborate the data previously presented.

The next step in defining average production profiles for Italy is to analyze the equivalent hours from recent years. As shown in figure 56, the average is approximately 3,294 equivalent hours.

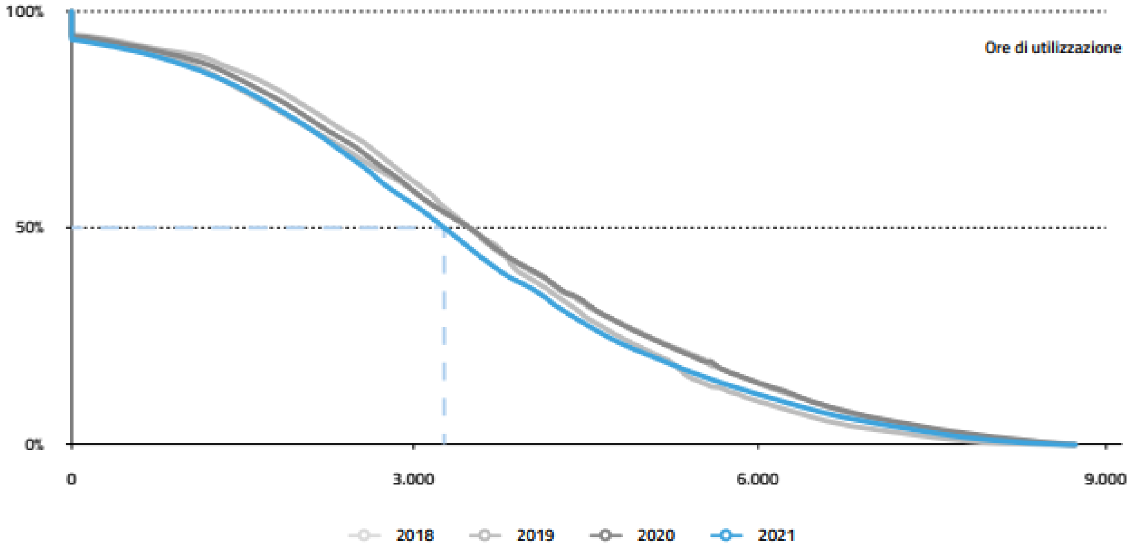
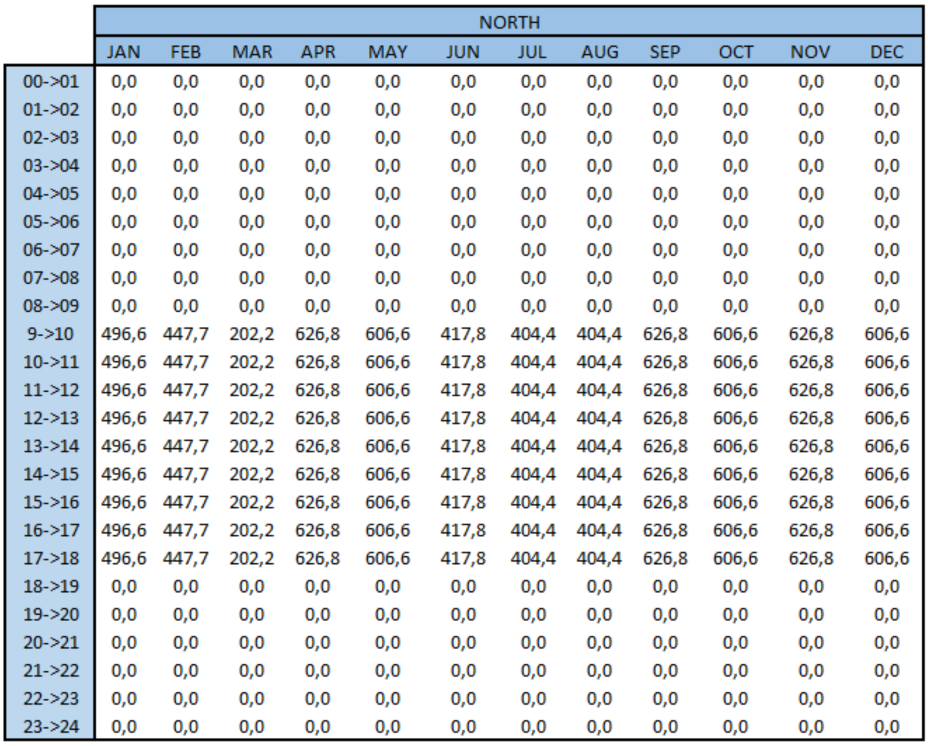


Figure 56 - Equivalent hours distribution for hydro plants [31]

This data is of fundamental importance because the production found in the previous points can be distributed as follows: since 3,294 hours represent approximately 38% of the annual hours, this translates to 9 hours out of a total of 24 hours in a day. Consequently, as hydroelectric power is usually modulated to cover periods of higher consumption, I have chosen to distribute the daily production from 9 AM to 6 PM throughout the year.

Considering all the previous steps, to define the most accurate simulation possible, I took the production data by zone, divided it throughout the year according to the more or less rainy months (with distribution varying according to the zones), and finally distributed it over 9 hours of the day.

The result for a typical region is shown as follows:



	NORTH											
	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00->01	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
01->02	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
02->03	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
03->04	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
04->05	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
05->06	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
06->07	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
07->08	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
08->09	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
9->10	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
10->11	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
11->12	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
12->13	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
13->14	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
14->15	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
15->16	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
16->17	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
17->18	496,6	447,7	202,2	626,8	606,6	417,8	404,4	404,4	626,8	606,6	626,8	606,6
18->19	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
19->20	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
20->21	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
21->22	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
22->23	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
23->24	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Figure 57 - Hydropower simulation example

In Figure 59, we can thus see the distribution of production across the various months of a typical day.

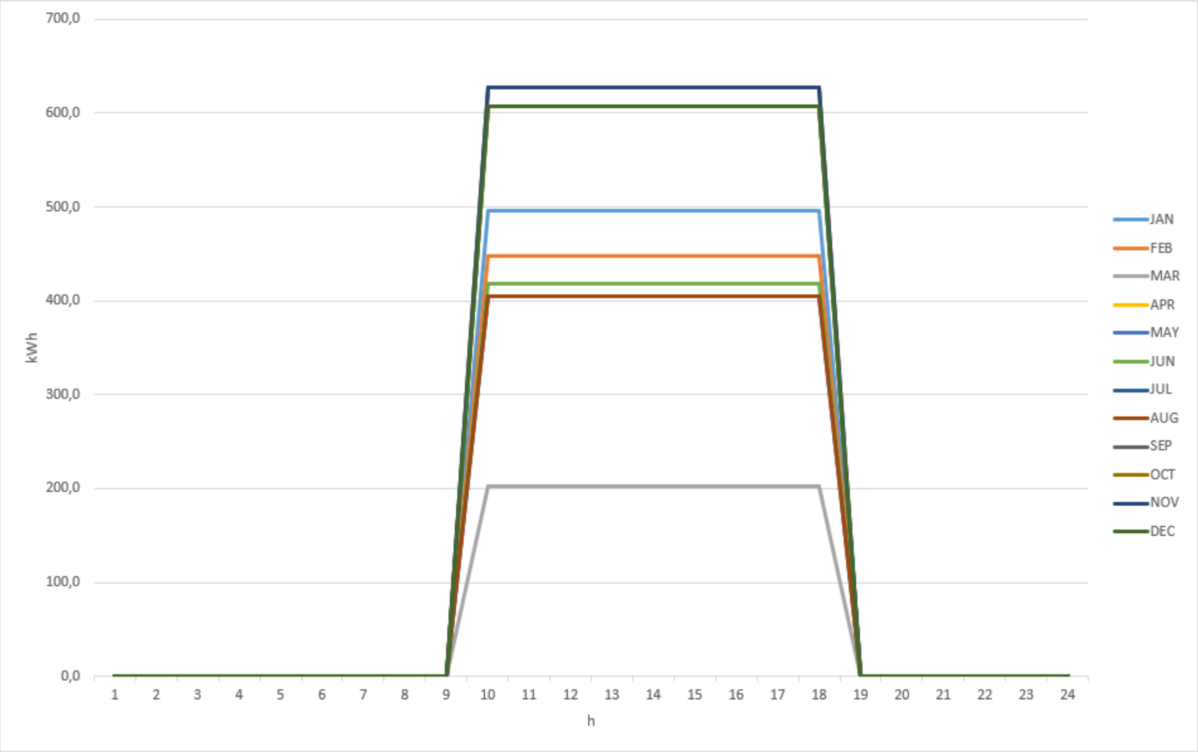


Figure 59 - Daily production distribution among months in Northern Italy

Instead, in Figure 58, we can see the difference between the various regions of Italy, with the North clearly prevailing, the South and the Center aligned, and the islands evidently less suitable for this type of technology.

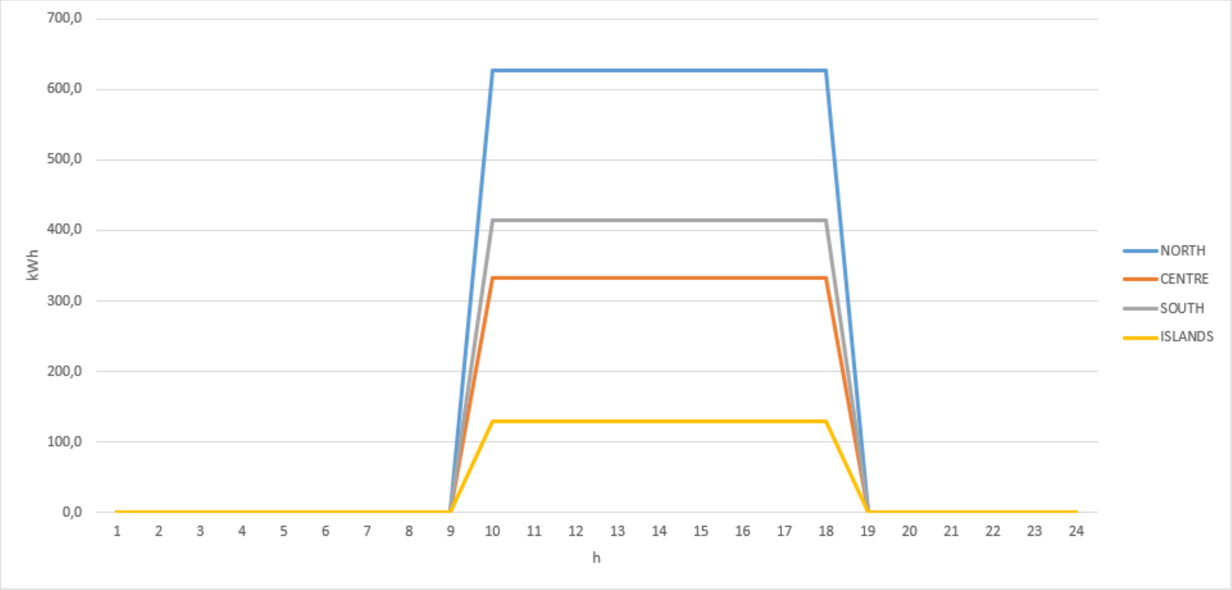


Figure 58 - Daily production comparison among zones

Electricity Consumption

Electricity consumers represent a pivotal component of the energy landscape, encompassing a broad spectrum of entities ranging from individual households and small businesses to large-scale industrial facilities and institutional organizations. Each category of consumer exhibits unique patterns of electricity usage, influenced by factors such as operational requirements, lifestyle preferences, and economic considerations.

Residential consumers, for instance, typically exhibit consumption patterns driven by daily routines, seasonal variations, and energy efficiency practices within their homes. Their energy usage is often characterized by peak demands during specific times of the day, such as evenings when lighting and appliances are in use. In contrast, commercial consumers, including offices, retail establishments, and service providers, experience fluctuations in consumption based on business hours, operational schedules, and the nature of their services. Their energy needs are often linked to lighting, heating, cooling, and electronic equipment.

Industrial consumers, on the other hand, have energy consumption profiles that are largely determined by production processes, machinery operation, and facility size. Their demand can be substantial and continuous, with variations depending on production cycles and operational efficiency. Institutional consumers, such as educational institutions and healthcare facilities, also have specific energy needs influenced by their operational demands and the necessity for 24/7 services.

Understanding the behavior and consumption patterns of these diverse consumer groups is crucial for several reasons. It informs the development of targeted energy policies, enhances grid management by predicting and accommodating demand fluctuations, and supports the design of energy efficiency programs tailored to different consumer needs.

This section will focus exclusively on industrial consumers, as they represent a particularly significant aspect of energy consumption due to their high demand and operational characteristics. Industrial consumers are of particular interest in the context of developing an energy community model because their substantial and often continuous energy needs offer valuable insights into managing and optimizing large-scale energy use. By examining their consumption patterns, operational influences, and energy demands, this analysis aims to provide a detailed understanding of how industrial sectors interact with the energy grid. This focus will help in developing strategies for efficient energy distribution, optimizing consumption, and enhancing the overall effectiveness of energy community models.

3.4. Industrial consumers categorization

Industrial consumers can be categorized based on various factors, including the nature of their production processes, the scale of their operations, and their specific energy requirements. This categorization helps in understanding their unique energy consumption patterns and optimizing energy management strategies.

The ATECO code, or "ATtività ECOnomiche" code, is a classification system used in Italy to categorize economic activities. It consists of a hierarchical numeric system that includes sections, divisions, groups, and classes, allowing for detailed classification of various sectors. The ATECO code is essential for business registration, tax reporting, and regulatory compliance. It helps streamline administrative processes and provides a standardized method for identifying and analyzing economic activities across different industries in Italy. [40]

The primary categories of industrial consumers include:

Heavy Industry: this type of consumers typically operates large-scale facilities that require substantial amounts of energy for their production processes. These industries are characterized by high energy consumption due to the intensive nature of their operations and machinery. Examples include:

- Steel Manufacturing (ATECO 24): Requires significant energy for melting and processing metal.
- Chemical Production (ATECO 20): Involves energy-intensive processes such as reactions, separations, and heating.
- Cement Production (ATECO 23.51): Needs large amounts of energy for grinding raw materials and heating kilns.

Light Industry: these consumers operate facilities that use less energy compared to heavy industries, focusing on the production of goods that do not require intensive processes. These industries typically involve smaller-scale production and often rely on less energy-intensive machinery. Examples include:

- Textile Manufacturing (ATECO 13.20): Involves energy for machines used in spinning, weaving, and dyeing.
- Electronics Assembly (ATECO 26): Requires energy for manufacturing and assembling electronic components.

- Food and Beverage Processing (ATECO 56): Includes energy use for cooking, packaging, and refrigeration.

Process Industry are involved in the continuous or batch processing of materials, where energy is crucial for maintaining specific process conditions and ensuring product quality. Examples include:

- Pharmaceutical Production (ATECO 21.10): Requires precise temperature and pressure control for drug manufacturing.
- Paper Production (ATECO 17.12): Involves energy for pulping, bleaching, and drying processes.
- Petroleum Refining (ATECO 19.20): Uses energy for distillation, cracking, and chemical treatments.

Manufacturing Industry consumers instead focus on the production of goods through various processes that involve energy for machinery, equipment, and operational activities. This category includes:

- Automobile Manufacturing (ATECO 29.10): Energy is used for assembly lines, machining, and paint processes.
- Machinery and Equipment Manufacturing (ATECO 28): Involves energy for fabricating and assembling industrial machines.
- Furniture Production (ATECO 31.09): Includes energy for woodworking, finishing, and assembly processes.

3.5. Consumers analysis

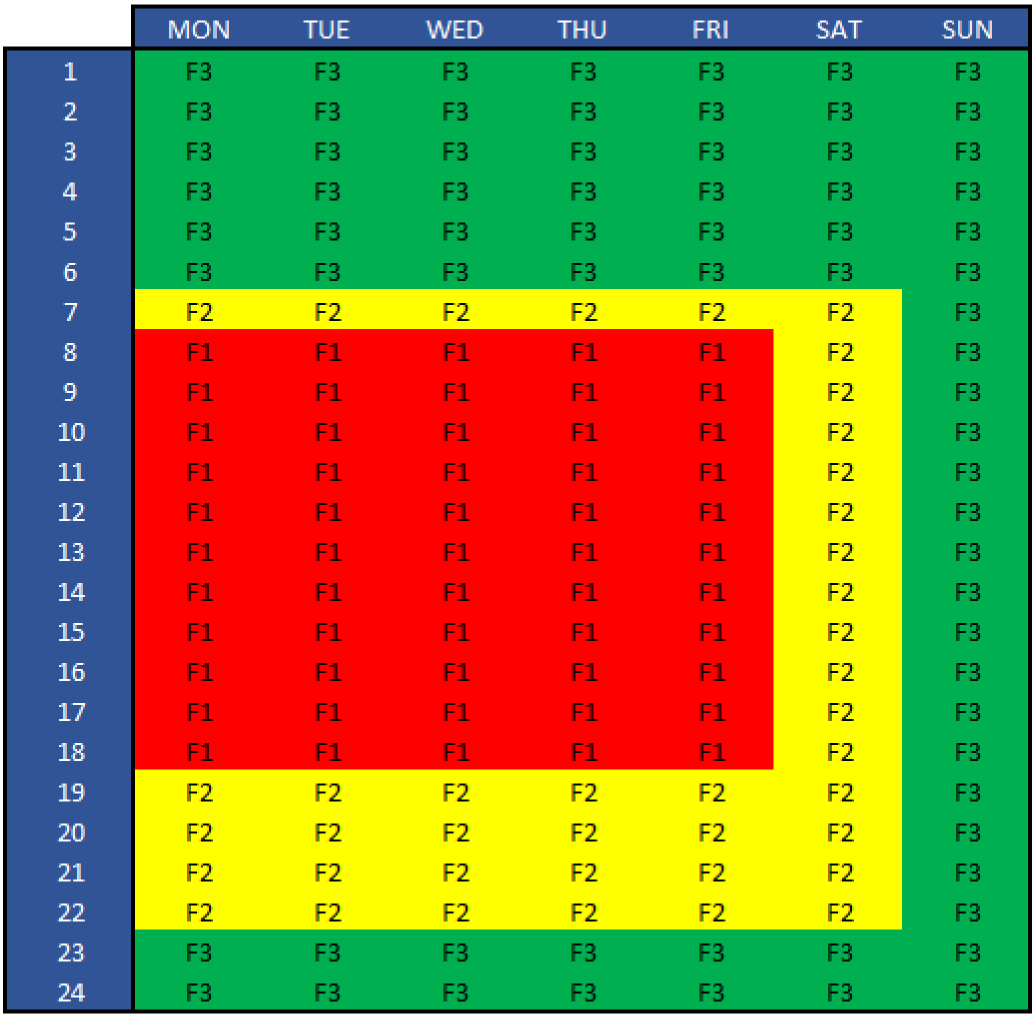
For the purposes of this thesis, the analysis we need to conduct concerns the consumption of potential consumers, categorized by their respective time slots.

In Italy, electricity consumption is categorized into three time slots: F1, F2, and F3, as shown in figure 57. These slots determine the varying rates applied to consumers and are designed to help manage energy demand more effectively, encouraging a balanced use of electricity throughout the day.

F1, or peak hours, typically runs from 8:00 AM to 7:00 PM on weekdays. This period sees the highest demand for electricity, as it coincides with standard working hours and the most active part of the day. As a result, the rates during F1 are higher, reflecting the increased strain on the energy grid during these times.

F2 represents the intermediate hours, generally from 7:00 AM to 8:00 AM and from 7:00 PM to 11:00 PM on weekdays, and throughout the day on weekends and public holidays. During this slot, the demand is moderate, leading to rates that are lower than those in F1 but still higher than in the off-peak hours. F2 includes early morning and evening periods, as well as the entirety of the weekend when people are more likely to be at home, leading to a varied yet steady consumption pattern.

F3, or off-peak hours, covers the time from 11:00 PM to 7:00 AM on weekdays and all day on weekends and public holidays. This period is characterized by the lowest energy consumption, such as during the night when most households and businesses are inactive. Consequently, the rates during F3 are the lowest, encouraging consumers to shift some of their energy usage to these less demanding times.

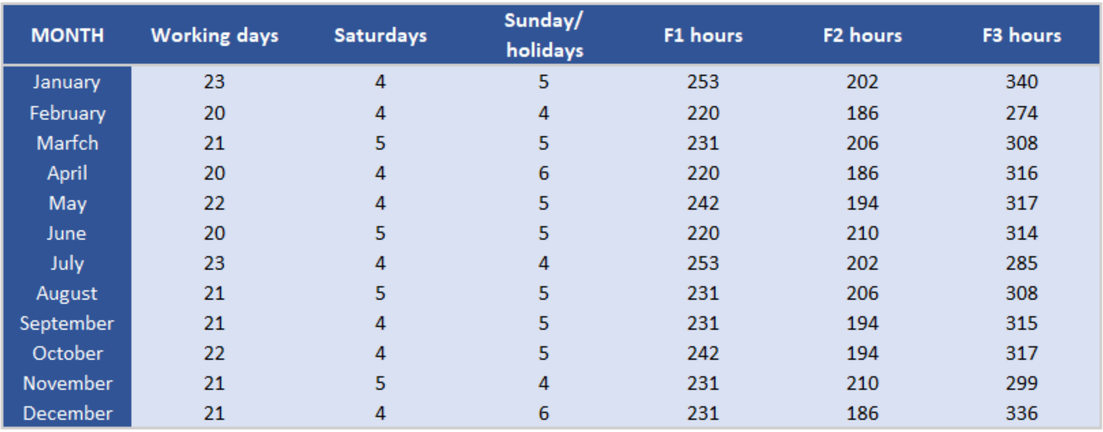


	MON	TUE	WED	THU	FRI	SAT	SUN
1	F3	F3	F3	F3	F3	F3	F3
2	F3	F3	F3	F3	F3	F3	F3
3	F3	F3	F3	F3	F3	F3	F3
4	F3	F3	F3	F3	F3	F3	F3
5	F3	F3	F3	F3	F3	F3	F3
6	F3	F3	F3	F3	F3	F3	F3
7	F2	F2	F2	F2	F2	F2	F3
8	F1	F1	F1	F1	F1	F2	F3
9	F1	F1	F1	F1	F1	F2	F3
10	F1	F1	F1	F1	F1	F2	F3
11	F1	F1	F1	F1	F1	F2	F3
12	F1	F1	F1	F1	F1	F2	F3
13	F1	F1	F1	F1	F1	F2	F3
14	F1	F1	F1	F1	F1	F2	F3
15	F1	F1	F1	F1	F1	F2	F3
16	F1	F1	F1	F1	F1	F2	F3
17	F1	F1	F1	F1	F1	F2	F3
18	F1	F1	F1	F1	F1	F2	F3
19	F2	F2	F2	F2	F2	F2	F3
20	F2	F2	F2	F2	F2	F2	F3
21	F2	F2	F2	F2	F2	F2	F3
22	F2	F2	F2	F2	F2	F2	F3
23	F3	F3	F3	F3	F3	F3	F3
24	F3	F3	F3	F3	F3	F3	F3

Figure 60 - Distribution of consumption time slots

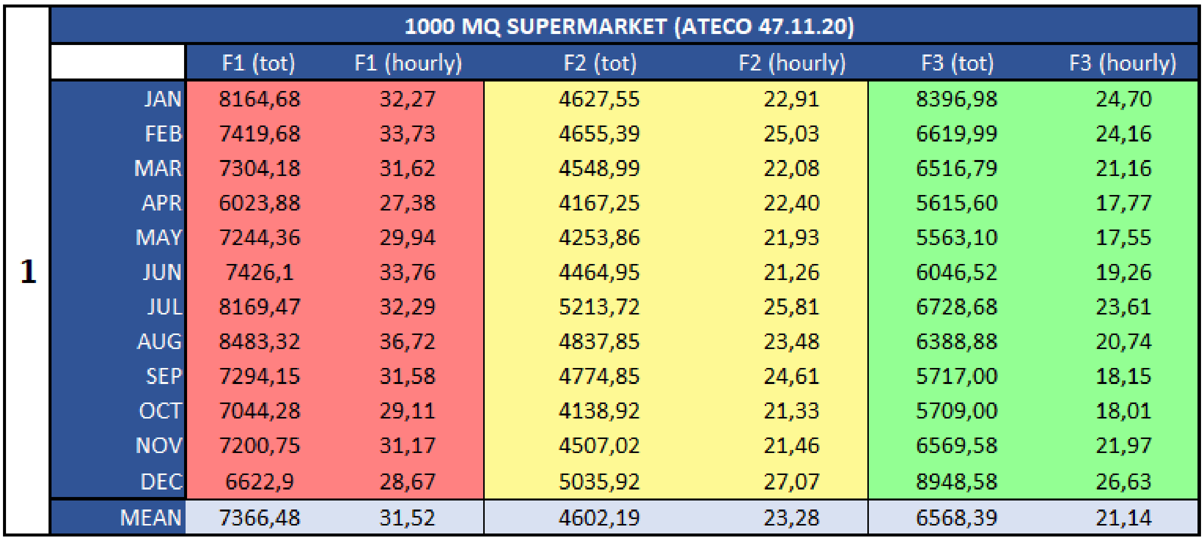
Altea Green Power Spa's clients provide their electricity bills from the past year to allow us to analyze the actual benefits and proper sizing of the photovoltaic system based on their consumption. These bills are recorded and categorized according to different time slots, as shown in Figure 60. I have selected seven sample companies located across Italy, each operating in different sectors according to their ATECO code, to provide a comprehensive overview of the landscape of Italian PMIs.

Each total value from the bills has been divided according to the actual hours of consumption for the year 2024, as shown in Figure 62.



MONTH	Working days	Saturdays	Sunday/ holidays	F1 hours	F2 hours	F3 hours
January	23	4	5	253	202	340
February	20	4	4	220	186	274
Marfch	21	5	5	231	206	308
April	20	4	6	220	186	316
May	22	4	5	242	194	317
June	20	5	5	220	210	314
July	23	4	4	253	202	285
August	21	5	5	231	206	308
September	21	4	5	231	194	315
October	22	4	5	242	194	317
November	21	5	4	231	210	299
December	21	4	6	231	186	336

Figure 62 - Distribution of different time slots in 2024



	1000 MQ SUPERMARKET (ATECO 47.11.20)						
		F1 (tot)	F1 (hourly)	F2 (tot)	F2 (hourly)	F3 (tot)	F3 (hourly)
1	JAN	8164,68	32,27	4627,55	22,91	8396,98	24,70
	FEB	7419,68	33,73	4655,39	25,03	6619,99	24,16
	MAR	7304,18	31,62	4548,99	22,08	6516,79	21,16
	APR	6023,88	27,38	4167,25	22,40	5615,60	17,77
	MAY	7244,36	29,94	4253,86	21,93	5563,10	17,55
	JUN	7426,1	33,76	4464,95	21,26	6046,52	19,26
	JUL	8169,47	32,29	5213,72	25,81	6728,68	23,61
	AUG	8483,32	36,72	4837,85	23,48	6388,88	20,74
	SEP	7294,15	31,58	4774,85	24,61	5717,00	18,15
	OCT	7044,28	29,11	4138,92	21,33	5709,00	18,01
	NOV	7200,75	31,17	4507,02	21,46	6569,58	21,97
	DEC	6622,9	28,67	5035,92	27,07	8948,58	26,63
	MEAN	7366,48	31,52	4602,19	23,28	6568,39	21,14

Figure 61 - Example of consumption analysis on a company

The same operation illustrated in the example in Figure 61 has been applied to the following companies, which I have numbered for simplicity in the subsequent steps, as shown in Figure 63.

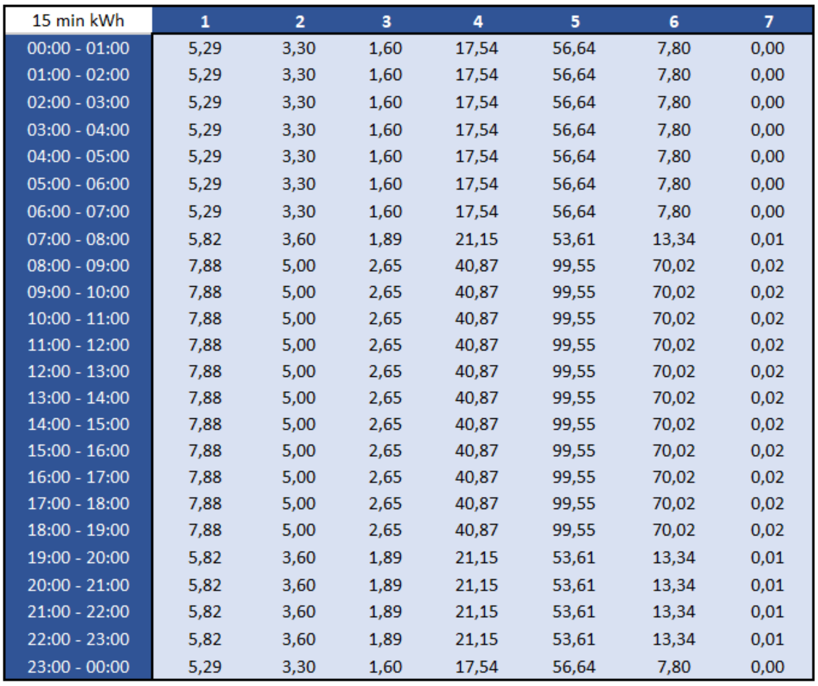
TYPE	NUMBER	F1	F2	F3
1000 MQ SUPERMARKET (ATECO 47.11.20)	1	7.366,48	4.602,19	6.568,39
450 MQ SUPERMARKET (ATECO 47.11.20)	2	4.190,05	2.840,68	1.976,20
150 MQ SUPERMARKET (ATECO 47.11.20)	3	2.478,50	1.496,90	1.976,20
ENERGY-INTENSIVE TEXTILE COMPANY (ATECO 13.96.2)	4	38.238,60	16.685,30	21.742,80
ENERGY-INTENSIVE ACOUSTIC PRODUCTS MANUFACTURING COMPANY (ATECO 23.99)	5	92.846,20	42.392,20	70.148,30
ENERGY-INTENSIVE FOUNDRY COMPANY (ATECO 24.51)	6	65.238,80	10.544,30	9.704,33
CONSTRUCTION SECTOR COMPANY WAREHOUSE (ATECO 43.39)	7	17,00	4,00	0,00

Figure 63 - List of analyzed PMI

I have included three main types of consumers:

- **Number 1, 2, and 3** are classified as supermarkets, each with different sizes but sharing similar sources of consumption: refrigeration, lighting, and air conditioning.
- **Number 4, 5, and 6** are typical manufacturing industries across various sectors, with significantly higher consumption. Among these is a foundry, which is one of the ATECO codes with the highest consumption levels in Italy.
- **Number 7** is a warehouse for a construction company, where materials are stored. Its only consumption is from lighting. I included this example because it represents a practical case AGP is analyzing of a company interested in an installation solely for network sale purposes, perfectly suitable for REC use.

Once the energy community is operational, the GSE will provide the hourly data on energy input and consumption. However, for completeness, I have included the consumption data in quarter-hourly intervals as in figure 64, as the GSE requires this type of data to perform simulations.



15 min kWh	1	2	3	4	5	6	7
00:00 - 01:00	5,29	3,30	1,60	17,54	56,64	7,80	0,00
01:00 - 02:00	5,29	3,30	1,60	17,54	56,64	7,80	0,00
02:00 - 03:00	5,29	3,30	1,60	17,54	56,64	7,80	0,00
03:00 - 04:00	5,29	3,30	1,60	17,54	56,64	7,80	0,00
04:00 - 05:00	5,29	3,30	1,60	17,54	56,64	7,80	0,00
05:00 - 06:00	5,29	3,30	1,60	17,54	56,64	7,80	0,00
06:00 - 07:00	5,29	3,30	1,60	17,54	56,64	7,80	0,00
07:00 - 08:00	5,82	3,60	1,89	21,15	53,61	13,34	0,01
08:00 - 09:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
09:00 - 10:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
10:00 - 11:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
11:00 - 12:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
12:00 - 13:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
13:00 - 14:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
14:00 - 15:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
15:00 - 16:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
16:00 - 17:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
17:00 - 18:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
18:00 - 19:00	7,88	5,00	2,65	40,87	99,55	70,02	0,02
19:00 - 20:00	5,82	3,60	1,89	21,15	53,61	13,34	0,01
20:00 - 21:00	5,82	3,60	1,89	21,15	53,61	13,34	0,01
21:00 - 22:00	5,82	3,60	1,89	21,15	53,61	13,34	0,01
22:00 - 23:00	5,82	3,60	1,89	21,15	53,61	13,34	0,01
23:00 - 00:00	5,29	3,30	1,60	17,54	56,64	7,80	0,00

Figure 64 - Summary of energy consumption in 15 min

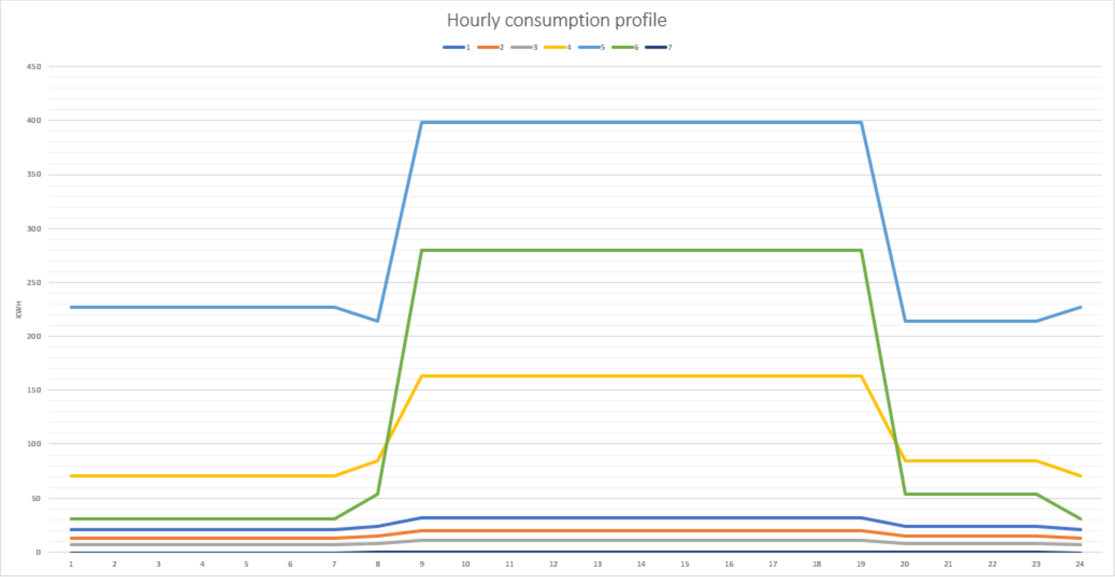


Figure 65 - Comparison of hourly consumption profiles

These data reflect only the working days, which constitute the majority. They must, however, be segmented in the Excel file according to the specific days and time slots to accurately determine the hourly consumption of each consumer.

4. Analysis of REC Configurations

In the preceding chapters, the current regulations for this decree were thoroughly analyzed, with particular emphasis on the decree's target audience, the various forms and technical aspects of energy production and consumption, the production technologies, and a detailed analysis of the relevant data, as well as the consumers involved.

In this chapter, I will present the development of the model used to analyze in a very accurate level of details the performances of different RECs in Italy. The model needed to accurately assess the hourly energy production and consumption of all participants within the energy community, allowing for precise simulation values. These values are crucial as they mirror the parameters considered by the GSE when calculating the incentives to be awarded to the community. It is important to precise that this level of accuracy in simulating RECs performances has been reached in response to the market requests.

To achieve this, Excel was employed as the primary tool, allowing for the programming of cells with equations capable of adjusting to various production and consumption scenarios. This approach enabled the calculation of necessary data, visualizing hour-by-hour, throughout the year, the percentage of energy shared within the community, and identifying specific areas for improvement on a case-by-case basis.

The entire process was designed and executed based on the requirements provided by clients of Altea Green Power SpA, who sought concrete simulations of performance for actual energy communities to be established across the country.

In response to the requests from PMIs operating within the national territory, there arose a need to establish an economic analysis framework. This framework would evaluate all aspects of investment and the return on investment for acquiring renewable energy production plants. The analysis was grounded in economic models already in use by most energy communities across the country, validated by banks and state institutions.

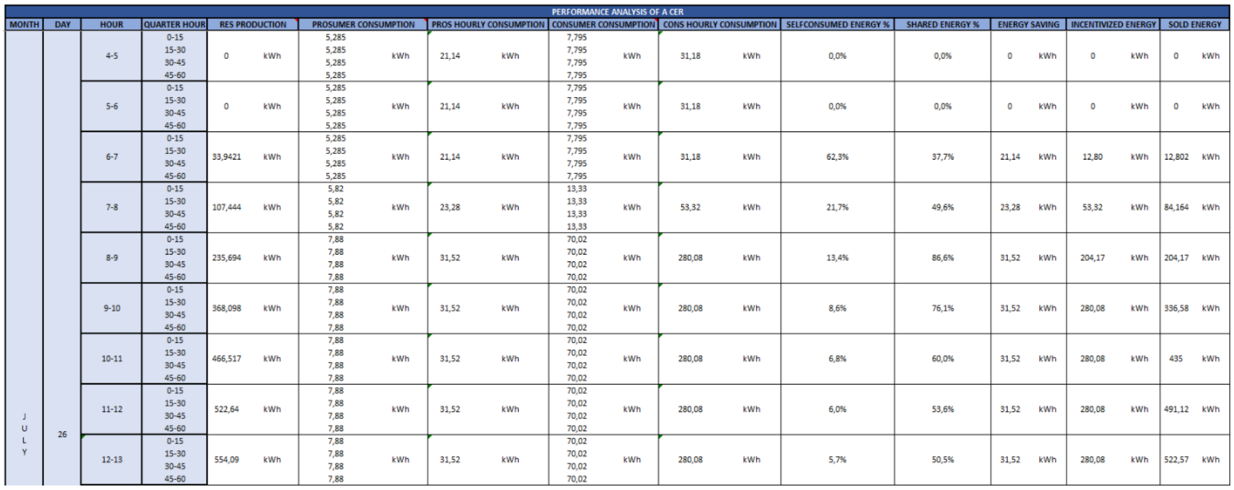
This comprehensive approach ensures that the model not only meets the technical demands of energy performance simulation but also aligns with the economic viability criteria essential for the widespread adoption of renewable energy solutions.

4.1. The Excel model

4.1.1. Performance analysis

As mentioned in the introduction to this chapter, the core of this thesis is embodied in the Excel model developed to analyze the hourly performance of an energy community. This analysis was conducted with a single prosumer, represented by a PMI that wants to invest in a 1 MW solar power system. This system is partially used for self-consumption and partially for energy sales. The consumption data, on the other hand, is represented by various PMIs, either individually or in groups, that do not have their own photovoltaic systems but are located within the area covered by the same primary substation as the prosumer.

Below is figure 66, representing a few hours of a day in July, inside the model sheet, which will be used to explain each component in detail.



PERFORMANCE ANALYSIS OF A CER

MONTH	DAY	HOUR	QUARTER HOUR	RES PRODUCTION	PROSUMER CONSUMPTION	PROS HOURLY CONSUMPTION	CONSUMER CONSUMPTION	CONS HOURLY CONSUMPTION	SELFCONSUMED ENERGY %	SHARED ENERGY %	ENERGY SAVING	INCENTIVIZED ENERGY	SOLD ENERGY
JULY	26	4-5	0-15 15-30 30-45 45-60	0 kWh	5,285 5,285 5,285 5,285 kWh	21,14 kWh	7,795 7,795 7,795 7,795 kWh	31,18 kWh	0,0%	0,0%	0 kWh	0 kWh	0 kWh
		5-6	0-15 15-30 30-45 45-60	0 kWh	5,285 5,285 5,285 5,285 kWh	21,14 kWh	7,795 7,795 7,795 7,795 kWh	31,18 kWh	0,0%	0,0%	0 kWh	0 kWh	0 kWh
		6-7	0-15 15-30 30-45 45-60	33,9421 kWh	5,285 5,285 5,285 5,285 kWh	21,14 kWh	7,795 7,795 7,795 7,795 kWh	31,18 kWh	62,3%	37,7%	21,14 kWh	12,80 kWh	12,802 kWh
		7-8	0-15 15-30 30-45 45-60	107,444 kWh	5,82 5,82 5,82 5,82 kWh	23,28 kWh	13,33 13,33 13,33 13,33 kWh	53,32 kWh	21,7%	49,6%	23,28 kWh	53,32 kWh	84,164 kWh
		8-9	0-15 15-30 30-45 45-60	235,694 kWh	7,88 7,88 7,88 7,88 kWh	31,52 kWh	70,02 70,02 70,02 70,02 kWh	280,08 kWh	13,4%	86,6%	31,52 kWh	204,17 kWh	204,17 kWh
		9-10	0-15 15-30 30-45 45-60	368,098 kWh	7,88 7,88 7,88 7,88 kWh	31,52 kWh	70,02 70,02 70,02 70,02 kWh	280,08 kWh	8,6%	76,1%	31,52 kWh	280,08 kWh	336,58 kWh
		10-11	0-15 15-30 30-45 45-60	466,517 kWh	7,88 7,88 7,88 7,88 kWh	31,52 kWh	70,02 70,02 70,02 70,02 kWh	280,08 kWh	6,8%	60,0%	31,52 kWh	280,08 kWh	435 kWh
		11-12	0-15 15-30 30-45 45-60	522,64 kWh	7,88 7,88 7,88 7,88 kWh	31,52 kWh	70,02 70,02 70,02 70,02 kWh	280,08 kWh	6,0%	53,6%	31,52 kWh	280,08 kWh	491,12 kWh
		12-13	0-15 15-30 30-45 45-60	554,09 kWh	7,88 7,88 7,88 7,88 kWh	31,52 kWh	70,02 70,02 70,02 70,02 kWh	280,08 kWh	5,7%	50,5%	31,52 kWh	280,08 kWh	522,57 kWh

Figure 66 - Abstract of Excel model

In the first four columns, the month, day, hour, and quarter-hour time slots are shown, corresponding to the data format provided by the GSE when the primary substation data is released.

The "RES PRODUCTION" column displays the hourly production from the renewable energy sources analyzed in Chapter 3.

The next two columns represent the prosumer's consumption data, shown first in quarter-hour intervals as provided by the distributor, and then aggregated into hourly data. Similarly, there is a column for the consumption of the consumer or consumers, also presented initially in quarter-hour intervals and then aggregated into hourly totals.

The last five columns are as follows:

- **Percentage of Self-Consumed Energy**: This column indicates the percentage of the produced energy that is consumed directly by the prosumer without being fed into the grid.

$$Self consumed\ energy\ \% = \frac{Prosumer\ consumption\ [kWh]}{RES\ production\ [kWh]} \quad (4)$$

- **Percentage of Shared Energy**: This column shows the percentage of the produced energy that is shared within the energy community, reflecting the portion of energy that is not consumed by the prosumer but is utilized by other members of the community.

$$Shared\ energy\ \% = \frac{Incentivized\ energy\ [kWh]}{RES\ production\ [kWh]} \quad (5)$$

- **Energy Savings of the Prosumer**: This column calculates the savings achieved by the prosumer through self-consumption, resulting in an economic benefit derived from reducing energy purchases from the grid.

$$Energy\ saving\ [kWh] = \begin{cases} PC; if\ PC \leq RESP \\ RESP; if\ PC > RESP \end{cases} \quad (6)$$

With:

PC = prosumer consumption [kWh]

RESP = Renewable Energy Source production [kWh]

- **Incentivized energy:** This column represents the amount of energy sold by the prosumer that is simultaneously consumed by the consumer(s) within the same time frame, facilitating direct energy transactions within the community.

$$Incentivized\ energy[kWh] = \begin{cases} CC; if\ CC \leq RESP\ - PC \\ RESP\ - PC; if\ CC > RESP\ - PC \\ \emptyset\ ;\ if\ RESP\ - PC \leq 0 \end{cases} \quad (7)$$

With:

$PC = prosumer\ consumption\ [kWh]$

$RESP = Renewable\ Energy\ Source\ production\ [kWh]$

$CC = consumer\ consumption\ [kWh]$

- **Energy Sold on the Market**: This column captures the amount of excess energy produced by the prosumer that is not self-consumed and is therefore sold on the open energy market. It could be higher than incentivized one, as not all the energy sold into the grid could be simultaneously consumed.

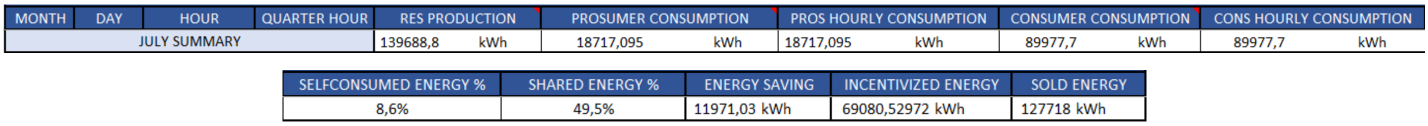
$$Sold\ energy\ [kWh] = \begin{cases} RESP - PC; if\ RESP - PC > 0 \\ 0\ ;\ if\ RESP - PC \leq 0 \end{cases} \tag{8}$$

With:

$PC = prosumer\ consumption\ [kWh]$

$RESP = Renewable\ Energy\ Source\ production\ [kWh]$

Additionally, at the end of each month, a summary is provided, which aggregates the data using the appropriate summation formulas. This monthly summary consolidates the key metrics such as total energy production, self-consumption, shared energy, energy savings, and energy sold, offering a comprehensive overview of the community's performance for that period:

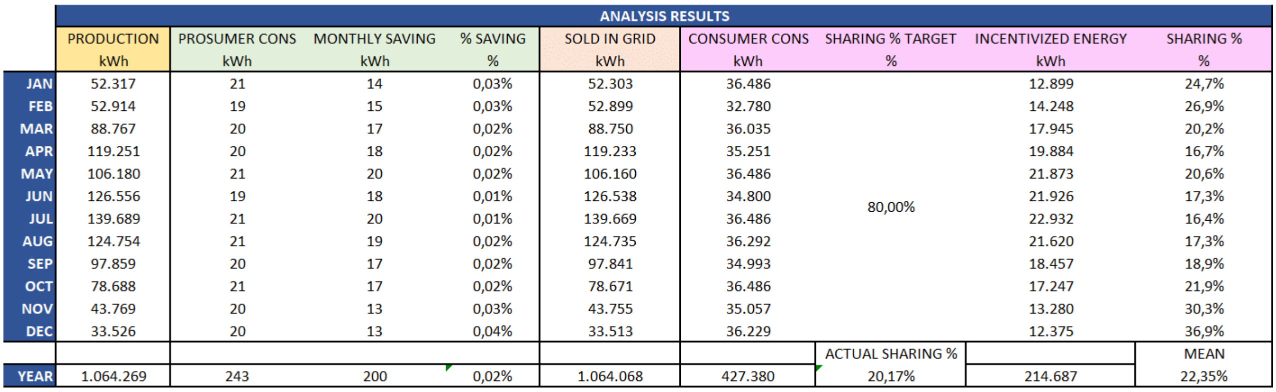


MONTH	DAY	HOUR	QUARTER HOUR	RES PRODUCTION	PROSUMER CONSUMPTION	PROS HOURLY CONSUMPTION	CONSUMER CONSUMPTION	CONS HOURLY CONSUMPTION
JULY SUMMARY				139688,8 kWh	18717,095 kWh	18717,095 kWh	89977,7 kWh	89977,7 kWh

SELFCONSUMED ENERGY %	SHARED ENERGY %	ENERGY SAVING	INCENTIVIZED ENERGY	SOLD ENERGY
8,6%	49,5%	11971,03 kWh	69080,52972 kWh	127718 kWh

Figure 67 - Example of a month summary

Given the extensive number of rows—over 35,000—required by this model to analyze an entire year, a summarized version of the yearly data is provided in figure 68. This summary offers a more immediate and accessible overview of the annual performance, allowing for a quicker and more efficient evaluation of the key metrics across the entire year.



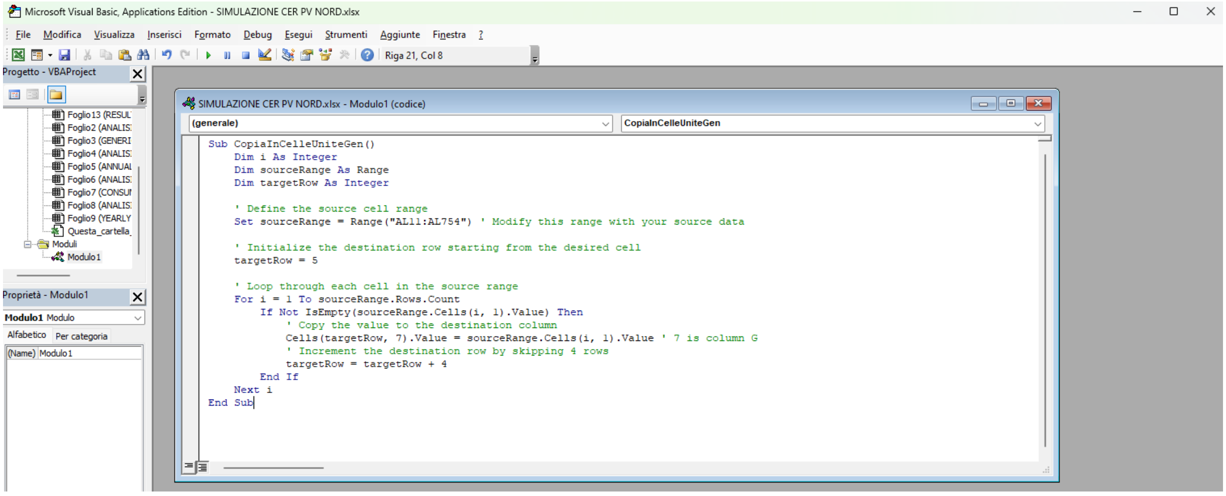
ANALYSIS RESULTS									
	PRODUCTION kWh	PROSUMER CONS kWh	MONTHLY SAVING kWh	% SAVING %	SOLD IN GRID kWh	CONSUMER CONS kWh	SHARING % TARGET %	INCENTIVIZED ENERGY kWh	SHARING % %
JAN	52.317	21	14	0,03%	52.303	36.486	80,00%	12.899	24,7%
FEB	52.914	19	15	0,03%	52.899	32.780		14.248	26,9%
MAR	88.767	20	17	0,02%	88.750	36.035		17.945	20,2%
APR	119.251	20	18	0,02%	119.233	35.251		19.884	16,7%
MAY	106.180	21	20	0,02%	106.160	36.486		21.873	20,6%
JUN	126.556	19	18	0,01%	126.538	34.800		21.926	17,3%
JUL	139.689	21	20	0,01%	139.669	36.486		22.932	16,4%
AUG	124.754	21	19	0,02%	124.735	36.292		21.620	17,3%
SEP	97.859	20	17	0,02%	97.841	34.993		18.457	18,9%
OCT	78.688	21	17	0,02%	78.671	36.486		17.247	21,9%
NOV	43.769	20	13	0,03%	43.755	35.057		13.280	30,3%
DEC	33.526	20	13	0,04%	33.513	36.229		12.375	36,9%
							ACTUAL SHARING %		MEAN
YEAR	1.064.269	243	200	0,02%	1.064.068	427.380	20,17%	214.687	22,35%

Figure 68 - Analysis results summary table

In this summary, the same categories from the complete table are presented on a month-by-month basis, along with several key data points of interest. These include the annual totals, the difference between the target sharing percentage and the actual achieved sharing percentage, as well as the average annual sharing rate. This condensed format allows for a clear comparison and assessment of the community's performance throughout the year, highlighting areas where the actual performance deviated from the expected targets.

The variables to be modified within the model to specifically analyze the performance of the energy community are:

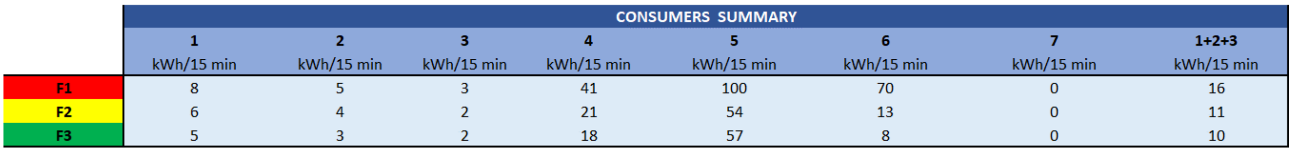
- **RES Production:** Depending on the type and location, using accurate simulators and pasting the data every 4 rows to ensure that the single hourly production row aligns with the four rows of quarter-hourly consumption data provided by the distributor. To achieve this, Excel has to be programmed, by using Microsoft Visual Basics, to perform this task correctly, allowing to input hourly production columns into the model.



```
Sub CopiaInCelleUniteGen()
    Dim i As Integer
    Dim sourceRange As Range
    Dim targetRow As Integer

    ' Define the source cell range
    Set sourceRange = Range("AL11:AL754") ' Modify this range with your source data

    ' Initialize the destination row starting from the desired cell
    targetRow = 5

    ' Loop through each cell in the source range
    For i = 1 To sourceRange.Rows.Count
        If Not IsEmpty(sourceRange.Cells(i, 1).Value) Then
            ' Copy the value to the destination column
            Cells(targetRow, 7).Value = sourceRange.Cells(i, 1).Value ' 7 is column G
            ' Increment the destination row by skipping 4 rows
            targetRow = targetRow + 4
        End If
    Next i
End Sub
```

Figure 69 - Excel programming window example

- **Prosumer Consumption:** This could vary from being energy-intensive, to preferring to sell most of the produced energy. AGP SpA request all their clients a summary bill of the last 12 months of consumption to understand their energy usage patterns.
- **Consumer Consumption:** This can vary depending on the individual consumer and may also represent a sum of multiple consumers in cases where there are several users. This is based on the provided bills, or simulated to understand how much energy consumption is needed to reach the sharing target.



	CONSUMERS SUMMARY							
	1	2	3	4	5	6	7	1+2+3
	kWh/15 min	kWh/15 min	kWh/15 min	kWh/15 min	kWh/15 min	kWh/15 min	kWh/15 min	kWh/15 min
F1	8	5	3	41	100	70	0	16
F2	6	4	2	21	54	13	0	11
F3	5	3	2	18	57	8	0	10

Figure 70 - Consumer consumption bands summary

As shown in figure 70, the values for the three consumption bands F1, F2 and F3 are summarized in the same Excel sheet. Since the values are already divided in the different days of the year, the "Find and Replace" command can be used to substitute the values for each consumer or prosumer across the three different bands. Each time just replace the values with the data corresponding to another consumer or prosumer.

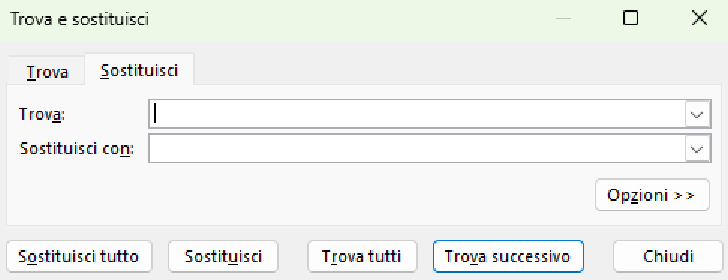


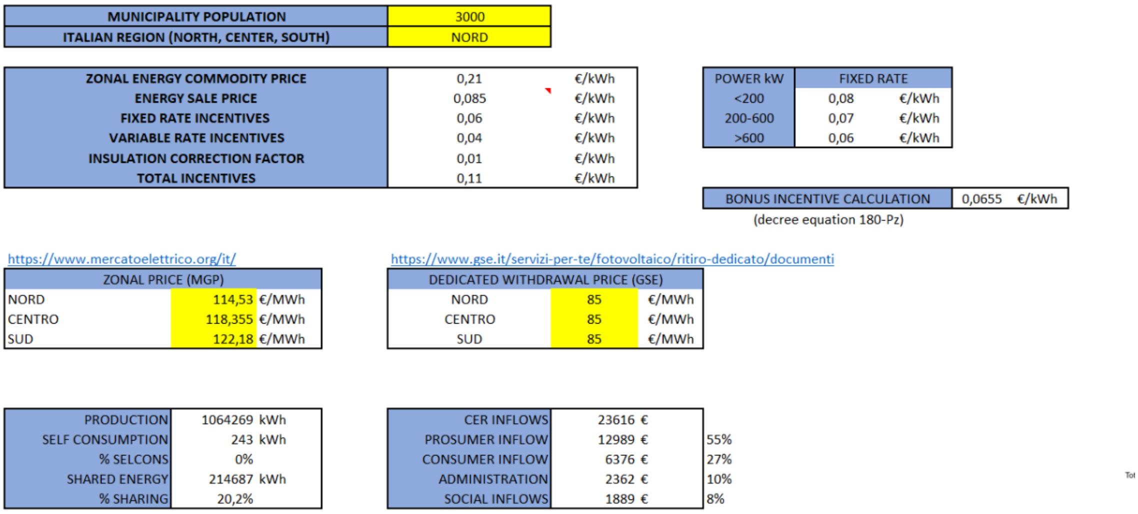
Figure 71 - Find and Replace window to use for consumers

4.1.2. Economic analysis

Regarding the economic analysis, the model is divided into three Excel sheets:

- **Generic Incentive Analysis Sheet**: This sheet provides a broad overview of the incentive structure, calculation of tariffs and distribution of inflows.
- **Detailed Analysis for the Prosumer Sheet**: This sheet contains a detailed economic analysis specifically for the prosumer who makes the investment.
- **Analysis for the Prosumer Outside a CER Sheet**: This sheet presents a similar analysis for the prosumer but this time not taking part in a REC.

All calculations are performed in accordance with the regulations specified in the REC Decree [25] regarding incentive calculations, incorporating both fixed and variable tariffs and considering correction factors. The incentive percentages to be allocated among members are derived from existing REC models validated by national authorities.



MUNICIPALITY POPULATION	3000
ITALIAN REGION (NORTH, CENTER, SOUTH)	NORD

ZONAL ENERGY COMMODITY PRICE	0,21	€/kWh
ENERGY SALE PRICE	0,085	€/kWh
FIXED RATE INCENTIVES	0,06	€/kWh
VARIABLE RATE INCENTIVES	0,04	€/kWh
INSULATION CORRECTION FACTOR	0,01	€/kWh
TOTAL INCENTIVES	0,11	€/kWh

POWER kW	FIXED RATE	
<200	0,08	€/kWh
200-600	0,07	€/kWh
>600	0,06	€/kWh

BONUS INCENTIVE CALCULATION	0,0655	€/kWh

(decree equation 180-Pz)

https://www.mercatoelettrico.org/it/

ZONAL PRICE (MGP)		
NORD	114,53	€/MWh
CENTRO	118,355	€/MWh
SUD	122,18	€/MWh

https://www.gse.it/servizi-per-te/fotovoltaico/ritiro-dedicato/documenti

DEDICATED WITHDRAWAL PRICE (GSE)		
NORD	85	€/MWh
CENTRO	85	€/MWh
SUD	85	€/MWh

PRODUCTION	1064269	kWh
SELF CONSUMPTION	243	kWh
% SELCONS	0%	
SHARED ENERGY	214687	kWh
% SHARING	20,2%	

CER INFLOWS	23616 €	
PROSUMER INFLOW	12989 €	55%
CONSUMER INFLOW	6376 €	27%
ADMINISTRATION	2362 €	10%
SOCIAL INFLOWS	1889 €	8%

Figure 72 - Generic economic analysis sheet

The input values (in yellow) are:

- **The number of inhabitants in the municipality where the prosumer is located:** this determines whether the prosumer is eligible for the PNRR (National Recovery and Resilience Plan) contribution.
- **The region of Italy:** this is used to define the irradiation correction factor based on the geographical location.
- **Updated energy market values** [41][42]: these reflect the current market conditions and are used for accurate calculations.

On the right side of the sheet, values specified by the decree for calculating the fixed tariff and those for calculating the variable tariff.

All other values are derived from equations that use conditional statements (IF functions) to select the appropriate values for each region and power range.

Below, indicative values extracted from the Decree:

Table 5 - REC Decree tariffs

Plant Power	Incentive tariff
P < 200 kW	80 €/MWh + 0/40 €/MWh
200 kW < P < 600 kW	70 €/MWh + 0/40 €/MWh
P > 600 kW	60 €/MWh + 0/40 €/MWh

Table 6 - Tariff increase based on italian zones

Geographic zone	Tariff increase
South regions	-
Centre regions	+ 4 €/MWh
North regions	+ 10 €/MWh

$$Variable\ rate\ incentive = \begin{cases} 180 - ZP\dfrac{€}{MWh}, if\ 180 - ZP < 40 \\ 40\dfrac{€}{MWh}, if\ 180 - ZP \geq 40 \end{cases} \qquad (9)$$

With:

$ZP = zonal\ price$

With the automatically calculated incentivizing tariff and the summary of performance values calculated in the previous chapter, the community's revenues are calculated under the section CER INFLOWS.

This amount in euros must then be distributed among the various participants in the community according to the most popular model in Italy in current period [43]:

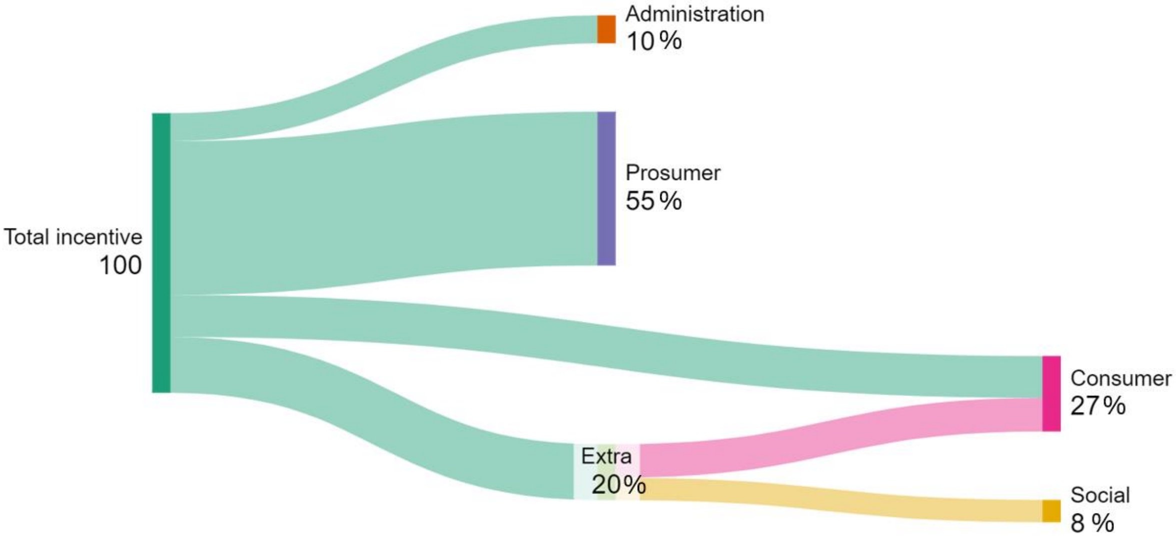


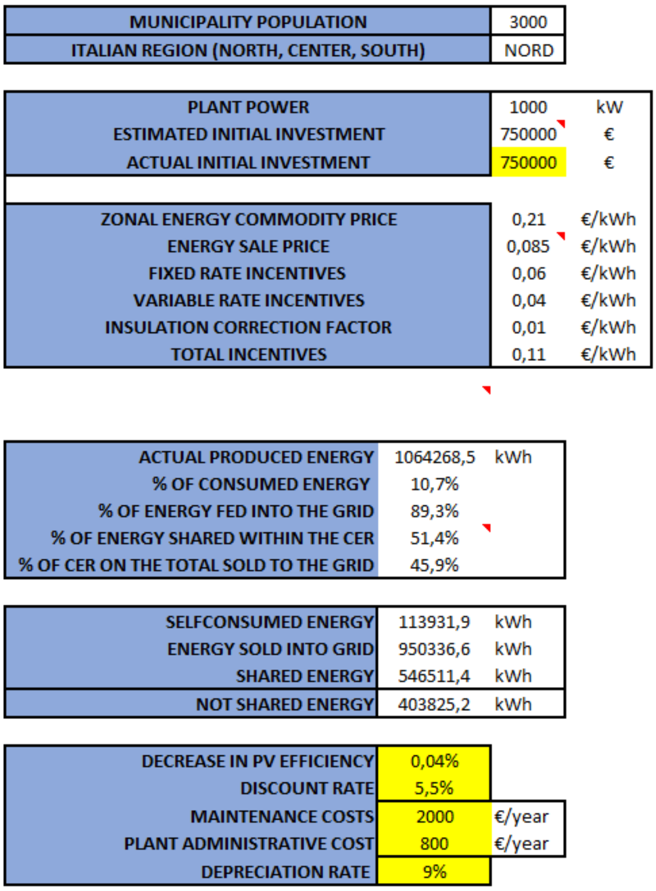
Figure 73 - Incentive users distribution

As illustrated in Figure 73, all revenue from the incentives and the sale of energy flows through the association specifically established to manage the REC. These funds are then distributed among the users, with 10% retained for management with the GSE.

The remaining 90% is allocated as follows:

- **55%** to the prosumer;
- **27%** to the consumers;
- **8%** for social initiatives in the area where the REC is located.

The calculated values are subsequently utilized in the following sheets to perform a comprehensive economic analysis tailored for prosumers considering an investment in renewable energy installations. This detailed evaluation helps potential investors assess the financial viability and returns of such projects.



MUNICIPALITY POPULATION	3000
ITALIAN REGION (NORTH, CENTER, SOUTH)	NORD

PLANT POWER	1000	kW
ESTIMATED INITIAL INVESTMENT	750000	€
ACTUAL INITIAL INVESTMENT	750000	€

ZONAL ENERGY COMMODITY PRICE	0,21	€/kWh
ENERGY SALE PRICE	0,085	€/kWh
FIXED RATE INCENTIVES	0,06	€/kWh
VARIABLE RATE INCENTIVES	0,04	€/kWh
INSULATION CORRECTION FACTOR	0,01	€/kWh
TOTAL INCENTIVES	0,11	€/kWh

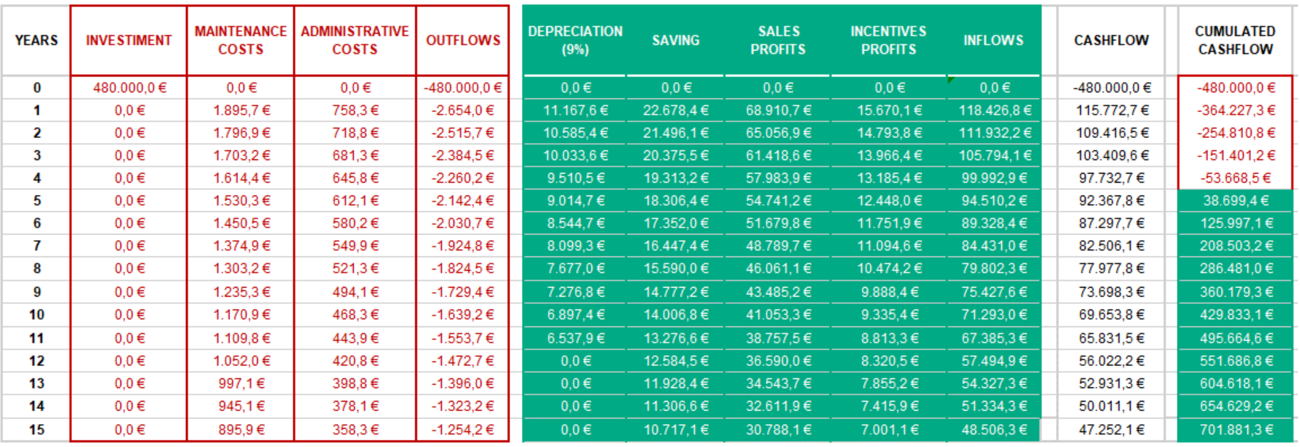
ACTUAL PRODUCED ENERGY	1064268,5	kWh
% OF CONSUMED ENERGY	10,7%	
% OF ENERGY FED INTO THE GRID	89,3%	
% OF ENERGY SHARED WITHIN THE CER	51,4%	
% OF CER ON THE TOTAL SOLD TO THE GRID	45,9%	

SELFCONSUMED ENERGY	113931,9	kWh
ENERGY SOLD INTO GRID	950336,6	kWh
SHARED ENERGY	546511,4	kWh
NOT SHARED ENERGY	403825,2	kWh

DECREASE IN PV EFFICIENCY	0,04%	
DISCOUNT RATE	5,5%	
MAINTENANCE COSTS	2000	€/year
PLANT ADMINISTRATIVE COST	800	€/year
DEPRECIATION RATE	9%	

Figure 74 - Summary of factors used for economic analysis

By entering the values into the yellow-highlighted cells, the economic analysis is set up to calculate the necessary financial metrics.



YEARS	INVESTIMENT	MAINTENANCE COSTS	ADMINISTRATIVE COSTS	OUTFLOWS	DEPRECIATION (9%)	SAVING	SALES PROFITS	INCENTIVES PROFITS	INFLOWS	CASHFLOW	CUMULATED CASHFLOW
0	480.000,0 €	0,0 €	0,0 €	-480.000,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	-480.000,0 €	-480.000,0 €
1	0,0 €	1.895,7 €	758,3 €	-2.654,0 €	11.167,6 €	22.678,4 €	68.910,7 €	15.670,1 €	118.426,8 €	115.772,7 €	-364.227,3 €
2	0,0 €	1.796,9 €	718,8 €	-2.515,7 €	10.585,4 €	21.496,1 €	65.056,9 €	14.793,8 €	111.932,2 €	109.416,5 €	-254.810,8 €
3	0,0 €	1.703,2 €	681,3 €	-2.384,5 €	10.033,6 €	20.375,5 €	61.418,6 €	13.966,4 €	105.794,1 €	103.409,6 €	-151.401,2 €
4	0,0 €	1.614,4 €	645,8 €	-2.260,2 €	9.510,5 €	19.313,2 €	57.983,9 €	13.185,4 €	99.992,9 €	97.732,7 €	-53.668,5 €
5	0,0 €	1.530,3 €	612,1 €	-2.142,4 €	9.014,7 €	18.306,4 €	54.741,2 €	12.448,0 €	94.510,2 €	92.367,8 €	38.699,4 €
6	0,0 €	1.450,5 €	580,2 €	-2.030,7 €	8.544,7 €	17.352,0 €	51.679,8 €	11.751,9 €	89.328,4 €	87.297,7 €	125.997,1 €
7	0,0 €	1.374,9 €	549,9 €	-1.924,8 €	8.099,3 €	16.447,4 €	48.789,7 €	11.094,6 €	84.431,0 €	82.506,1 €	208.503,2 €
8	0,0 €	1.303,2 €	521,3 €	-1.824,5 €	7.677,0 €	15.590,0 €	46.061,1 €	10.474,2 €	79.802,3 €	77.977,8 €	286.481,0 €
9	0,0 €	1.235,3 €	494,1 €	-1.729,4 €	7.276,8 €	14.777,2 €	43.485,2 €	9.888,4 €	75.427,6 €	73.698,3 €	360.179,3 €
10	0,0 €	1.170,9 €	468,3 €	-1.639,2 €	6.897,4 €	14.006,8 €	41.053,3 €	9.335,4 €	71.293,0 €	69.653,8 €	429.833,1 €
11	0,0 €	1.109,8 €	443,9 €	-1.553,7 €	6.537,9 €	13.276,6 €	38.757,5 €	8.813,3 €	67.385,3 €	65.831,5 €	495.664,6 €
12	0,0 €	1.052,0 €	420,8 €	-1.472,7 €	0,0 €	12.584,5 €	36.590,0 €	8.320,5 €	57.494,9 €	56.022,2 €	551.686,8 €
13	0,0 €	997,1 €	398,8 €	-1.396,0 €	0,0 €	11.928,4 €	34.543,7 €	7.855,2 €	54.327,3 €	52.931,3 €	604.618,1 €
14	0,0 €	945,1 €	378,1 €	-1.323,2 €	0,0 €	11.306,6 €	32.611,9 €	7.415,9 €	51.334,3 €	50.011,1 €	654.629,2 €
15	0,0 €	895,9 €	358,3 €	-1.254,2 €	0,0 €	10.717,1 €	30.788,1 €	7.001,1 €	48.506,3 €	47.252,1 €	701.881,3 €

Figure 75 - Full economic analysis

In the following section, the formulas used to calculate all the necessary economic factors are detailed. These formulas are essential for determining the amortization of the investment, the revenues generated from the incentives and energy sales, and the overall financial performance of the project. It is important to note that this analysis does not include taxes, as banks typically require a "cleaner" perspective for this type of investment.

$$Investment[€] = \begin{cases} Actual\ investment, if\ population \geq 5000 \\ 40\%\ of\ actual\ investment, if\ population < 5000 \end{cases} \quad (10)$$

$$Outflows\ [€] = investment + maintenance\ costs + administrative\ costs\ (11)$$

$$Depreciation\ (9\%) = \frac{27\%\ of\ Investment}{11\ years}\ [€](12)$$

$$Saving\ [€] = zonal\ price\ \left[\frac{€}{kWh}\right] \cdot selfconsumed\ energy[kWh]\ (13)$$

$$Sales\ profits\ [€] = energy\ sale\ price\ \left[\frac{€}{kWh}\right] \cdot sold\ energy\ [kWh]\ (14)$$

$$Inflows\ [€] = depreciation + \ saving + sales\ (15)$$

$$Cashflow\ [€] = Inflows - Outflows\ (16)$$

$$Cumulated\ Cashflow\ [€] = \ Cumulated\ cashflow\ (precendent\ year) + Cashflow\ (current\ year)(17)$$

An essential requirement from clients for presenting this analysis to the reference bank is the discounted valuation of the investment, considering the discount rate. To ensure accuracy and relevance, it is imperative that all previously calculated figures be adjusted using the prescribed formula. This adjustment is necessary to account for inflation and the consequent erosion of the value of money over time.

$$Discounting\ factor = \ \frac{1}{(1 + discount\ rate)^{year}}\ (18)$$

The most important factors in this type of economic analysis are the PayBack Time and the Internal Rate of Return (IRR), which respectively represent the time it will take for the investment to start generating net profit and the annual average rate of return that the investment will produce.

The PBT indicates how long it will take to recover the invested capital through positive cash flows generated by the project. The IRR on the other hand, represents the annual compound rate of return that makes the net present value (NPV) of the investment equal to zero. Both factors provide crucial insights into the profitability and effectiveness of the investment.

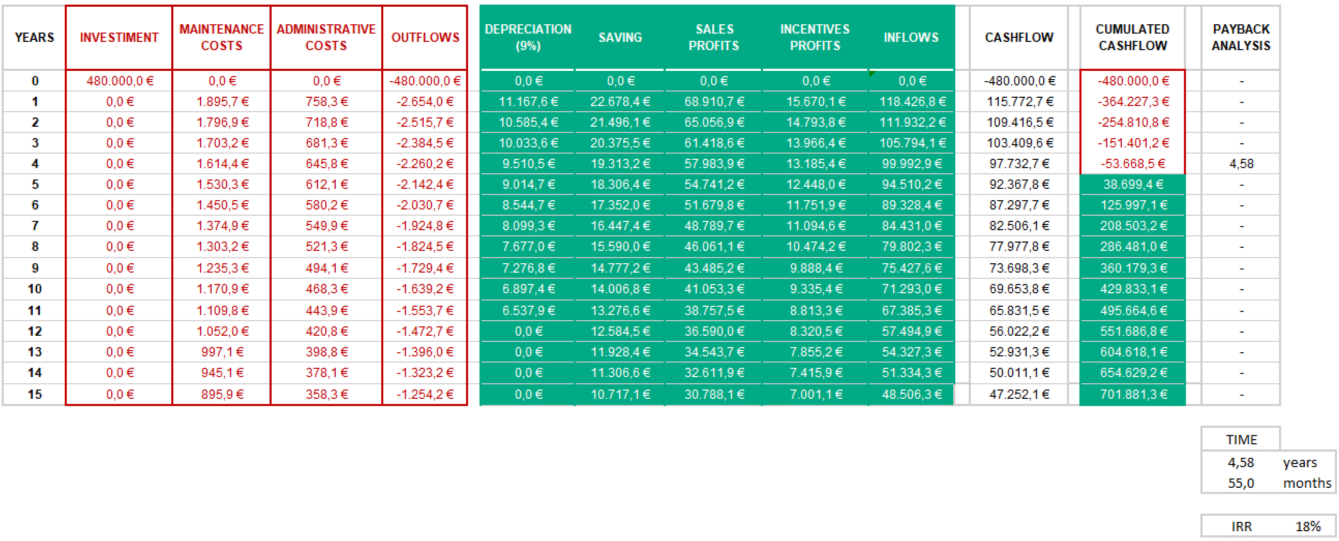
$$Payback\ time\ [years] = \ T + \left| \frac{cumulated\ cash\ flow\ (at\ T)}{cashflow\ (at\ T+1)} \right| \ (19)$$

Where T is the year where we can find the last negative value of cumulated cashflow.

$$NPV = \ \sum_{t=0}^{n} \frac{CF}{(1+IRR)^{t}} = 0\ (20)$$

Where:

- NPV is the net present value.
- CFt represents the cash flow at time t.
- IRR is the internal rate of return.
- t is the time period (e.g., year).
- n is the total number of periods.



YEARS	INVESTIMENT	MAINTENANCE COSTS	ADMINISTRATIVE COSTS	OUTFLOWS	DEPRECIATION (9%)	SAVING	SALES PROFITS	INCENTIVES PROFITS	INFLOWS	CASHFLOW	CUMULATED CASHFLOW	PAYBACK ANALYSIS
0	480.000,0 €	0,0 €	0,0 €	-480.000,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	-480.000,0 €	-480.000,0 €	-
1	0,0 €	1.895,7 €	758,3 €	-2.654,0 €	11.167,6 €	22.678,4 €	68.910,7 €	15.670,1 €	118.426,8 €	115.772,7 €	-364.227,3 €	-
2	0,0 €	1.796,9 €	718,8 €	-2.515,7 €	10.585,4 €	21.496,1 €	65.056,9 €	14.793,8 €	111.932,2 €	109.416,5 €	-254.810,8 €	-
3	0,0 €	1.703,2 €	681,3 €	-2.384,5 €	10.033,6 €	20.375,5 €	61.418,6 €	13.966,4 €	105.794,1 €	103.409,6 €	-151.401,2 €	-
4	0,0 €	1.614,4 €	645,8 €	-2.260,2 €	9.510,5 €	19.313,2 €	57.983,9 €	13.185,4 €	99.992,9 €	97.732,7 €	-53.668,5 €	4,58
5	0,0 €	1.530,3 €	612,1 €	-2.142,4 €	9.014,7 €	18.306,4 €	54.741,2 €	12.448,0 €	94.510,2 €	92.367,8 €	38.699,4 €	-
6	0,0 €	1.450,5 €	580,2 €	-2.030,7 €	8.544,7 €	17.352,0 €	51.679,8 €	11.751,9 €	89.328,4 €	87.297,7 €	125.997,1 €	-
7	0,0 €	1.374,9 €	549,9 €	-1.924,8 €	8.099,3 €	16.447,4 €	48.789,7 €	11.094,6 €	84.431,0 €	82.506,1 €	208.503,2 €	-
8	0,0 €	1.303,2 €	521,3 €	-1.824,5 €	7.677,0 €	15.590,0 €	46.061,1 €	10.474,2 €	79.802,3 €	77.977,8 €	286.481,0 €	-
9	0,0 €	1.235,3 €	494,1 €	-1.729,4 €	7.276,8 €	14.777,2 €	43.485,2 €	9.888,4 €	75.427,6 €	73.698,3 €	360.179,3 €	-
10	0,0 €	1.170,9 €	468,3 €	-1.639,2 €	6.897,4 €	14.006,8 €	41.053,3 €	9.335,4 €	71.293,0 €	69.653,8 €	429.833,1 €	-
11	0,0 €	1.109,8 €	443,9 €	-1.553,7 €	6.537,9 €	13.276,6 €	38.757,5 €	8.813,3 €	67.385,3 €	65.831,5 €	495.664,6 €	-
12	0,0 €	1.052,0 €	420,8 €	-1.472,7 €	0,0 €	12.584,5 €	36.590,0 €	8.320,5 €	57.494,9 €	56.022,2 €	551.686,8 €	-
13	0,0 €	997,1 €	398,8 €	-1.396,0 €	0,0 €	11.928,4 €	34.543,7 €	7.855,2 €	54.327,3 €	52.931,3 €	604.618,1 €	-
14	0,0 €	945,1 €	378,1 €	-1.323,2 €	0,0 €	11.306,6 €	32.611,9 €	7.415,9 €	51.334,3 €	50.011,1 €	654.629,2 €	-
15	0,0 €	895,9 €	358,3 €	-1.254,2 €	0,0 €	10.717,1 €	30.788,1 €	7.001,1 €	48.506,3 €	47.252,1 €	701.881,3 €	-

TIME	
4,58	years
55,0	months

IRR	18%

Figure 76 - Full economic analysis with PBT and IRR analysis

As we can see in Figure 76, the model provides a PBT analysis that allows for a precise and automatic value, without the need to manually search for the last negative value of the cumulative cash flow each time.

The final crucial aspect of the economic analysis is the graphical representation of the investment. In this case, it can be illustrated through the trend of cumulative cash flow over the years. This visual depiction provides a clear and immediate understanding of how the investment's cash flow evolves over time, highlighting key phases such as the point at which the investment starts to generate net positive returns.

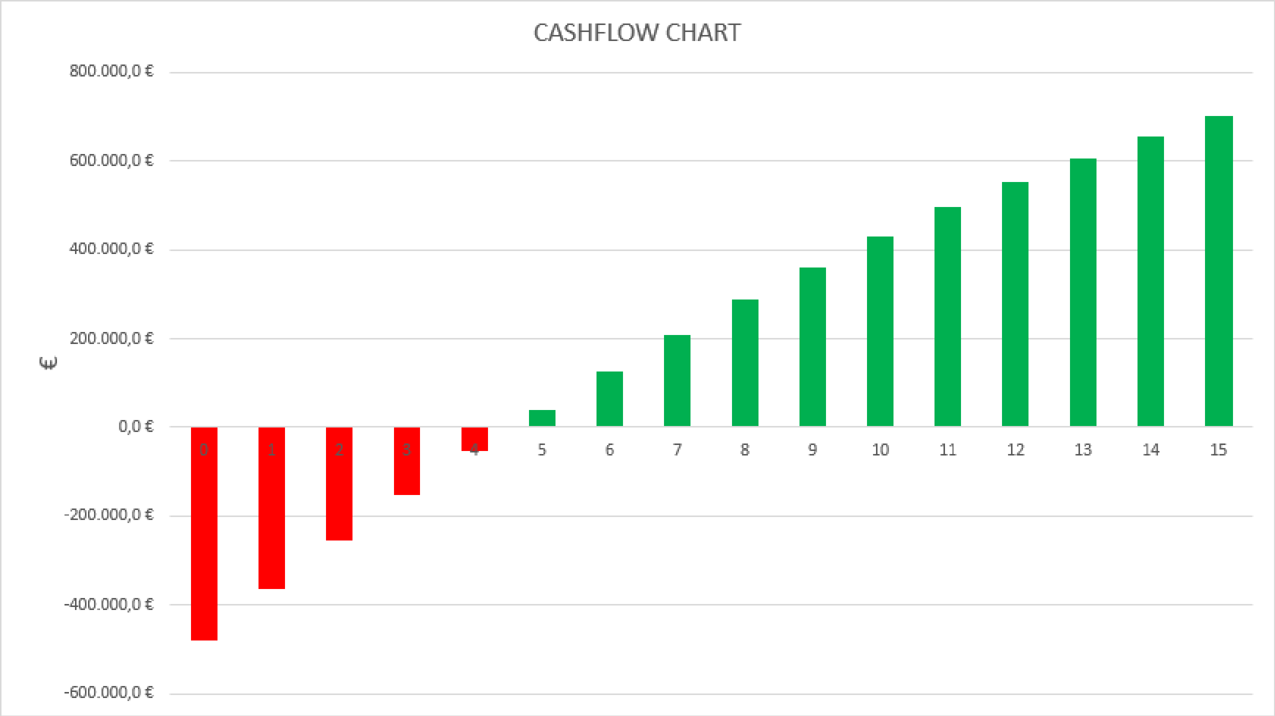
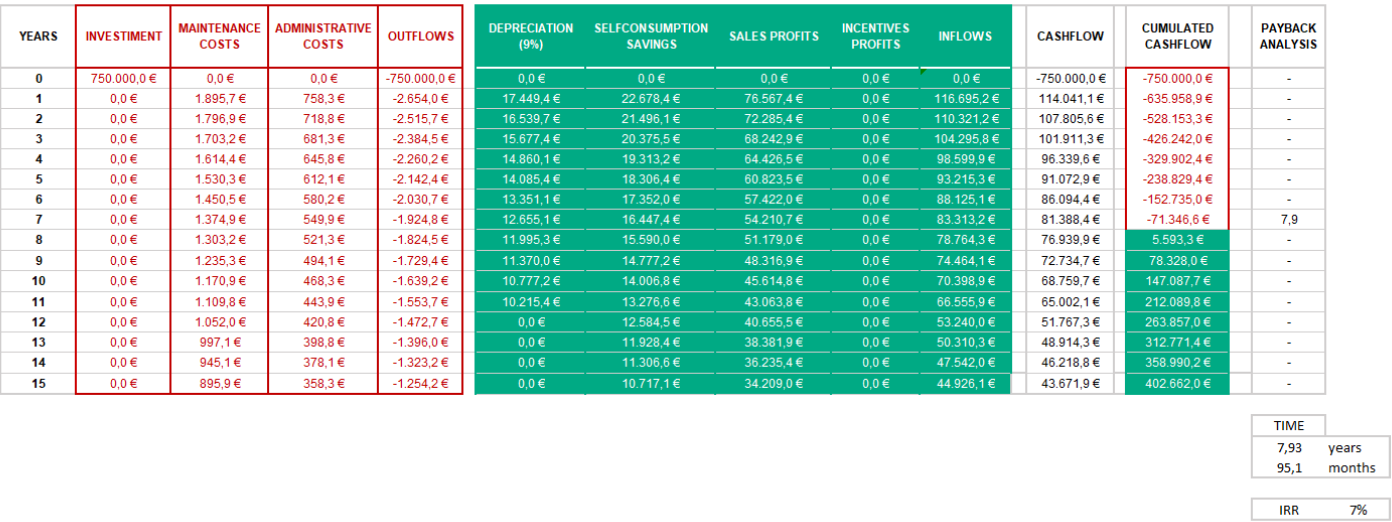


Figure 77 - Cashflow chart highlighting positive negative difference

The same economic analysis is conducted in the final economic worksheet of the model; however, in this case, the incentive column contains null values, and the investment will not benefit from the 40% reduction of PNRR. This additional analysis is intended to highlight the advantages of participating in an energy community compared to making an investment solely for personal benefit. These advantages are not only economic but also social, as previously discussed in an earlier chapter. By illustrating the impact of the grant and the benefits of community involvement, this analysis underscores the broader value of collective engagement beyond individual investments.



YEARS	INVESTIMENT	MAINTENANCE COSTS	ADMINISTRATIVE COSTS	OUTFLOWS	DEPRECIATION (9%)	SELFCONSUMPTION SAVINGS	SALES PROFITS	INCENTIVES PROFITS	INFLOWS	CASHFLOW	CUMULATED CASHFLOW	PAYBACK ANALYSIS
0	750.000,0 €	0,0 €	0,0 €	-750.000,0 €	0,0 €	0,0 €	0,0 €	0,0 €	0,0 €	-750.000,0 €	-750.000,0 €	-
1	0,0 €	1.895,7 €	758,3 €	-2.654,0 €	17.449,4 €	22.678,4 €	76.567,4 €	0,0 €	116.695,2 €	114.041,1 €	-635.958,9 €	-
2	0,0 €	1.796,9 €	718,8 €	-2.515,7 €	16.539,7 €	21.496,1 €	72.285,4 €	0,0 €	110.321,2 €	107.805,6 €	-528.153,3 €	-
3	0,0 €	1.703,2 €	681,3 €	-2.384,5 €	15.677,4 €	20.375,5 €	68.242,9 €	0,0 €	104.295,8 €	101.911,3 €	-426.242,0 €	-
4	0,0 €	1.614,4 €	645,8 €	-2.260,2 €	14.860,1 €	19.313,2 €	64.426,5 €	0,0 €	98.599,9 €	96.339,6 €	-329.902,4 €	-
5	0,0 €	1.530,3 €	612,1 €	-2.142,4 €	14.085,4 €	18.306,4 €	60.823,5 €	0,0 €	93.215,3 €	91.072,9 €	-238.829,4 €	-
6	0,0 €	1.450,5 €	580,2 €	-2.030,7 €	13.351,1 €	17.352,0 €	57.422,0 €	0,0 €	88.125,1 €	86.094,4 €	-152.735,0 €	-
7	0,0 €	1.374,9 €	549,9 €	-1.924,8 €	12.655,1 €	16.447,4 €	54.210,7 €	0,0 €	83.313,2 €	81.388,4 €	-71.346,6 €	7,9
8	0,0 €	1.303,2 €	521,3 €	-1.824,5 €	11.995,3 €	15.590,0 €	51.179,0 €	0,0 €	78.764,3 €	76.939,9 €	5.593,3 €	-
9	0,0 €	1.235,3 €	494,1 €	-1.729,4 €	11.370,0 €	14.777,2 €	48.316,9 €	0,0 €	74.464,1 €	72.734,7 €	78.328,0 €	-
10	0,0 €	1.170,9 €	468,3 €	-1.639,2 €	10.777,2 €	14.006,8 €	45.614,8 €	0,0 €	70.398,9 €	68.759,7 €	147.087,7 €	-
11	0,0 €	1.109,8 €	443,9 €	-1.553,7 €	10.215,4 €	13.276,6 €	43.063,8 €	0,0 €	66.555,9 €	65.002,1 €	212.089,8 €	-
12	0,0 €	1.052,0 €	420,8 €	-1.472,7 €	0,0 €	12.584,5 €	40.655,5 €	0,0 €	53.240,0 €	51.767,3 €	263.857,0 €	-
13	0,0 €	997,1 €	398,8 €	-1.396,0 €	0,0 €	11.928,4 €	38.381,9 €	0,0 €	50.310,3 €	48.914,3 €	312.771,4 €	-
14	0,0 €	945,1 €	378,1 €	-1.323,2 €	0,0 €	11.306,6 €	36.235,4 €	0,0 €	47.542,0 €	46.218,8 €	358.990,2 €	-
15	0,0 €	895,9 €	358,3 €	-1.254,2 €	0,0 €	10.717,1 €	34.209,0 €	0,0 €	44.926,1 €	43.671,9 €	402.662,0 €	-

TIME	
7,93	years
95,1	months

IRR	7%

Figure 78 - Economic analysis without REC

In conclusion, this economic analysis serves two main objectives:

- To clearly illustrate to both the client and the reference bank the investment's performance over time.
- To provide the Payback Period (PBT) and the Internal Rate of Return (IRR) as outputs, enabling the comparison of various scenarios.

By achieving these goals, the analysis facilitates a comprehensive understanding of the investment's trajectory and financial viability, allowing for informed decision-making and effective evaluation of different investment options.

4.2. Cases analysis

In this chapter, the results of the analysis will be presented, with a focus on the performance of the energy community model. By adjusting key variables such as RES Production, Prosumer Consumption, and Consumer Consumption, the aim is to evaluate how different configurations and scenarios impact the overall efficiency and sustainability. These variables are crucial in determining the balance between energy production, consumption, and sharing within the community, making it essential to explore how variations in these parameters influence the outcome.

The first parameter, RES Production, is central to the operation of the energy community. It represents the renewable energy generated by various sources and is adjusted to reflect different production levels depending on the location and type of energy sources. Precise simulators and historical data were used to ensure an accurate alignment between production and consumption data. Since the distributor provides consumption data in quarter-hourly intervals, while production data is typically available on an hourly basis, Excel was programmed to adjust the hourly production input, ensuring seamless integration with the consumption data. The objective of adjusting the production is to determine which type of technology is most suitable for this model.

The second variable, Prosumer Consumption, refers to the energy use of prosumers, community members who both consume and produce energy. By varying this parameter, different prosumer behaviors are examined, ranging from high energy consumption to a preference for selling surplus energy. This data is informed by a summary of the last 12 months of consumption requested by AGP SpA, providing valuable insight into typical energy usage patterns. This flexibility allows the model to adapt to different types of prosumers, each with unique energy needs and contributions to the community.

Finally, Consumer Consumption represents the energy demand of non-prosumer members within the community. This can range from individual consumers to a collective group of multiple users. This variable is informed by historical billing data or, when necessary, simulated consumption levels to explore how energy consumption impacts the community's ability to reach its energy-sharing targets. By modifying this parameter, the aim is to assess the energy requirements needed to optimize resource sharing and meet sustainability goals.

The following analysis will explore how these three key variables influence the energy community's performance, providing insight into the best strategies for achieving energy balance, maximizing efficiency, and meeting sharing objectives. Through this exploration, actionable insights will be provided for the optimal operation of energy communities under different conditions.

It is important to specify that all the scenarios analyze a 1 MW system for all three technologies, across all the regions of Italy that were examined. The same power, with different technologies and different regions of Italy, is expected to produce varying amounts of energy. The main differences, aside from the energy produced, are expected to be in CAPEX and OPEX, as in table 7, which can even make a technology highly disadvantageous.

Table 7 - CAPEX and OPEX values of different technologies for 1 MW plant

	CAPEX	OPEX
PHOTOVOLTAIC	750.000 €	10.000 €/year
EOLIC	1.500.000 €	30.000 €/year
HYDRO	3.000.000 €	60.000 €/year

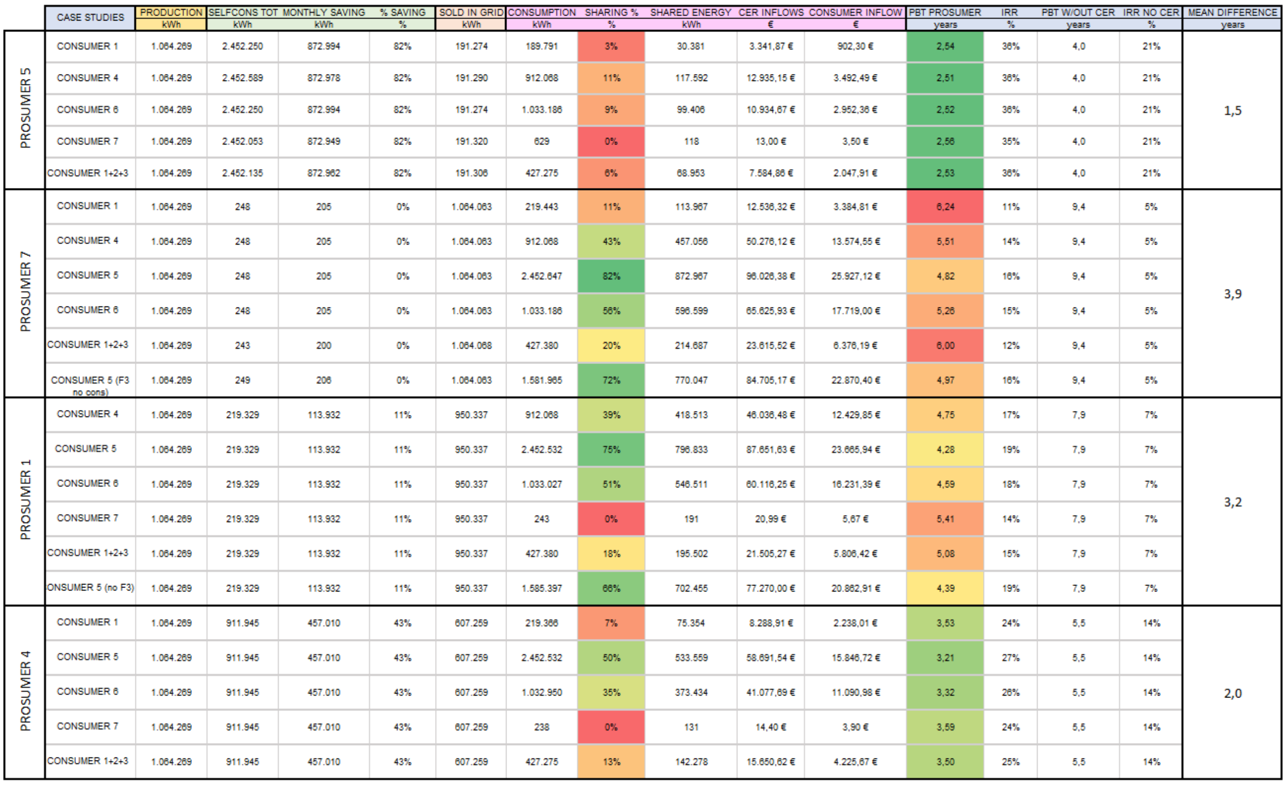
As shown in Table 7, the least expensive technology is photovoltaics, while wind power costs twice as much and hydroelectricity even four times more. At first glance, it may seem that the latter two technologies cannot compete with the first, but the results will also depend on how much energy is produced and subsequently consumed.

In the subsequent sections, the key values to be analyzed will pertain to both performance and economic factors, previously discussed. Among these, particular attention will be given to the sharing percentage and the payback period, together with a new parameter, called DIFF for simplicity, which represents the mean difference between the payback time within a REC and without the participation in a REC. All analysis conducted will be presented, followed by a detailed examination.

4.2.1. Photovoltaic prosumer

In figure 79 it is shown an example of the analysis conducted on all the different scenarios. As can be seen, four distinct prosumers were chosen from the set of consumers initially considered. Prosumer 5 represents the highest energy consumer, Prosumer 7 is a user with no consumption who intends to sell all generated energy, Prosumer 1 is a typical supermarket in Italy, and finally, Prosumer 4 is a medium-sized energy-intensive company.

With regard to consumers, analyzed various scenarios were analyzed. In addition to pairing the same four previously mentioned prosumers, other cases were also considered. Among these is Consumer 6, another energy-intensive company with lower consumption during the F3 period, the combination of three supermarkets to represent a hypermarket, and finally, an examination of how the situation would change if the most energy-intensive consumer had zero consumption during the F3 period, in order to understand the impact of this factor.



	CASE STUDIES	PRODUCTION	SELFCONS TOT	MONTHLY SAVING	% SAVING	SOLD IN GRID	CONSUMPTION	SHARING %	SHARED ENERGY	CER INFLOWS	CONSUMER INFLOW	PBT PROSUMER	IRR	PBT W/OUT CER	IRR NO CER	MEAN DIFFERENCE
		kWh	kWh	kWh	%	kWh	kWh	%	kWh	€	€	years	%	years	%	years
PROSUMER 5	CONSUMER 1	1.064.269	2.452.250	872.994	82%	191.274	189.791	3%	30.381	3.341,87 €	902,30 €	2,54	36%	4,0	21%	1,5
	CONSUMER 4	1.064.269	2.452.589	872.978	82%	191.290	912.068	11%	117.592	12.935,15 €	3.492,49 €	2,51	36%	4,0	21%	
	CONSUMER 6	1.064.269	2.452.250	872.994	82%	191.274	1.033.186	9%	99.406	10.934,67 €	2.952,36 €	2,52	36%	4,0	21%	
	CONSUMER 7	1.064.269	2.452.053	872.949	82%	191.320	629	0%	118	13,00 €	3,50 €	2,56	35%	4,0	21%	
	CONSUMER 1+2+3	1.064.269	2.452.135	872.962	82%	191.306	427.275	6%	68.953	7.584,86 €	2.047,91 €	2,53	36%	4,0	21%	
PROSUMER 7	CONSUMER 1	1.064.269	248	205	0%	1.064.063	219.443	11%	113.967	12.536,32 €	3.384,81 €	6,24	11%	9,4	5%	3,9
	CONSUMER 4	1.064.269	248	205	0%	1.064.063	912.068	43%	457.056	50.276,12 €	13.574,55 €	5,51	14%	9,4	5%	
	CONSUMER 5	1.064.269	248	205	0%	1.064.063	2.452.647	82%	872.967	96.026,38 €	25.927,12 €	4,82	16%	9,4	5%	
	CONSUMER 6	1.064.269	248	205	0%	1.064.063	1.033.186	56%	596.599	65.625,93 €	17.719,00 €	5,26	15%	9,4	5%	
	CONSUMER 1+2+3	1.064.269	243	200	0%	1.064.068	427.380	20%	214.687	23.615,52 €	6.376,19 €	6,00	12%	9,4	5%	
	CONSUMER 5 (F3 no cons)	1.064.269	249	206	0%	1.064.063	1.581.965	72%	770.047	84.705,17 €	22.870,40 €	4,97	16%	9,4	5%	
PROSUMER 1	CONSUMER 4	1.064.269	219.329	113.932	11%	950.337	912.068	39%	418.513	46.036,48 €	12.429,85 €	4,75	17%	7,9	7%	3,2
	CONSUMER 5	1.064.269	219.329	113.932	11%	950.337	2.452.532	75%	796.833	87.651,63 €	23.665,94 €	4,28	19%	7,9	7%	
	CONSUMER 6	1.064.269	219.329	113.932	11%	950.337	1.033.027	51%	546.511	60.116,25 €	16.231,39 €	4,59	18%	7,9	7%	
	CONSUMER 7	1.064.269	219.329	113.932	11%	950.337	243	0%	191	20,99 €	5,67 €	5,41	14%	7,9	7%	
	CONSUMER 1+2+3	1.064.269	219.329	113.932	11%	950.337	427.380	18%	195.502	21.505,27 €	5.806,42 €	5,08	15%	7,9	7%	
	ONSUMER 5 (no F3)	1.064.269	219.329	113.932	11%	950.337	1.585.397	66%	702.455	77.270,00 €	20.862,91 €	4,39	19%	7,9	7%	
PROSUMER 4	CONSUMER 1	1.064.269	911.945	457.010	43%	607.259	219.366	7%	75.354	8.288,91 €	2.238,01 €	3,53	24%	5,5	14%	2,0
	CONSUMER 5	1.064.269	911.945	457.010	43%	607.259	2.452.532	50%	533.559	58.691,54 €	15.846,72 €	3,21	27%	5,5	14%	
	CONSUMER 6	1.064.269	911.945	457.010	43%	607.259	1.032.950	35%	373.434	41.077,69 €	11.090,98 €	3,32	26%	5,5	14%	
	CONSUMER 7	1.064.269	911.945	457.010	43%	607.259	238	0%	131	14,40 €	3,90 €	3,59	24%	5,5	14%	
	CONSUMER 1+2+3	1.064.269	911.945	457.010	43%	607.259	427.275	13%	142.278	15.650,62 €	4.225,67 €	3,50	25%	5,5	14%	

Figure 79 - Example of results summary photovoltaic

From this initial analysis, which has been confirmed across all other scenarios, two key results emerge both in terms of performance and economic outcomes.

From a performance perspective, the most interesting prosumer is the one with the lowest self-consumption, as it generates significantly more energy to share, as evidenced by the predominance of green in Figure 79. Among the consumers, as expected, the highest percentage of energy consumed within the Energy Community (REC) is associated with Consumer 5, the most energy-intensive user. These findings further validate the reliability of the model.

Other noteworthy results include the least efficient prosumer, which is Prosumer 5, again due to self-consumption reasons, and the least efficient consumer across all scenarios, Consumer 7, as might be anticipated. The remaining consumers and prosumers display similar percentages, yielding the expected results: the combination of lower self-consumption and higher consumption by the consumer leads to better REC performance outcomes.

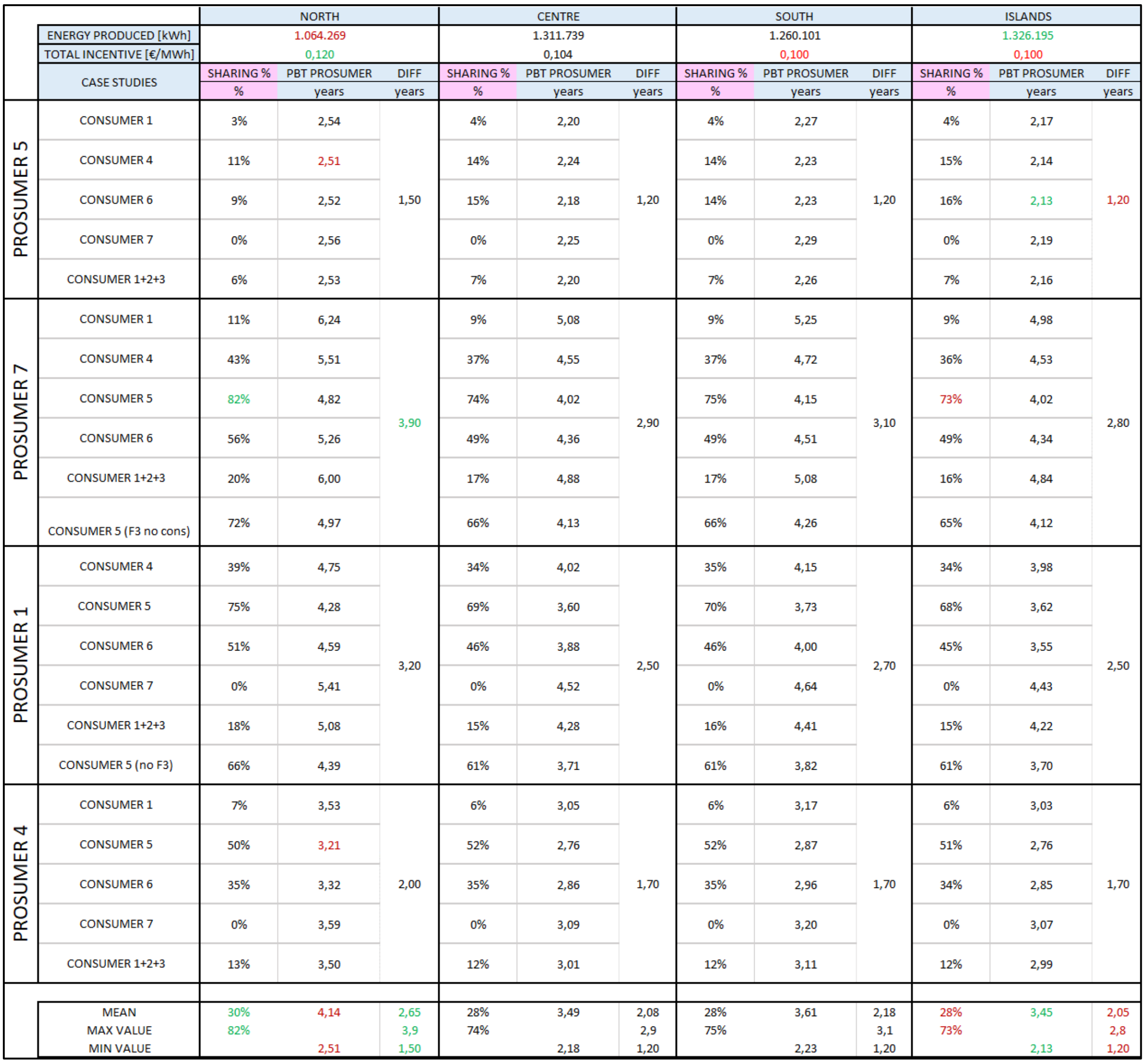
The actual results shift when we analyze the economic factor, where it becomes evident that prosumers with higher self-consumption experience the shortest payback periods, primarily due to the substantial influence of savings. However, this is not a significant discovery regarding energy communities, which are better assessed by looking at the average difference in payback periods between scenarios without the REC (no incentives or grants) and those with the REC. In this case, the best outcome is observed for prosumers with lower self-consumption, particularly Prosumer 7, which demonstrates a difference of over three years, effectively showing that the most advantageous situations for implementing a REC are those with low self-consumption and high energy sales.

It is also worth noting that the overall average difference in payback periods exceeds two years, further proving that participating in an Energy Community is a sound investment in any case.

In general, it is notable that, despite the prosumers with lower self-consumption presents the best performance results, the most interesting results are obtained by most consuming prosumers, as they take advantage of saving money to buy energy, therefore lowering the payback time of the investment independently from the REC configuration. On the other hand, the aim of this research is to analyze RECs effects on different users, so it is important to look to both configurations.

In the following sections, all the scenarios for the various regions and technologies will be presented and later analyzed in detail. This aspect is crucial to identify the most advantageous region of Italy to create and participate in a REC.

Figure 80 provides a summary of the scenarios across various regions of Italy for photovoltaic systems, with particular focus on the sharing percentage and payback time.



		NORTH			CENTRE			SOUTH			ISLANDS		
	ENERGY PRODUCED [kWh]	1.064.269			1.311.739			1.260.101			1.326.195		
	TOTAL INCENTIVE [€/MWh]	0,120			0,104			0,100			0,100		
	CASE STUDIES	SHARING %	PBT PROSUMER	DIFF	SHARING %	PBT PROSUMER	DIFF	SHARING %	PBT PROSUMER	DIFF	SHARING %	PBT PROSUMER	DIFF
		%	years	years	%	years	years	%	years	years	%	years	years
PROSUMER 5	CONSUMER 1	3%	2,54	1,50	4%	2,20	1,20	4%	2,27	1,20	4%	2,17	1,20
	CONSUMER 4	11%	2,51		14%	2,24		14%	2,23		15%	2,14	
	CONSUMER 6	9%	2,52		15%	2,18		14%	2,23		16%	2,13	
	CONSUMER 7	0%	2,56		0%	2,25		0%	2,29		0%	2,19	
	CONSUMER 1+2+3	6%	2,53		7%	2,20		7%	2,26		7%	2,16	
PROSUMER 7	CONSUMER 1	11%	6,24	3,90	9%	5,08	2,90	9%	5,25	3,10	9%	4,98	2,80
	CONSUMER 4	43%	5,51		37%	4,55		37%	4,72		36%	4,53	
	CONSUMER 5	82%	4,82		74%	4,02		75%	4,15		73%	4,02	
	CONSUMER 6	56%	5,26		49%	4,36		49%	4,51		49%	4,34	
	CONSUMER 1+2+3	20%	6,00		17%	4,88		17%	5,08		16%	4,84	
	CONSUMER 5 (F3 no cons)	72%	4,97		66%	4,13		66%	4,26		65%	4,12	
PROSUMER 1	CONSUMER 4	39%	4,75	3,20	34%	4,02	2,50	35%	4,15	2,70	34%	3,98	2,50
	CONSUMER 5	75%	4,28		69%	3,60		70%	3,73		68%	3,62	
	CONSUMER 6	51%	4,59		46%	3,88		46%	4,00		45%	3,55	
	CONSUMER 7	0%	5,41		0%	4,52		0%	4,64		0%	4,43	
	CONSUMER 1+2+3	18%	5,08		15%	4,28		16%	4,41		15%	4,22	
	CONSUMER 5 (no F3)	66%	4,39		61%	3,71		61%	3,82		61%	3,70	
PROSUMER 4	CONSUMER 1	7%	3,53	2,00	6%	3,05	1,70	6%	3,17	1,70	6%	3,03	1,70
	CONSUMER 5	50%	3,21		52%	2,76		52%	2,87		51%	2,76	
	CONSUMER 6	35%	3,32		35%	2,86		35%	2,96		34%	2,85	
	CONSUMER 7	0%	3,59		0%	3,09		0%	3,20		0%	3,07	
	CONSUMER 1+2+3	13%	3,50		12%	3,01		12%	3,11		12%	2,99	
	MEAN	30%	4,14	2,65	28%	3,49	2,08	28%	3,61	2,18	28%	3,45	2,05
	MAX VALUE	82%		3,9	74%		2,9	75%		3,1	73%		2,8
	MIN VALUE		2,51	1,50		2,18	1,20		2,23	1,20		2,13	1,20

Figure 80 - Summary for photovoltaic REC cases

In this case, the best REC performance results are observed in Northern Italy, both in terms of average and maximum values, surpassing the other regions by at least six percentage points. The remaining three zones show very similar results, with the lowest figures recorded in the Islands.

From an economic standpoint, however, the best scenario is found in the Islands, with average payback times significantly lower than those in the worst-performing region, the North.

A noteworthy observation concerns the energy produced by the plants in the various regions: while the North does indeed exhibit higher performance, its energy generation is considerably lower than in the other regions. As the same consumers are present in all areas, the percentage of shared energy will naturally be higher in the North. The fact that the regions with higher energy production are more economically advantageous demonstrates once again that, with the same consumers, the zones with greater energy generation are the most suitable for an investment of this type.

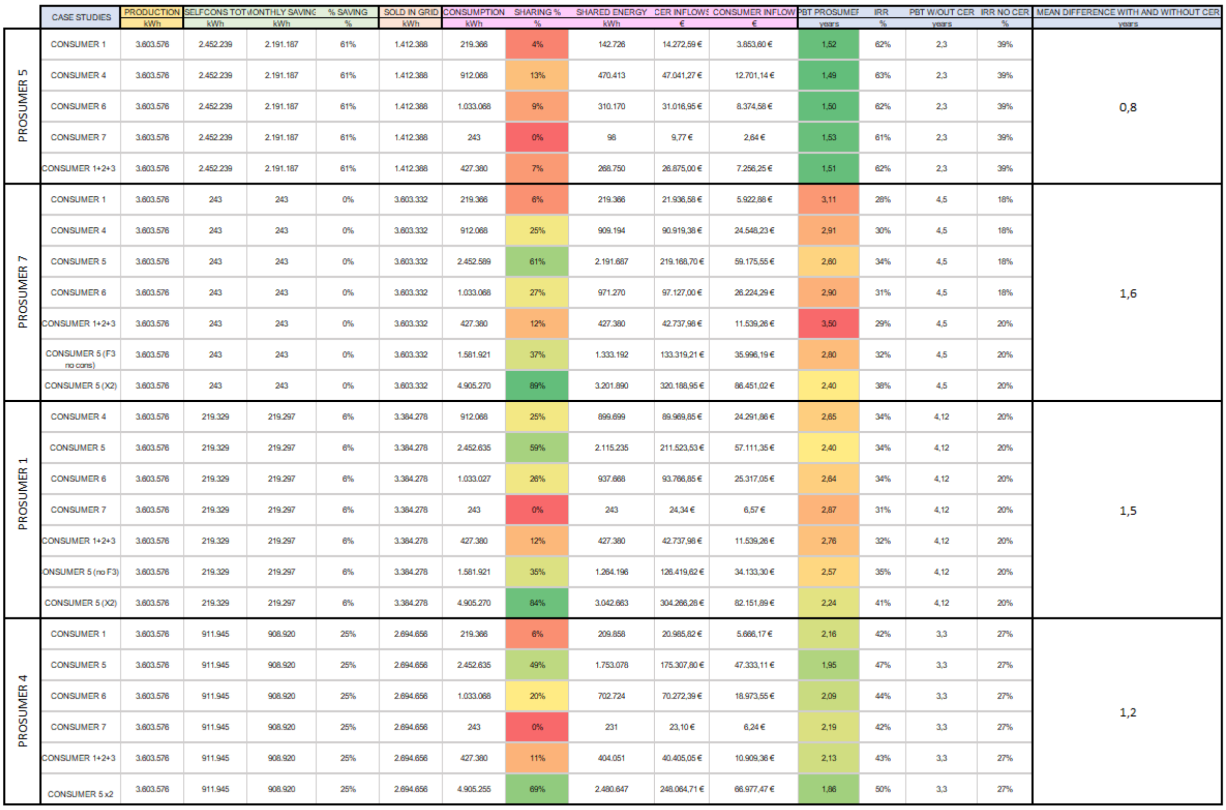
Analyzing the DIFF values, it becomes apparent that the North exhibits a wider gap compared to other regions, highlighting the fact that higher performance of the energy community correlates with greater economic improvements. This outcome positions Northern Italy as the region where the establishment of an energy community would be most effective.

Overall, photovoltaic systems present excellent economic values, benefiting from the cost-effectiveness of the investment. On the performance side, the average values are relatively low across Italy, with peaks exceeding 70% only in cases of minimal self-consumption and higher consumer demand, thus in the optimized REC configuration, as previously discussed.

4.2.2. Eolic prosumer

The same analysis performed for photovoltaics has been extended to wind power. However, due to the significantly higher energy output from wind turbines, as will be shown in the subsequent sections, an additional consumer profile with double the consumption of Consumer 5 has been introduced. This adjustment aims to optimize the utilization of the surplus energy generated by wind power and better align consumption with production, thereby enhancing the overall efficiency of the system.

As shown in Figure 81, once again, the best performance of the energy community is observed where there is the lowest level of self-consumption and the highest consumption by the consumer. However, these results do not translate into an economic advantage, as prosumers with the highest self-consumption rates experience significantly shorter payback periods compared to the average.



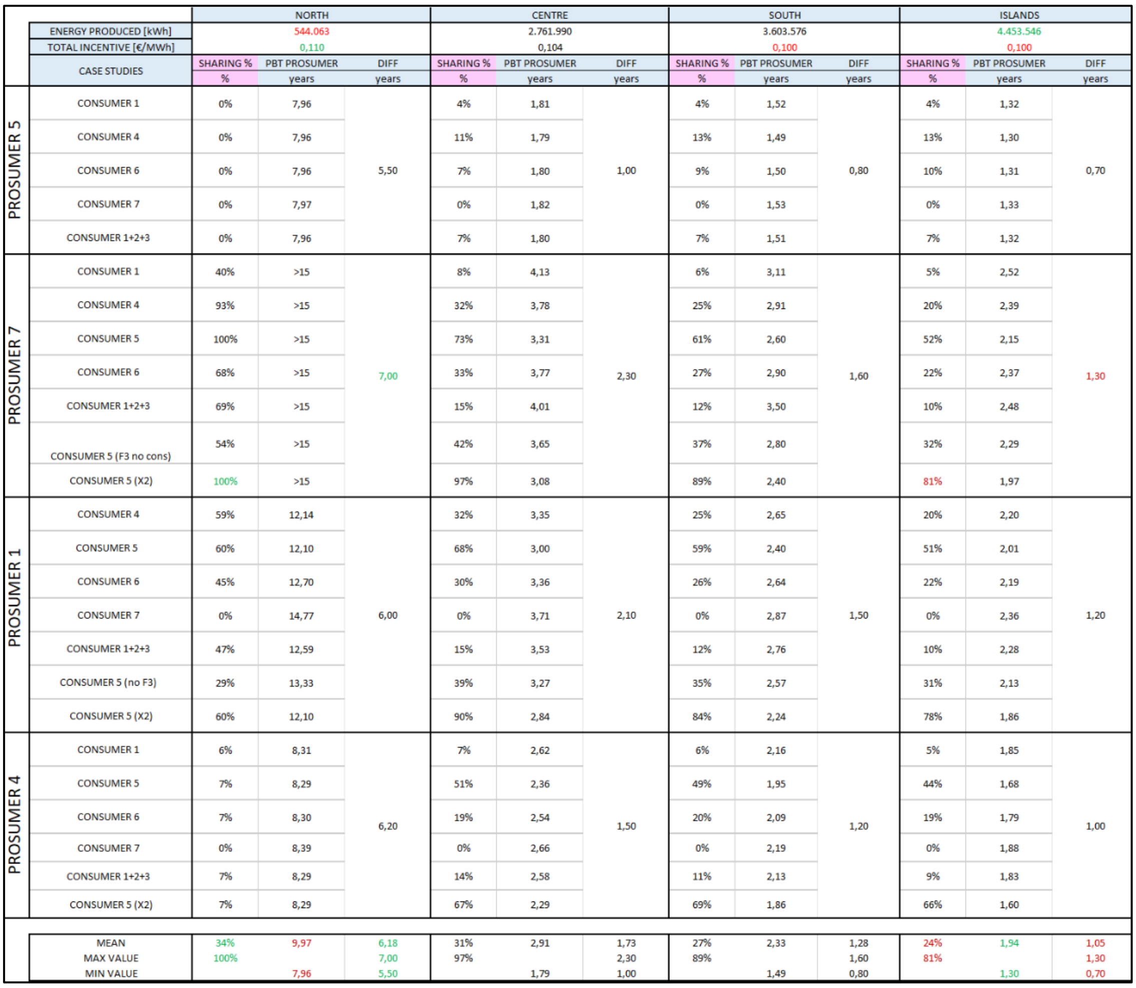
	CASE STUDIES	PRODUCTION	SELFCONS TOT	ONTHLY SAVING	% SAVING	SOLD IN GRID	CONSUMPTION	SHARING %	SHARED ENERGY	CER INFLOWS	CONSUMER INFLOW	BT PROSUMER	IRR	PBT W/OUT CER	IRR NO CER	MEAN DIFFERENCE WITH AND WITHOUT CER
		kWh	kWh	kWh	%	kWh	kWh	%	kWh	€	€	years	%	years	%	years
PROSUMER 5	CONSUMER 1	3.603.576	2.452.239	2.191.187	61%	1.412.388	219.366	4%	142.726	14.272,59 €	3.853,60 €	1,52	62%	2,3	39%	0,8
	CONSUMER 4	3.603.576	2.452.239	2.191.187	61%	1.412.388	912.068	13%	470.413	47.041,27 €	12.701,14 €	1,49	63%	2,3	39%	
	CONSUMER 6	3.603.576	2.452.239	2.191.187	61%	1.412.388	1.033.068	9%	310.170	31.016,95 €	8.374,58 €	1,50	62%	2,3	39%	
	CONSUMER 7	3.603.576	2.452.239	2.191.187	61%	1.412.388	243	0%	98	9,77 €	2,64 €	1,53	61%	2,3	39%	
	CONSUMER 1+2+3	3.603.576	2.452.239	2.191.187	61%	1.412.388	427.380	7%	268.750	26.875,00 €	7.256,25 €	1,51	62%	2,3	39%	
PROSUMER 7	CONSUMER 1	3.603.576	243	243	0%	3.603.332	219.366	6%	219.366	21.936,58 €	5.922,88 €	3,11	28%	4,5	18%	1,6
	CONSUMER 4	3.603.576	243	243	0%	3.603.332	912.068	25%	909.194	90.919,38 €	24.548,23 €	2,91	30%	4,5	18%	
	CONSUMER 5	3.603.576	243	243	0%	3.603.332	2.452.589	61%	2.191.687	219.168,70 €	59.175,55 €	2,60	34%	4,5	18%	
	CONSUMER 6	3.603.576	243	243	0%	3.603.332	1.033.068	27%	971.270	97.127,00 €	26.224,29 €	2,90	31%	4,5	18%	
	CONSUMER 1+2+3	3.603.576	243	243	0%	3.603.332	427.380	12%	427.380	42.737,98 €	11.539,26 €	3,50	29%	4,5	20%	
	CONSUMER 5 (F3 no cons)	3.603.576	243	243	0%	3.603.332	1.581.921	37%	1.333.192	133.319,21 €	35.996,19 €	2,80	32%	4,5	20%	
	CONSUMER 5 (X2)	3.603.576	243	243	0%	3.603.332	4.905.270	89%	3.201.890	320.188,95 €	86.451,02 €	2,40	38%	4,5	20%	
PROSUMER 1	CONSUMER 4	3.603.576	219.329	219.297	6%	3.384.278	912.068	25%	899.699	89.969,85 €	24.291,86 €	2,65	34%	4,12	20%	1,5
	CONSUMER 5	3.603.576	219.329	219.297	6%	3.384.278	2.452.635	59%	2.115.235	211.523,53 €	57.111,35 €	2,40	34%	4,12	20%	
	CONSUMER 6	3.603.576	219.329	219.297	6%	3.384.278	1.033.027	26%	937.668	93.766,85 €	25.317,05 €	2,64	34%	4,12	20%	
	CONSUMER 7	3.603.576	219.329	219.297	6%	3.384.278	243	0%	243	24,34 €	6,57 €	2,87	31%	4,12	20%	
	CONSUMER 1+2+3	3.603.576	219.329	219.297	6%	3.384.278	427.380	12%	427.380	42.737,98 €	11.539,26 €	2,76	32%	4,12	20%	
	ONSUMER 5 (no F3)	3.603.576	219.329	219.297	6%	3.384.278	1.581.921	35%	1.264.196	126.419,62 €	34.133,30 €	2,57	35%	4,12	20%	
	CONSUMER 5 (X2)	3.603.576	219.329	219.297	6%	3.384.278	4.905.270	84%	3.042.663	304.266,28 €	82.151,89 €	2,24	41%	4,12	20%	
PROSUMER 4	CONSUMER 1	3.603.576	911.945	908.920	25%	2.694.656	219.366	6%	209.858	20.985,82 €	5.666,17 €	2,16	42%	3,3	27%	1,2
	CONSUMER 5	3.603.576	911.945	908.920	25%	2.694.656	2.452.635	49%	1.753.078	175.307,80 €	47.333,11 €	1,95	47%	3,3	27%	
	CONSUMER 6	3.603.576	911.945	908.920	25%	2.694.656	1.033.068	20%	702.724	70.272,39 €	18.973,55 €	2,09	44%	3,3	27%	
	CONSUMER 7	3.603.576	911.945	908.920	25%	2.694.656	243	0%	231	23,10 €	6,24 €	2,19	42%	3,3	27%	
	CONSUMER 1+2+3	3.603.576	911.945	908.920	25%	2.694.656	427.380	11%	404.051	40.405,05 €	10.909,36 €	2,13	43%	3,3	27%	
	CONSUMER 5 x2	3.603.576	911.945	908.920	25%	2.694.656	4.905.255	69%	2.480.647	248.064,71 €	66.977,47 €	1,86	50%	3,3	27%	

Figure 81 - Example of results summary for eolic

Thus, it is reaffirmed that participation in an energy community is generally advantageous and more effective in scenarios with low self-consumption. However, having a high level of self-consumption consistently proves to be more beneficial, demonstrating that monetary savings outweigh the earnings from incentives.

It is also crucial to notice that for this type of investment the DIFF values shown are lower, practically highlighting the fact that wind energy investments could stand alone, even out of a REC.

Figure 82 provides a summary of the scenarios across various regions of Italy for Eolic systems.



		NORTH			CENTRE			SOUTH			ISLANDS		
	ENERGY PRODUCED [kWh]	544.063			2.761.990			3.603.576			4.453.546		
	TOTAL INCENTIVE [€/MWh]	0,110			0,104			0,100			0,100		
	CASE STUDIES	SHARING %	PBT PROSUMER	DIFF	SHARING %	PBT PROSUMER	DIFF	SHARING %	PBT PROSUMER	DIFF	SHARING %	PBT PROSUMER	DIFF
		%	years	years	%	years	years	%	years	years	%	years	years
PROSUMER 5	CONSUMER 1	0%	7,96	5,50	4%	1,81	1,00	4%	1,52	0,80	4%	1,32	0,70
	CONSUMER 4	0%	7,96		11%	1,79		13%	1,49		13%	1,30	
	CONSUMER 6	0%	7,96		7%	1,80		9%	1,50		10%	1,31	
	CONSUMER 7	0%	7,97		0%	1,82		0%	1,53		0%	1,33	
	CONSUMER 1+2+3	0%	7,96		7%	1,80		7%	1,51		7%	1,32	
PROSUMER 7	CONSUMER 1	40%	>15	7,00	8%	4,13	2,30	6%	3,11	1,60	5%	2,52	1,30
	CONSUMER 4	93%	>15		32%	3,78		25%	2,91		20%	2,39	
	CONSUMER 5	100%	>15		73%	3,31		61%	2,60		52%	2,15	
	CONSUMER 6	68%	>15		33%	3,77		27%	2,90		22%	2,37	
	CONSUMER 1+2+3	69%	>15		15%	4,01		12%	3,50		10%	2,48	
	CONSUMER 5 (F3 no cons)	54%	>15		42%	3,65		37%	2,80		32%	2,29	
	CONSUMER 5 (X2)	100%	>15		97%	3,08		89%	2,40		81%	1,97	
PROSUMER 1	CONSUMER 4	59%	12,14	6,00	32%	3,35	2,10	25%	2,65	1,50	20%	2,20	1,20
	CONSUMER 5	60%	12,10		68%	3,00		59%	2,40		51%	2,01	
	CONSUMER 6	45%	12,70		30%	3,36		26%	2,64		22%	2,19	
	CONSUMER 7	0%	14,77		0%	3,71		0%	2,87		0%	2,36	
	CONSUMER 1+2+3	47%	12,59		15%	3,53		12%	2,76		10%	2,28	
	CONSUMER 5 (no F3)	29%	13,33		39%	3,27		35%	2,57		31%	2,13	
	CONSUMER 5 (X2)	60%	12,10		90%	2,84		84%	2,24		78%	1,86	
PROSUMER 4	CONSUMER 1	6%	8,31	6,20	7%	2,62	1,50	6%	2,16	1,20	5%	1,85	1,00
	CONSUMER 5	7%	8,29		51%	2,36		49%	1,95		44%	1,68	
	CONSUMER 6	7%	8,30		19%	2,54		20%	2,09		19%	1,79	
	CONSUMER 7	0%	8,39		0%	2,66		0%	2,19		0%	1,88	
	CONSUMER 1+2+3	7%	8,29		14%	2,58		11%	2,13		9%	1,83	
	CONSUMER 5 (X2)	7%	8,29		67%	2,29		69%	1,86		66%	1,60	
	MEAN	34%	9,97	6,18	31%	2,91	1,73	27%	2,33	1,28	24%	1,94	1,05
	MAX VALUE	100%		7,00	97%		2,30	89%		1,60	81%		1,30
	MIN VALUE		7,96	5,50		1,79	1,00		1,49	0,80		1,30	0,70

Figure 82 - Summary for eolic REC cases

In this case, the best REC performance results are observed in Northern Italy, both in terms of average and maximum values, surpassing the other regions by up to ten percentage points. The remaining three zones show very similar results, with the lowest figures recorded in the Islands.

From an economic standpoint, however, the best scenario is found in the Islands, with average payback times abundantly lower than those in the worst-performing region, the North, underlining that this type of investment is not to be considered in Northern Italy, due to its lack of wind resource.

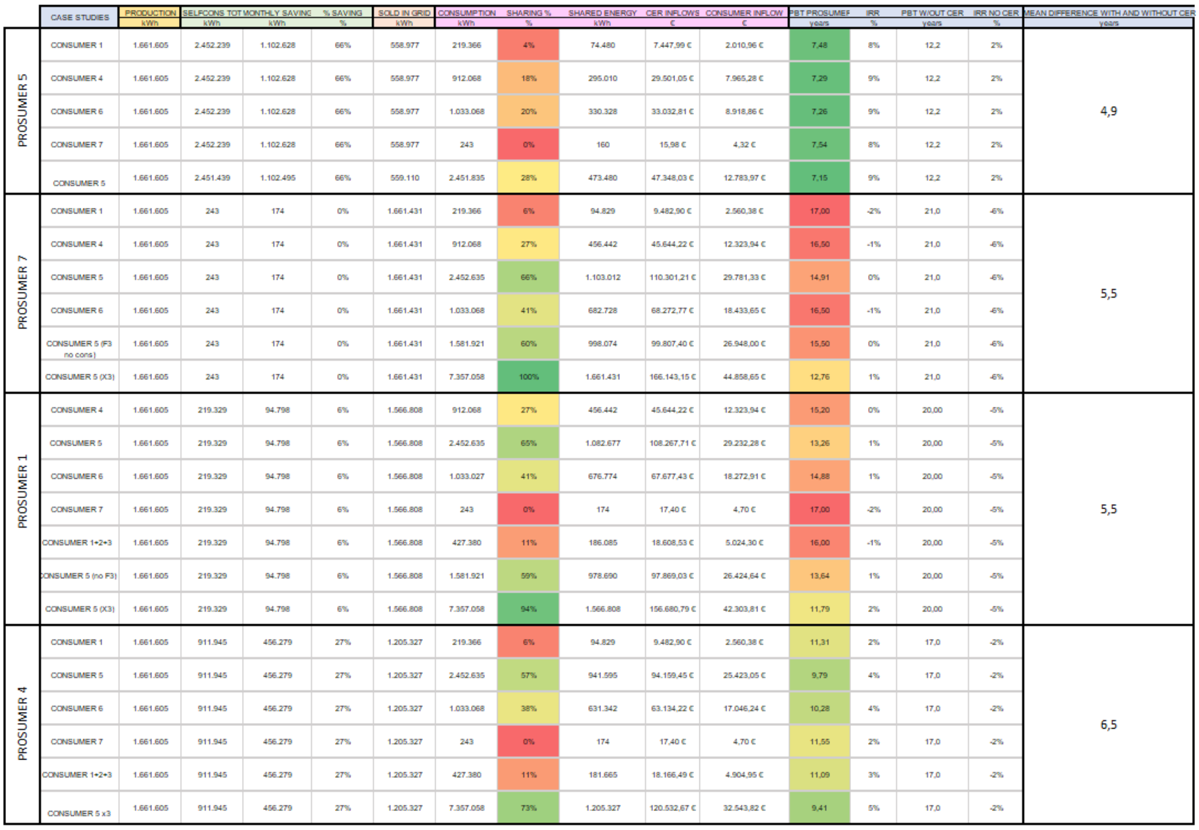
Once again, it is demonstrated that the performance of the energy community does not reflect the actual advantages of such an investment, which is recommended to be reconsidered in the regions of Northern Italy.

Analyzing the DIFF values, it becomes apparent that the North exhibits a significant wider gap compared to other regions, highlighting the fact that higher performance of the energy community correlates with greater economic improvements. This outcome positions Northern Italy as the region where the establishment of an energy community would be most effective, but in terms of investment still not viable, in contrast with the rest of Italy, where this type of technology demonstrates excellent results.

Overall, Eolic systems present better economic values with respect to photovoltaic ones, benefiting from the richness of the resource in particular regions of Italy. On the performance side, the average values are relatively low across Italy, but presenting a 100% sharing percentage only in the case of minimal self-consumption and higher consumer demand, combined with a significantly reduced energy production.

4.2.3. Hydroelectric prosumer

The same analysis performed for previous two has been extended to the last technology. However, due to the significant difference in the CAPEX and OPEX prices and the high energy output from hydro turbines, as will be shown in the subsequent sections, an additional consumer profile with triple the consumption of Consumer 5 has been introduced. This adjustment aims to maximize the consumption of energy produced and therefore the performances, in order to lower the payback time.

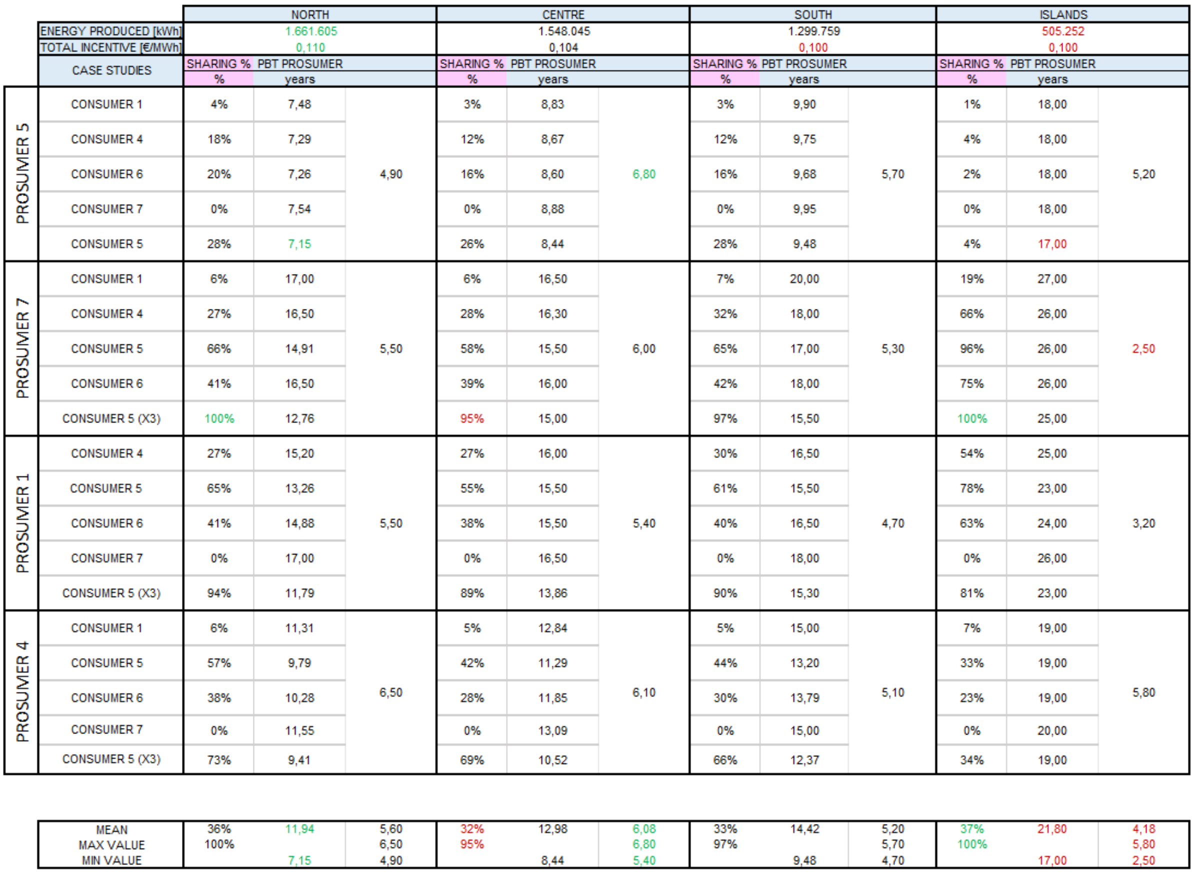


	CASE STUDIES	PRODUCTION	SELFCONS TOT	MONTHLY SAVING	% SAVING	SOLD IN GRID	CONSUMPTION	SHARING %	SHARED ENERGY	CER INFLOWS	CONSUMER INFLOW	PBT PROSUMEF	IRR	PBT W/OUT CER	IRR NO CER	MEAN DIFFERENCE WITH AND WITHOUT CER
		kWh	kWh	kWh	%	kWh	kWh	%	kWh	€	€	years	%	years	%	years
PROSUMER 5	CONSUMER 1	1.661.605	2.452.239	1.102.628	66%	558.977	219.366	4%	74.480	7.447,99 €	2.010,96 €	7,48	8%	12,2	2%	4,9
	CONSUMER 4	1.661.605	2.452.239	1.102.628	66%	558.977	912.068	18%	295.010	29.501,05 €	7.965,28 €	7,29	9%	12,2	2%	
	CONSUMER 6	1.661.605	2.452.239	1.102.628	66%	558.977	1.033.068	20%	330.328	33.032,81 €	8.918,86 €	7,26	9%	12,2	2%	
	CONSUMER 7	1.661.605	2.452.239	1.102.628	66%	558.977	243	0%	160	15,98 €	4,32 €	7,54	8%	12,2	2%	
	CONSUMER 5	1.661.605	2.451.439	1.102.495	66%	559.110	2.451.835	28%	473.480	47.348,03 €	12.783,97 €	7,15	9%	12,2	2%	
PROSUMER 7	CONSUMER 1	1.661.605	243	174	0%	1.661.431	219.366	6%	94.829	9.482,90 €	2.560,38 €	17,00	-2%	21,0	-6%	5,5
	CONSUMER 4	1.661.605	243	174	0%	1.661.431	912.068	27%	456.442	45.644,22 €	12.323,94 €	16,50	-1%	21,0	-6%	
	CONSUMER 5	1.661.605	243	174	0%	1.661.431	2.452.635	66%	1.103.012	110.301,21 €	29.781,33 €	14,91	0%	21,0	-6%	
	CONSUMER 6	1.661.605	243	174	0%	1.661.431	1.033.068	41%	682.728	68.272,77 €	18.433,65 €	16,50	-1%	21,0	-6%	
	CONSUMER 5 (F3 no cons)	1.661.605	243	174	0%	1.661.431	1.581.921	60%	998.074	99.807,40 €	26.948,00 €	15,50	0%	21,0	-6%	
	CONSUMER 5 (X3)	1.661.605	243	174	0%	1.661.431	7.357.058	100%	1.661.431	166.143,15 €	44.858,65 €	12,76	1%	21,0	-6%	
PROSUMER 1	CONSUMER 4	1.661.605	219.329	94.798	6%	1.566.808	912.068	27%	456.442	45.644,22 €	12.323,94 €	15,20	0%	20,00	-5%	5,5
	CONSUMER 5	1.661.605	219.329	94.798	6%	1.566.808	2.452.635	65%	1.082.677	108.267,71 €	29.232,28 €	13,26	1%	20,00	-5%	
	CONSUMER 6	1.661.605	219.329	94.798	6%	1.566.808	1.033.027	41%	676.774	67.677,43 €	18.272,91 €	14,88	1%	20,00	-5%	
	CONSUMER 7	1.661.605	219.329	94.798	6%	1.566.808	243	0%	174	17,40 €	4,70 €	17,00	-2%	20,00	-5%	
	CONSUMER 1+2+3	1.661.605	219.329	94.798	6%	1.566.808	427.380	11%	186.085	18.608,53 €	5.024,30 €	16,00	-1%	20,00	-5%	
	ONSUMER 5 (no F3)	1.661.605	219.329	94.798	6%	1.566.808	1.581.921	59%	978.690	97.869,03 €	26.424,64 €	13,64	1%	20,00	-5%	
	CONSUMER 5 (X3)	1.661.605	219.329	94.798	6%	1.566.808	7.357.058	94%	1.566.808	156.680,79 €	42.303,81 €	11,79	2%	20,00	-5%	
PROSUMER 4	CONSUMER 1	1.661.605	911.945	456.279	27%	1.205.327	219.366	6%	94.829	9.482,90 €	2.560,38 €	11,31	2%	17,0	-2%	6,5
	CONSUMER 5	1.661.605	911.945	456.279	27%	1.205.327	2.452.635	57%	941.595	94.159,45 €	25.423,05 €	9,79	4%	17,0	-2%	
	CONSUMER 6	1.661.605	911.945	456.279	27%	1.205.327	1.033.068	38%	631.342	63.134,22 €	17.046,24 €	10,28	4%	17,0	-2%	
	CONSUMER 7	1.661.605	911.945	456.279	27%	1.205.327	243	0%	174	17,40 €	4,70 €	11,55	2%	17,0	-2%	
	CONSUMER 1+2+3	1.661.605	911.945	456.279	27%	1.205.327	427.380	11%	181.665	18.166,49 €	4.904,95 €	11,09	3%	17,0	-2%	
	CONSUMER 5 x3	1.661.605	911.945	456.279	27%	1.205.327	7.357.058	73%	1.205.327	120.532,67 €	32.543,82 €	9,41	5%	17,0	-2%	

Figure 83 - Example of results summary for hydropower

As shown in Figure 83, once again, the best performance of the energy community is observed where there is the lowest level of self-consumption and the highest consumption by the consumer. As previously seen, performance results does not directly translate in economic benefits, as prosumers with the highest self-consumption rates experience significantly shorter payback periods compared to the average.

It is important to immediately highlight that the average payback periods for this technology are significantly higher compared to the first two technologies. In fact, acceptable payback times can only be achieved in scenarios with exceptionally high consumption levels. It should also be noted that the useful lifespan of this type of installation is generally longer than that of the other two technologies, so these timelines must be evaluated while considering this aspect.



		NORTH			CENTRE			SOUTH			ISLANDS		
	ENERGY PRODUCED [kWh]	1.661.605			1.548.045			1.299.759			505.252		
	TOTAL INCENTIVE [€/MWh]	0,110			0,104			0,100			0,100		
	CASE STUDIES	SHARING %	PBT PROSUMER		SHARING %	PBT PROSUMER		SHARING %	PBT PROSUMER		SHARING %	PBT PROSUMER	
		%	years		%	years		%	years		%	years	
PROSUMER 5	CONSUMER 1	4%	7,48	4,90	3%	8,83	6,80	3%	9,90	5,70	1%	18,00	5,20
	CONSUMER 4	18%	7,29		12%	8,67		12%	9,75		4%	18,00	
	CONSUMER 6	20%	7,26		16%	8,60		16%	9,68		2%	18,00	
	CONSUMER 7	0%	7,54		0%	8,88		0%	9,95		0%	18,00	
	CONSUMER 5	28%	7,15		26%	8,44		28%	9,48		4%	17,00	
PROSUMER 7	CONSUMER 1	6%	17,00	5,50	6%	16,50	6,00	7%	20,00	5,30	19%	27,00	2,50
	CONSUMER 4	27%	16,50		28%	16,30		32%	18,00		66%	26,00	
	CONSUMER 5	66%	14,91		58%	15,50		65%	17,00		96%	26,00	
	CONSUMER 6	41%	16,50		39%	16,00		42%	18,00		75%	26,00	
	CONSUMER 5 (X3)	100%	12,76		95%	15,00		97%	15,50		100%	25,00	
PROSUMER 1	CONSUMER 4	27%	15,20	5,50	27%	16,00	5,40	30%	16,50	4,70	54%	25,00	3,20
	CONSUMER 5	65%	13,26		55%	15,50		61%	15,50		78%	23,00	
	CONSUMER 6	41%	14,88		38%	15,50		40%	16,50		63%	24,00	
	CONSUMER 7	0%	17,00		0%	16,50		0%	18,00		0%	26,00	
	CONSUMER 5 (X3)	94%	11,79		89%	13,86		90%	15,30		81%	23,00	
PROSUMER 4	CONSUMER 1	6%	11,31	6,50	5%	12,84	6,10	5%	15,00	5,10	7%	19,00	5,80
	CONSUMER 5	57%	9,79		42%	11,29		44%	13,20		33%	19,00	
	CONSUMER 6	38%	10,28		28%	11,85		30%	13,79		23%	19,00	
	CONSUMER 7	0%	11,55		0%	13,09		0%	15,00		0%	20,00	
	CONSUMER 5 (X3)	73%	9,41		69%	10,52		66%	12,37		34%	19,00	
	MEAN	36%	11,94	5,60	32%	12,98	6,08	33%	14,42	5,20	37%	21,80	4,18
	MAX VALUE	100%		6,50	95%		6,80	97%		5,70	100%		5,80
	MIN VALUE		7,15	4,90		8,44	5,40		9,48	4,70		17,00	2,50

Figure 84 - Summary for hydro REC cases

Figure 84 provides a summary of the scenarios across various regions of Italy for hydropower systems. In this case, the best REC performance results are observed in Islands, despite in other regions values are quite aligned.

From an economic perspective, the best scenario is in Northern Italy, where the average payback period is significantly reduced compared to the worst scenario in the islands. This aspect confirms expectations regarding the lack of water and water basins, as well as the absence of significant elevation changes in these regions.

Once again, it is demonstrated that the performance of the energy community does not reflect the actual advantages of such an investment, which is recommended to be reconsidered in general, except form Northern Italy.

Analyzing the value of the difference, it becomes apparent that in each region the values are similar, but compared to other technologies, they are significantly higher. This highlights the effectiveness of participating in a REC when dealing with high investment levels of this nature.

Overall, hydropower systems demonstrate high performance values, comparable to those of other technologies. However, these performance levels do not translate into economic benefits, as the scale of the investment makes this technology less suitable for producing energy at this capacity and for such a limited number of users.

4.3. Results commentary

In the subsequent sections, a comprehensive analysis of the results from the application of the proposed model will be conducted, delving into three critical dimensions. The first dimension addresses the performance aspect, focusing primarily on the model's ability to optimize the percentage of shared energy. This will allow for an in-depth assessment of the efficiency and effectiveness of energy distribution within the system.

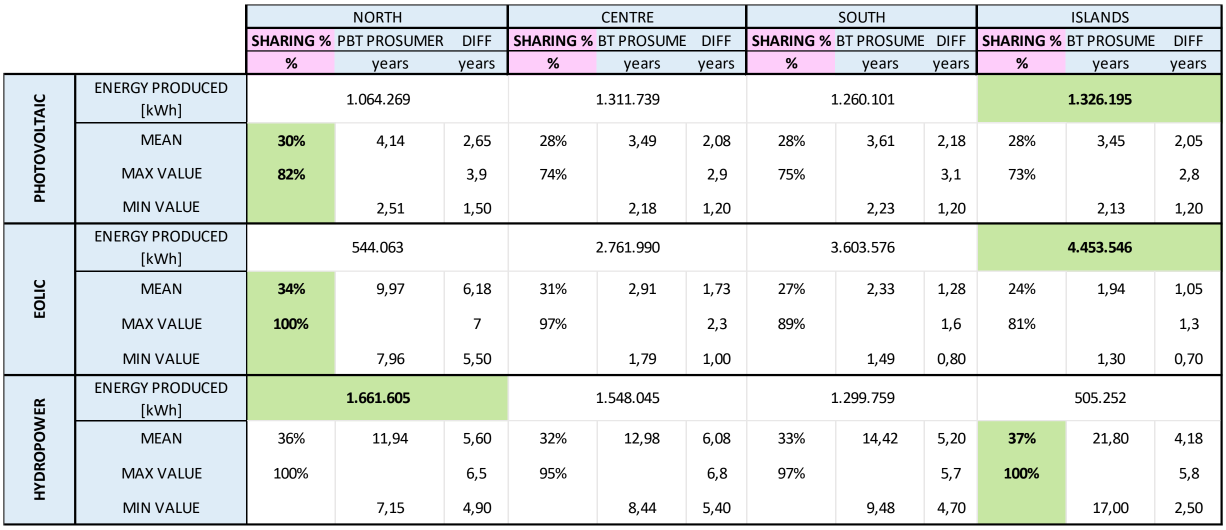
The second dimension is the economic aspect, where a thorough evaluation of the Payback Time (PBT) will be undertaken. This analysis will not only examine the overall economic viability of the model but also highlight the differences in PBT within a Citizen Energy Community compared to scenarios without such a community. By exploring these financial variations, the aim is to provide insight into how the model influences economic outcomes in both collaborative and non-collaborative energy settings.

Finally, the third dimension focuses on the geographical evaluation, supported by data provided by Terna [31]. These data highlight the current distribution of energy plants across the Italian territory, enabling an assessment of the regions where different energy technologies are most effectively implemented. This spatial analysis will underline which areas are more favorable for specific types of energy production, offering insights into the regional strengths and potential optimizations for energy technology deployment.

Taken together, these three aspects, performance, economics, and geography, offer a holistic view of the model's implications, providing valuable insights into its potential real-world applications and broader significance.

4.3.1. Performance results

This section focuses on the analysis of the model's performance, with particular emphasis on the percentage of shared energy within the system. The evaluation will consider how effectively the model facilitates energy sharing among participants, measuring its capacity to optimize energy distribution. By examining the share of locally generated and consumed energy, this performance analysis aims to assess both the efficiency and the overall effectiveness of the model. In doing so, it will provide insights into the potential benefits and limitations of the energy-sharing mechanism, shedding light on the model’s ability to enhance energy autonomy and reduce reliance on external energy sources.



		NORTH			CENTRE			SOUTH			ISLANDS		
		SHARING %	PBT PROSUMER	DIFF	**SHARING %**	BT PROSUME	DIFF	**SHARING %**	BT PROSUME	DIFF	**SHARING %**	BT PROSUME	DIFF
		%	years	years	%	years	years	%	years	years	%	years	years
PHOTOVOLTAIC	ENERGY PRODUCED [kWh]	1.064.269			1.311.739			1.260.101			**1.326.195**		
	MEAN	**30%**	4,14	2,65	28%	3,49	2,08	28%	3,61	2,18	28%	3,45	2,05
	MAX VALUE	**82%**		3,9	74%		2,9	75%		3,1	73%		2,8
	MIN VALUE		2,51	1,50		2,18	1,20		2,23	1,20		2,13	1,20
EOLIC	ENERGY PRODUCED [kWh]	544.063			2.761.990			3.603.576			**4.453.546**		
	MEAN	**34%**	9,97	6,18	31%	2,91	1,73	27%	2,33	1,28	24%	1,94	1,05
	MAX VALUE	**100%**		7	97%		2,3	89%		1,6	81%		1,3
	MIN VALUE		7,96	5,50		1,79	1,00		1,49	0,80		1,30	0,70
HYDROPOWER	ENERGY PRODUCED [kWh]	**1.661.605**			1.548.045			1.299.759			505.252		
	MEAN	36%	11,94	5,60	32%	12,98	6,08	33%	14,42	5,20	**37%**	21,80	4,18
	MAX VALUE	100%		6,5	95%		6,8	97%		5,7	**100%**		5,8
	MIN VALUE		7,15	4,90		8,44	5,40		9,48	4,70		17,00	2,50

Figure 85 - Performance results summary

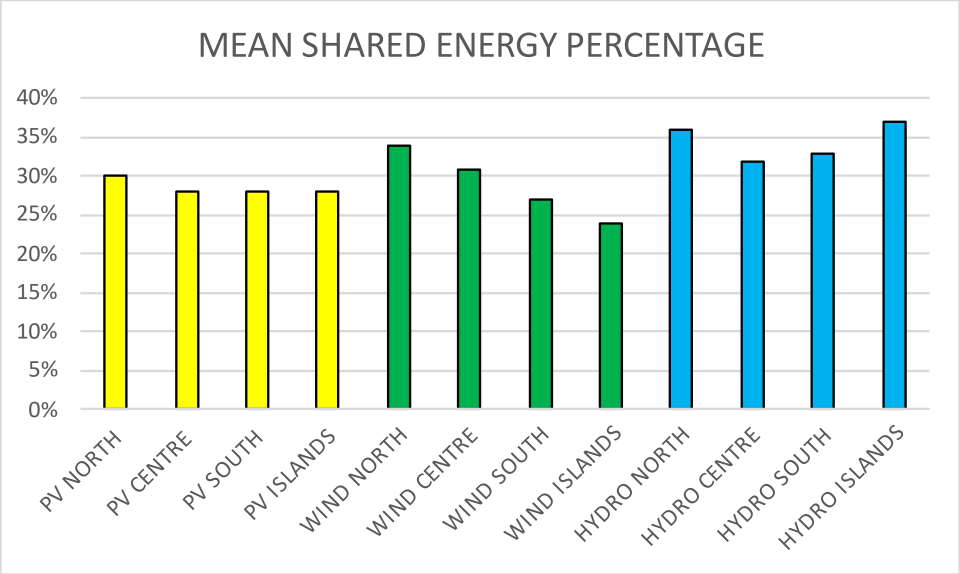


Figure 86 - Mean shared energy summary

Figure 85 and Figure 86 presents a detailed breakdown of energy production and sharing percentages across various technologies, Photovoltaic, Eolic and Hydropower, across four key regions: North, Centre, South, and the Islands. Among the technologies, wind power stands out as the most productive, particularly in the Islands, where wind farms generate an impressive 4,453,546 kWh of energy. This highlights the Islands as the most favorable region for wind power generation, far exceeding the production levels in the North, Centre, and South, where wind energy is still significant but much lower in comparison.

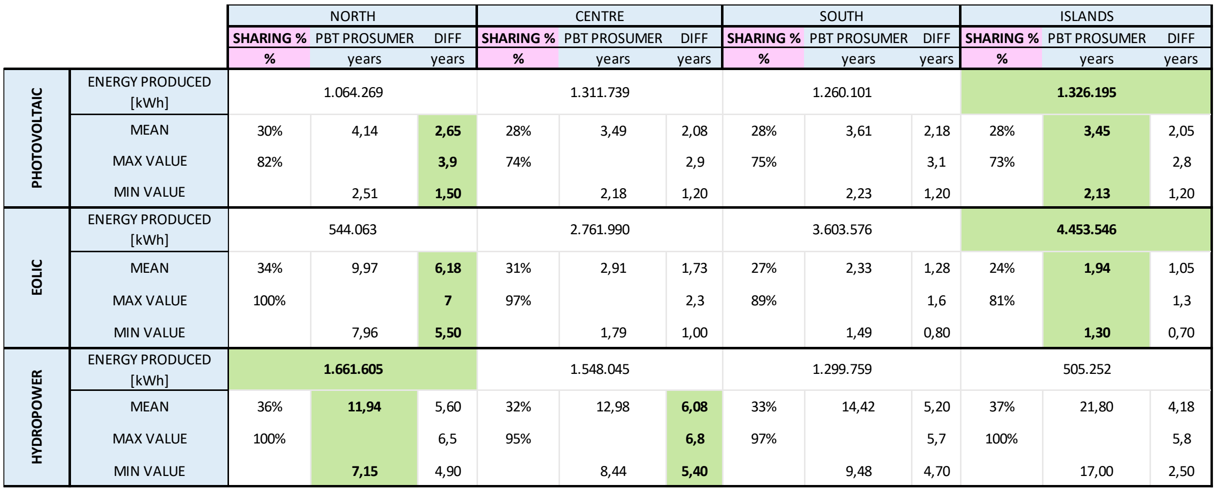
When examining Photovoltaic (solar) energy production, the Islands again prove to be a leading region, with a total production of 1,326,195 kWh, underscoring its strong potential for solar energy generation. In contrast, the North and Centre regions produce slightly lower amounts, although they still maintain consistent levels of energy generation through photovoltaic systems. As for Hydropower, the North is the dominant region, producing 1,661,605 kWh, significantly outperforming other regions such as the Centre, South, and Islands, where hydropower output is much less pronounced.

In terms of energy sharing efficiency, which measures the percentage of locally produced energy that is shared within the system, the results vary by both technology and region. Hydropower in the Islands achieves the highest sharing percentage at 37%, making it the most effective in terms of distributing shared energy across the community. For Eolic technology, the North leads with a sharing percentage of 34%, indicating a robust ability to share wind energy locally in this region. Meanwhile, Photovoltaic energy in the South reaches the highest sharing rate for solar power, with 28% of the energy being shared. Notably, we observe that regions with lower overall energy production, such as the South for photovoltaic energy or the North for eolic energy, tend to have higher sharing percentages. This phenomenon can be explained by the fact that in regions with lower production, a greater percentage of the energy generated is consumed locally by the same number of consumers, thereby increasing the share of locally consumed energy relative to total production. Moreover, Hydropower demonstrates superior performance not only in terms of production but also in its ability to optimize energy sharing. One key factor contributing to this is that hydropower plants primarily generate energy during the day when demand is highest, aligning production with consumption patterns more effectively. Additionally, hydropower systems have the unique ability to modulate and adjust energy output, making it easier to balance supply with demand and optimize the use of shared energy. This flexibility, combined with its high daytime production, helps hydropower achieve both high production and efficient energy sharing, particularly in the Islands, where its performance is strongest.

Overall, the data reveals important insights into the regional performance of different energy technologies. The Islands emerge as the strongest region for both Eolic and Photovoltaic energy production, while the North excels in Hydropower generation. When it comes to energy sharing, the Islands also show strength, particularly for Hydropower, while the North and South regions demonstrate effective sharing mechanisms for Eolic and Photovoltaic technologies, respectively.

4.3.2. Economic results

This section analyzes the economic effectiveness of the Renewable Energy Community (REC) model by focusing on the payback time (PBT) values associated with different renewable energy technologies. The aim is to identify the lowest PBT, which indicates the most financially viable option for prosumers. Additionally, a new parameter, the **Diff** values, is introduced, representing the difference in payback time between prosumers participating in a REC and those operating independently. By examining these values, insights can be gained into the advantages of REC participation and its impact on the financial outcomes for prosumers across various technologies and regions. The analysis will highlight the potential benefits of community engagement in renewable energy production and its role in enhancing economic returns.



		NORTH			CENTRE			SOUTH			ISLANDS		
		SHARING %	PBT PROSUMER	DIFF	**SHARING %**	PBT PROSUMER	DIFF	**SHARING %**	PBT PROSUMER	DIFF	**SHARING %**	PBT PROSUMER	DIFF
		%	years	years	**%**	years	years	**%**	years	years	**%**	years	years
PHOTOVOLTAIC	ENERGY PRODUCED [kWh]	1.064.269			1.311.739			1.260.101			**1.326.195**		
	MEAN	30%	4,14	**2,65**	28%	3,49	2,08	28%	3,61	2,18	28%	**3,45**	2,05
	MAX VALUE	82%		**3,9**	74%		2,9	75%		3,1	73%		2,8
	MIN VALUE		2,51	**1,50**		2,18	1,20		2,23	1,20		**2,13**	1,20
EOLIC	ENERGY PRODUCED [kWh]	544.063			2.761.990			3.603.576			**4.453.546**		
	MEAN	34%	9,97	**6,18**	31%	2,91	1,73	27%	2,33	1,28	24%	**1,94**	1,05
	MAX VALUE	100%		**7**	97%		2,3	89%		1,6	81%		1,3
	MIN VALUE		7,96	**5,50**		1,79	1,00		1,49	0,80		**1,30**	0,70
HYDROPOWER	ENERGY PRODUCED [kWh]	**1.661.605**			1.548.045			1.299.759			505.252		
	MEAN	36%	**11,94**	5,60	32%	12,98	**6,08**	33%	14,42	5,20	37%	21,80	4,18
	MAX VALUE	100%		6,5	95%		**6,8**	97%		5,7	100%		5,8
	MIN VALUE		**7,15**	4,90		8,44	**5,40**		9,48	4,70		17,00	2,50

Figure 87 - Economic results summary

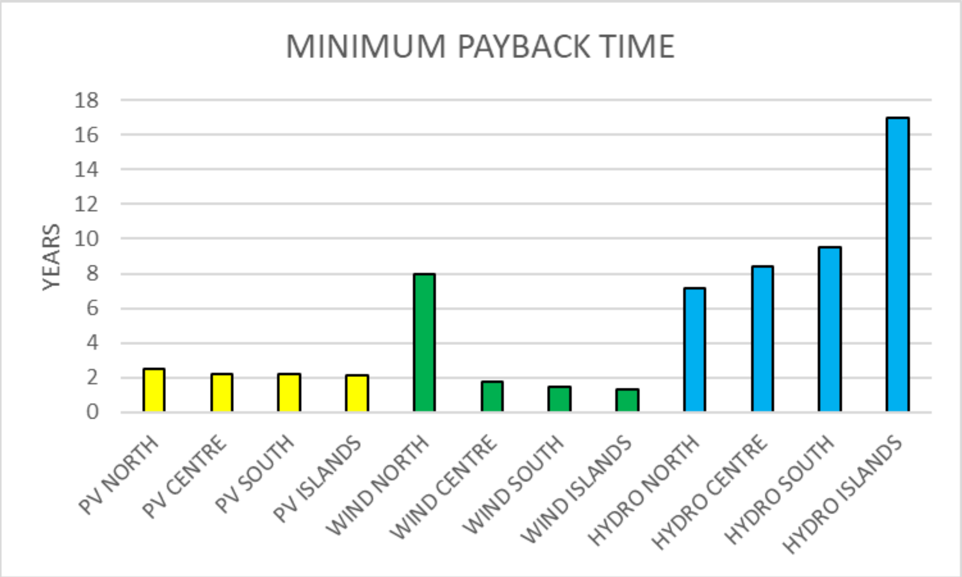


Figure 88 - Minimum payback time summary

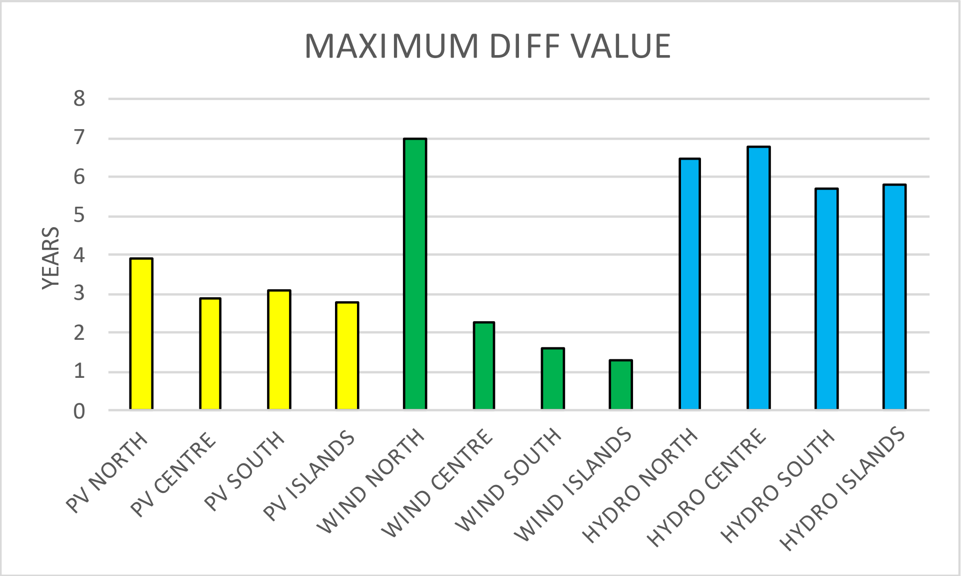


Figure 89 - Maximum diff value summary

The table provides insights into the payback times (PBT) and the differences (Diff) in payback periods for prosumers participating in a Renewable Energy Community versus those who do not. Among the three technologies analysed, Eolic energy in the Islands stands out with the lowest mean PBT of 1,94 years, making it the most financially attractive option also looking at the minimum value of only 1,3 years, followed closely by the South, where wind power has a slightly longer mean PBT of 2,33 years. These values reflect the overall efficiency of wind energy in these regions, where the natural conditions favor quick returns on investment. For Photovoltaic energy, the Islands also perform well, with a mean PBT of 3.45 years, while the North shows a slightly higher PBT of 4,14 years, indicating a slower return on solar investments, likely due to less solar exposure compared to southern regions. The

Centre displays even longer payback periods for photovoltaic systems, making it less financially attractive compared to wind power. In the case of Hydropower, the North demonstrates the best performance, with a minimum PBT of 7.15 years, which is significantly lower than the mean value of 11.94 years, but still longer compared to wind and solar due to the higher initial infrastructure costs and lower energy-sharing percentages. Hydropower generally has a slower return on investment, though its stability and consistent production make it a valuable energy source over the long term.

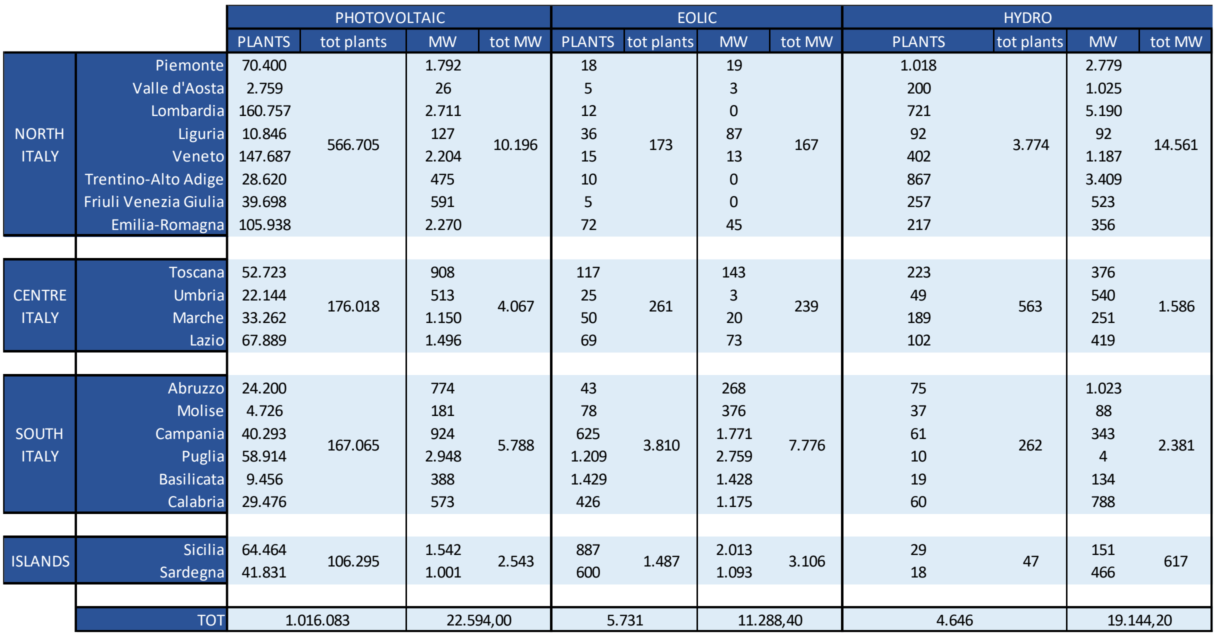
When focusing on the Diff values, which indicate the number of years by which REC participation shortens the payback period, Hydropower in the centre stands out with the largest reduction, where participating in a community energy system decreases the PBT by 6,8 years. This significant difference suggests that hydropower in the centre benefits greatly from collective energy sharing, as it helps optimize production and consumption, particularly during peak demand hours, thus enhancing financial returns. The north on the other hand shows a noteworthy Diff values for Eolic, with a mean reduction of 6,18 years, indicating that community participation in wind energy yields high benefits in this region. While the Islands have the lowest overall PBT for wind energy, they present a smaller Diff value of 1 year, likely because the high efficiency of wind power already results in fast payback times, leaving less room for REC participation to improve the financial return.

For Photovoltaic systems, the North demonstrates the largest mean Diff with a reduction of 2,65 years in payback time due to REC participation, underscoring the significant role community involvement plays in enhancing the economic viability of solar investments in regions with lower solar efficiency. The Islands, due to their favorable solar conditions, exhibit a smaller mean Diff of 2,05 years, indicating that while REC participation is beneficial, the strong solar production levels already make payback times attractive, thus limiting the impact of community energy sharing, as seen for Eolic.

The highest Diff values are attributed to the substantial benefits associated with participation in a REC, including a 40% reduction in investment costs and the incentives derived from shared energy. These benefits are particularly effective in regions where the payback times are higher without REC participation, further demonstrating that involvement in a REC is a significant advantage for prosumers. The larger Diff values observed in these regions highlight the importance of community energy sharing in making renewable investments more financially viable.

4.3.3. Geographical results

This section synthesizes values from Chapter 3, specifically focusing on the database analysis, to identify the regions in Italy where specific renewable energy technologies—namely, Photovoltaic, Eolic, and Hydropower—are most prevalent. This analysis examines both the number of plants and the total installed capacity in megawatts (MW) for each technology across different regions. By correlating these findings with the performance and economic results previously analyzed, this section aims to validate whether the existing distribution of renewable energy infrastructure supports the observed performance and financial outcomes. Understanding the geographical distribution of these technologies will provide critical insights into how the actual deployment of renewable energy systems aligns with their theoretical and empirical benefits, thus enhancing the overall comprehension of the REC model's effectiveness in the Italian context.



		PHOTOVOLTAIC				EOLIC				HYDRO			
		PLANTS	tot plants	MW	tot MW	PLANTS	tot plants	MW	tot MW	PLANTS	tot plants	MW	tot MW
NORTH ITALY	Piemonte	70.400	566.705	1.792	10.196	18	173	19	167	1.018	3.774	2.779	14.561
	Valle d'Aosta	2.759		26		5		3		200		1.025	
	Lombardia	160.757		2.711		12		0		721		5.190	
	Liguria	10.846		127		36		87		92		92	
	Veneto	147.687		2.204		15		13		402		1.187	
	Trentino-Alto Adige	28.620		475		10		0		867		3.409	
	Friuli Venezia Giulia	39.698		591		5		0		257		523	
	Emilia-Romagna	105.938		2.270		72		45		217		356	
CENTRE ITALY	Toscana	52.723	176.018	908	4.067	117	261	143	239	223	563	376	1.586
	Umbria	22.144		513		25		3		49		540	
	Marche	33.262		1.150		50		20		189		251	
	Lazio	67.889		1.496		69		73		102		419	
SOUTH ITALY	Abruzzo	24.200	167.065	774	5.788	43	3.810	268	7.776	75	262	1.023	2.381
	Molise	4.726		181		78		376		37		88	
	Campania	40.293		924		625		1.771		61		343	
	Puglia	58.914		2.948		1.209		2.759		10		4	
	Basilicata	9.456		388		1.429		1.428		19		134	
	Calabria	29.476		573		426		1.175		60		788	
ISLANDS	Sicilia	64.464	106.295	1.542	2.543	887	1.487	2.013	3.106	29	47	151	617
	Sardegna	41.831		1.001		600		1.093		18		466	
	TOT	1.016.083		22.594,00		5.731		11.288,40		4.646		19.144,20	

Figure 90 - Geographical census data from Terna summary

From Figure 87 it can be noted that photovoltaic systems have the highest number of installed plants in Italy, with over 1 million installations, compared to only a few thousand installations for other technologies. This prevalence supports the notion that photovoltaic energy is functional throughout the country, particularly in the North, where favorable fiscal incentives are more readily available. However, this predominance is not reflected in the total installed capacity in megawatts (MW), where photovoltaic systems account for only twice the capacity of their counterparts. This discrepancy arises because wind and hydropower installations typically feature higher total capacities within single plants.

Regarding regional prevalence, photovoltaic energy shows the greatest concentration in Northern Italy, primarily due to the previously mentioned fiscal incentives, while similar values are observed across other regions. Conversely, wind energy demonstrates a clear predominance in Southern Italy and the Islands, corroborating the findings from previous sections regarding the excellent performance of this technology in these regions.

For hydropower, a similar, yet opposite, distribution pattern with eolic power is evident, as more than 90% of installed plants and capacity are located in the North. The presence of hydropower installations in other parts of Italy is minimal, which aligns with the results obtained from the model, reflecting the limited availability of precipitation and elevation differences in other regions of the country.

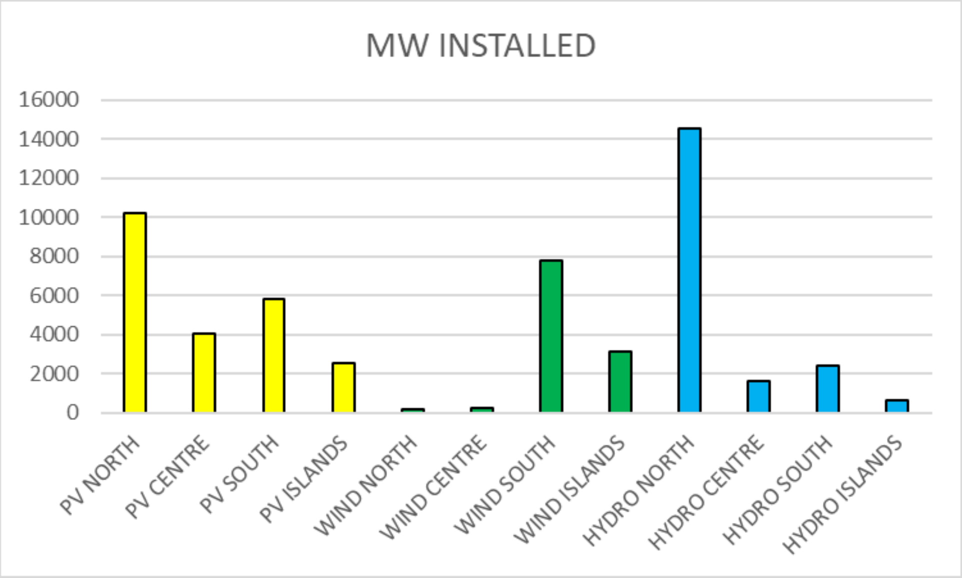


Figure 91 - Installed MW summary

Overall, the census data from Terna completely validate the results derived from the model, demonstrating that the established presence of various types of renewable energy installations across the Italian territory corresponds perfectly with the performance and economic data generated from the various scenarios analyzed in this project. This aspect is crucial for affirming the actual validity of the conducted study.

5. Conclusion

This thesis emerges in response to the growing need to simulate Renewable Energy Communities (RECs) to better assess their effectiveness in energy sharing and investment outcomes, particularly within the context of Italy's transition toward sustainable energy systems. It was driven by the recognition that RECs—where local communities generate, share, and consume renewable energy—offer a promising solution to reduce dependency on fossil fuels and enhance energy autonomy. However, a critical gap existed in accurately simulating these communities to assess both their energy performance and economic viability. The primary objective of this work was to develop a simulation model capable of evaluating REC effectiveness, considering the integration of various renewable energy technologies and the unique regional conditions across Italy.

The first part of the thesis involved a comprehensive review of the regulatory framework surrounding RECs, particularly how these communities are structured within the Italian legislative landscape. This review provided the foundation for understanding the opportunities and constraints that shape the development of RECs, particularly the financial incentives and regulatory support mechanisms available. From there, the focus shifted to building a detailed simulation model designed to estimate the performance of different renewable energy technologies, such as Photovoltaic, Eolic and Hydropower, within the framework of an REC. The model accounted for regional differences in solar irradiance, wind availability, and water resources to simulate realistic energy production profiles in four distinct Italian regions: North, Centre, South, and the Islands.

The model developed in this thesis was based on real consumption data, primarily provided by Altea Green Power S.p.A., a partner company involved in the study. This data was crucial in reflecting the actual energy use of industrial consumers who are potential participants in Renewable Energy Communities (RECs). Altea Green Power's clients, particularly industrial users, required an accurate simulation of how RECs would perform both in terms of energy production and economic returns. The goal was to provide them with concrete insights into the viability of joining an REC, helping them make informed decisions about whether to invest in renewable energy systems. By simulating real-world scenarios, the model allowed these companies to evaluate the potential financial benefits of reduced energy costs and the incentives associated with participating in a community-based energy-sharing system.

The simulation model itself was designed to assess both performance and economic aspects of RECs. It took several inputs, including hourly energy production profiles for Photovoltaic

(PV), Eolic (wind), and Hydropower technologies, as well as the actual consumption profiles of participating users. The outputs of the model included key performance metrics such as self-consumption percentages, shared energy among community members, and most importantly, the payback time (PBT), which measures the time required to recoup the initial investment in renewable energy systems. In addition to the PBT, the model introduced a new parameter called DIFF values, which measure the reduction in payback time when prosumers participate in a REC compared to acting independently. This allowed for a thorough evaluation of the economic benefits of community energy sharing, providing stakeholders with a clear understanding of the potential return on investment when joining an REC. To validate the model's results, these outputs were compared with geographical data from Terna census data, which provided insights into the distribution and installed capacity of renewable energy plants across Italy. This comparison ensured that the model's findings were grounded in the actual geographic distribution of renewable energy technologies, further reinforcing the accuracy and relevance of the results.

The simulation yielded important results. The first crucial aspect of this analysis with the model is that the optimization of the REC configuration can be viewed from two perspectives. From a technical performance standpoint, all results show that the highest values of shared energy, and consequently the highest sharing percentages, are achieved in cases where the prosumer has very low self-consumption values, thus being able to feed much more energy into the grid. This aspect is reflected in an increase in the DIFF value, effectively leading to a reduction in payback time. The second, quite opposite, aspect concerns the fact that prosumers with higher self-consumption values experience significantly shorter payback times than others, regardless of the presence of a REC, proving that self-consuming energy is always more advantageous. However, in both cases, being part of a REC consistently demonstrates a reduction in payback time, making participation in a REC beneficial.

As a second interesting point emerging from this analysis, it was found that the output values of the model reflect the geographical presence of certain types of plants in specific areas of Italy. Photovoltaic systems RECs perform well across the country, especially in Southern Italy, with shorter payback times, although most installations are concentrated in the North, where fiscal incentives are more favorable. Despite the high number of PV systems installed in Italy, their total power output is lower than other technologies due to smaller individual plant capacities, but their lower CAPEX allows them to be very market competitive. Wind energy showed high performance in Southern Italy and the Islands, where abundant natural wind resources result in strong energy output, reflected in high energy sharing, and shorter payback times, confirming wind as an efficient technology in these regions, and the best in terms of RECs performances. Hydropower, on the contrary, demonstrated strong performance in the North, where over 90% of installations are located due to suitable environmental conditions like water flow and elevation, but nothing comparable with the other technologies in terms of payback time values, practically excluding this configuration from the decision-making factors. As depicted in Figure 92 the most energy producing regions are also the ones where most of MW are installed, according to Terna. These findings validate the model's accuracy and provide practical insights for making renewable energy investment decisions based on geographical realities.

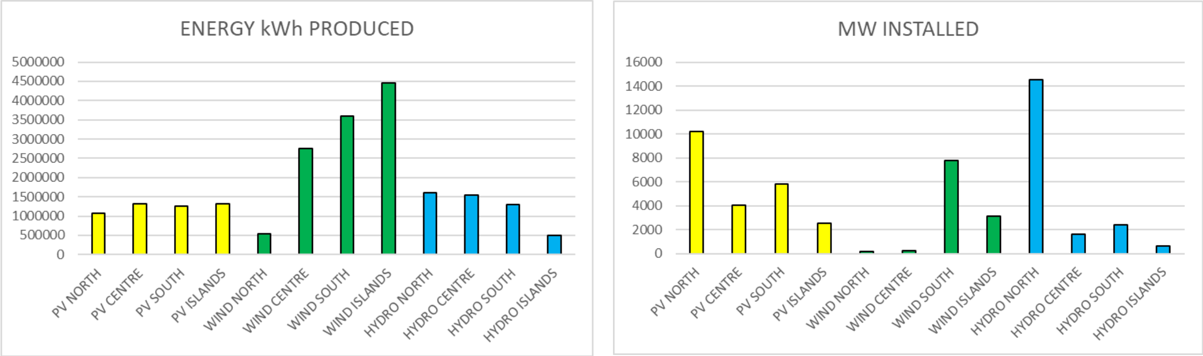


Figure 92 - Energy production and MW installed summary

The economic analysis, too, provided crucial insights into the financial advantages of REC participation. The DIFF values emerged as a key indicator of the financial benefit associated with RECs, particularly in regions where payback times without REC involvement were naturally longer. The model showed that participation in a REC leads to significant reductions in payback time due to the combined effects of a 40% reduction in investment costs—enabled by REC incentives—and the financial benefits derived from shared energy production. This is especially evident for Hydropower, where the largest DIFF values were recorded. The reduction in payback time highlights the crucial role of RECs in making renewable energy investments more financially viable, especially for technologies like hydropower, which require higher initial investments. Figure 93 clearly illustrates that while hydropower is the least efficient technology, it demonstrates the greatest potential when integrated into a REC. Photovoltaic and wind energy exhibit comparable performance, with the exception of wind energy in Northern Italy, where it shows a slight variation mainly due to lack of resource.

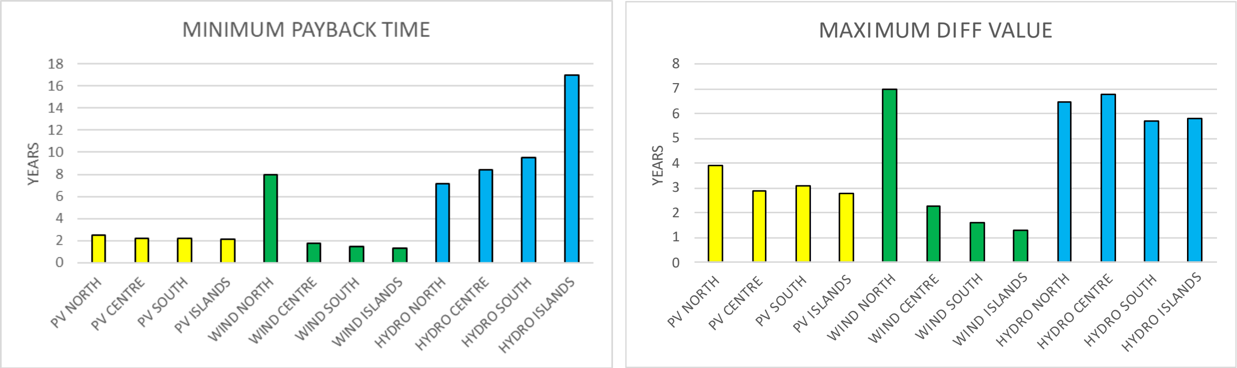


Figure 93 - Economic results summary

The highest DIFF values were found in regions and technologies where payback times are longer without REC participation. This confirms that RECs offer the most significant financial advantages in areas where the initial economic barriers to renewable energy investments are higher. The combination of investment cost reduction and incentives proves particularly effective in these regions, underscoring the importance of community participation in making renewable energy projects more accessible and economically attractive. These findings validate the thesis' core hypothesis that RECs not only enhance energy autonomy and sustainability but also offer tangible economic benefits to participants.

In summary, the results of this thesis provide a clear demonstration of how RECs can optimize both energy performance and financial returns across different technologies and regions in Italy. Photovoltaic energy proved to be widely applicable across the country, wind energy showed exceptional performance in the South and Islands, and hydropower was dominant in the North, although not comparable with the others. The economic analysis highlighted the significant reductions in payback time made possible by REC participation, with the largest benefits seen in regions where individual investments in renewable energy face higher economic barriers. Another crucial result involves the optimization of prosumer/consumer configurations, which allowed for an understanding of how a REC can either maximize energy sharing percentages, thus increasing the associated incentives, or minimize payback time, depending on the configuration of participants. These findings not only validate the effectiveness of the simulation model developed in this thesis but also underscore the broader relevance of RECs in promoting a more sustainable and economically viable energy transition in Italy.

This research offers critical insights for decision-makers, stakeholders, and policymakers, providing them with a practical tool to evaluate the feasibility and success of RECs in different contexts. Ultimately, the thesis demonstrates that RECs are a powerful model for fostering sustainable energy practices, delivering economic benefits, and supporting Italy's energy transition in a way that is both technically and financially sound.

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