POLITECNICO DI TORINO

Master's Degree in Renewable Energy Systems

Master's Degree Thesis

Implementation, statutory aspects and benefit sharing in an Energy Community

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To mum Emanuela, to dad Daniele and to sis Elena.
To my greatest friends Marco, Andrea, Attilio, Edoardo, Riccardo, Matteo, Fabio, Matteo, Luca.
To my colleagues and friends Roberta, Francesco, Annalisa.
To the high school professors Michela, Paola, Simona, Mirko, Manuela.
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To all the members of Egea S.p.A. that helped me in my first work experience and a special thanks to the so - called "Team 23" composed by Francesco, Gianmarco, Arianna and me.
In general, to everyone who has been part of my life in the last five years and affected it, one way or another.
This is a personal award but each one of you contributed to achieve it, so thank you all.

Abstract

Renewable energy communities are a growing and extraordinarily multifaceted phenomenon which involves a range of possible activities around renewable energy (production, supply, distribution, sharing and consumption) collectively carried out by citizens, often in partnership with small and medium enterprises and local public authorities. Being a new technological solution in the world of energy, it is essential to have a clear understanding of what they consist of, who can be part of them and why they are important for achieving a sustainable future. This thesis work aims to deal with the issue of energy communities in their entirety, starting from basic aspects, then focusing on the topic of the statute and on how to define the criteria for dividing incomes within the community, given the different nature of the participants. These last two parts are interconnected since the benefit sharing is ruled by the Private law contract. The case study of the energy community of Monticello d'Alba will be studied, in its original configuration and in one characterized by the presence of two additional users, and obtained results will be reported. Two different algorithms will be analyzed: one based on the theory of cooperative games and one based on a more common theory of redistribution already applied in different realities. The experimental results shown were obtained by *Team 23*: a working group of which I was a part operating for *Egea S.p.A.*, whose purpose was to deal with the issue of benefit sharing. The energy community of Monticello d'Alba, in both the configurations, will be tested in an optimized layout from the production point of view since all the involved plants have an optimal size. The thesis concludes with a parenthesis on the potential of Demand Side Management for energy communities, which is the key to achieve best performances of the whole community.

The Appendix B consists in an Italian version of the thesis containing the main points. References to involved figures/tables are included. Since the thesis is focused on the Italian scenario, this has been done in order to give a better comprehension, especially with regard to the statutory aspect. For that chapter Appendix B contains additional figures showing how the main documents, needed in order to realize an energy community, are formulated.

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Acronym	Meaning
REC	Renewable Energy Community
CEP	Clean Energy Package
GHG	Greenhouse gas
EU	European Union
ETS	Emission Trading Scheme
JTM	Just Transition Mechanism
JTF	Just Transition Fund
RES	Renewable Energy Source
JRC	Joint Research Center
NIMBY	Not In My Back Yard
CHP	Combined Heat and Power
WWCE	Wiltshire Wildlife Community Energy
WWT	Wiltshire Wildlife Trust
PU	Production Unit
CU	Consumption Unit
POD	Point Of Delivery
SMEs	Small and Medium-sized Enterprises
GSE	Gestore dei Servizi Energetici
CEG	Cooperativa Elettrica Gignod
SEM	Società Elettrica di Morbegno
GECO	Green Energy COmmunity
IoT	Internet of Things
ECH	Energy City Hall
EV	Electric Vehicle
RDM	Repetto's Distribution Model
TU	Transferable Unit
KPIs	Key Performance Indicators
PCR	Percentage Consumption Reduction
IRR	Internal Rate of Return
PBT	Pay-Back Time
PV	Photovoltaic
DSM	Demand Side Management
DR	Demand Response
SEDC	Smart Energy Demand Coalition
SG	Smart Grid
EMS	Energy Management System
MDC	Matrix of Demand Curves

Table 1: Adopted nomenclature

Introduction

The energy transition is necessary in terms of environmental sustainability and so it cannot be fully realized without a joint management of environmental, social and economic problems using a co-evolutionary and interactive approach, given the inseparability and mutual influence of social and technological change. An energy transition requires cultural changes, both tangible and intangible, based on energy saving and consumption efficiency. The identification of a common citizen in a community is the first step to undertake an ethic of peaceful coexistence between men and environment [1].

Renewable Energy Communities (RECs) consist in a growing phenomenon which

Figure 1: Key dimensions for sustainable development [1]

involves a range of possible activities around renewable energy (production, supply, distribution, sharing and consumption) collectively carried out by citizens, often in partnership with small and medium enterprises and local public authorities. Energy communities organize collective and citizen-driven energy actions that will help

pave the way for a clean energy transition, while moving citizens to the foreground. They contribute to increase public acceptance of renewable energy projects and make it easier to attract private investments in the clean energy transition. At the same time, they have the potential to provide direct benefits to members by improving energy efficiency and lowering their electricity bills [2].
This thesis document aims to describe in detail the topic of RECs, starting from their diffusion in Europe up to going to concentrate in Italy.
Chapter 1 will be focused on the definition of a REC and on their historical penetration in Europe. Furthermore, for what concern Italy, the regulatory evolution of the laws put in place to allow the dissemination of RECs will be analyzed in detail.
Chapter 2 will deal with an important aspect to consider: the composition of the *statute*. This is an important topic because in that document all the situations that can occur within a REC are treated. Taking a cue from already existing associations, it will be analyzed in detail how a statute for an energy community must be composed.
Chapter 3 will discuss what can be considered the core of the thesis: the theme of *benefit sharing*. Once the identification of the different nature of subjects present inside a REC is done, it comes natural to understand the necessity of having an algorithm able to distribute economic benefits within the community. Two different algorithms will be then analyzed, based on different theories: one based on the cooperative games theory and one, more popular, based on the principle of "thousandth table". Then both the two will be applied to the case study of the REC of Monticello d'Alba. This one will be analyzed in its basic configuration and in a further developed one. At the end of the chapter, there will be a short section explaining the evolutions of the model based on cooperative games.
Chapter 4 will introduce the concept of KPIs and which are important in order to estimate the goodness of the previously proposed algorithms. The two proposed configurations of the REC of Monticello d'Alba will be tested in order to estimate the KPIs of interest to see how the algorithms behave, if they are coherent or not and which one suites better.
Chapter 5 will be focused on the concept of Demand Side Management. After an introduction on this topic, it will be explained why this is important for RECs and how the active role of the members is a key to obtain better performances of the entire community.

Chapter 1

Energy communities

Through the *Clean Energy Package* (CEP) for all Europeans, the EU has introduced the concept of energy communities in its legislation, notably as citizen energy communities and renewable energy communities. More specifically, the *Directive on common rules for the internal electricity market* ((EU) 2019/944) includes new rules that enable active consumer participation, individually or through citizen energy communities, in all markets, either by generating, consuming, sharing or selling electricity, or by providing flexibility services through demand-response and storage. In addition, the *revised Renewable energy directive* (2018/2001/EU) aims to strengthen the role of renewable self-consumers and renewable energy communities. EU countries should therefore ensure that they can participate in available support schemes, on equal footing with large participants [2].
By seizing the opportunities offered by new technologies, citizens around the world are already grouping to regain relevance in the energy sector, through direct and participatory actions that aim at building a fairer and more sustainable society. This trend is growing and, in fact, in view of the reduction of carbon emissions in the electricity sector expected by 2050, it is estimated that 264 million citizens of the European Union will join the energy market as *prosumer*, generating up to 45% of the total renewable electricity of the system [1]. The term *prosumer* is used to refer to the user who is not limited to the passive role of consumer, but actively participates in the various stages of the production process. In practice, he/she is someone who owns his/her energy production plant, of which he/she consumes a part of it. The remaining portion of energy can be fed into the network, exchanged with consumers physically close to the prosumer or even accumulated in a storage system and therefore returned to the consumption units at the most appropriate time. Therefore, the *prosumer* is an active player in the management of energy flows, and can enjoy not only relative autonomy but also economic benefits.

This transformation of the role of the citizen from purely *consumer* to a *prosumer*

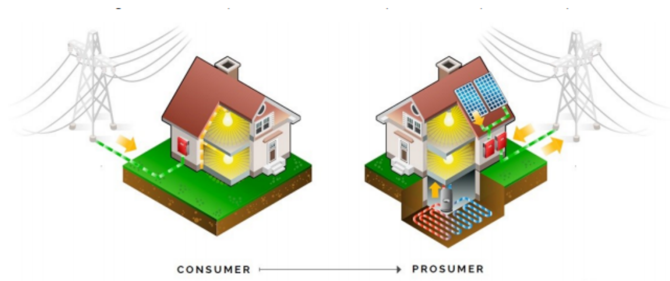


Figure 1.1: Prosumer Vs Consumer [1]

is in accordance with the *Green Deal*: the European strategic plan to face environmental problems in order to achieve a decarbonized future. The proposed plan of fiscal stimulus envisaged by the European Commission considers the *Green Deal* to be an essential tool to boost and recover the European economy. After a first commitment to reduce greenhouse gas (GHG) emissions by 40% by 2030, the EU Commission unveiled in summer 2020 a plan to increase the targets for greenhouse gas emission reductions by 2030 to between 50% and 55% compared to 1990 levels. To reach these targets and become carbon neutral by 2050, the EU is striving to update a wide range of instruments and adopt new policies to boost the transition towards a new economic system and an energy and industrial transition through four main pillars: carbon pricing, sustainable investment, a new industrial policy and a just transition [3]. The four main pillars are here summarized:

1. The first pillar is based on the idea that all the reform action to be carried out by the Commission must ensure effective carbon pricing throughout the economy. The EU intends to extend the European *Emission Trading System* (ETS) to new sectors, and make sure that taxation is aligned with climate goals;

2. Sustainable investments are the second driver of a transition towards a sustainable economy. According to a recent European Commission report, the EU is experiencing a green investment gap of €260 billion per year, with almost half generated in the housing sector. The Commission has adopted an EU industrial strategy to boost the green and digital revolutions;

3. The third pillar is represented by a new EU industrial strategy. The target of carbon neutrality cannot be reached at the expense of the competitiveness of European industry and so a competitive industry will be essential to face the economic consequences of the Corona virus outbreak. To overcome the challenge of making the whole European economy sustainable while maintaining the competitiveness of its industry, the EU needs to become a global innovation powerhouse in energy, mobility and construction technologies;

4. Finally, the fourth pillar of the *Green Deal* is the *Just Transition Mechanism* (JTM), intended as a compensation scheme to counter the adverse distributional effects of the transition. In particular, the JTM will have a *Just Transition Fund* (JTF) that will finance the territories with high employment in coal, lignite, oil shale and peat production, as well as territories with greenhouse gas-intensive industries, which could be severely impacted by the transition.

The United Nations 2030 Agenda identifies energy communities as a tool through which ensure access to affordable, reliable, sustainable and modern energy systems for all, and to make cities and human settlements inclusive, safe, long-lasting and sustainable [4].
In energy communities, citizens have democratic control or ownership over their energy supply. Energy communities vary from one community to the next: some simply host wind and solar generation installations, while others are a fully balanced, self-sufficient system functioning as a microgrid; some have a local footprint, while others cover a larger area geographically. Moreover, they can focus on renewable electricity and heating only, or include a range of other energy activities, for example peer-to-peer energy trading and electromobility. Digitization can greatly support such initiatives by creating innovative billing mechanisms and generating data that will provide important investment information to the energy market. Energy communities can also co-operate with system operators to increase the resilience of the energy grid by taking full advantage of the large number of active households involved, benefiting from the aggregation of demand response and offering flexibility to the system operator. In fact, one of their principal aims is to shift energy consumption to times when local resources are generating, thereby enhancing the resilience of the system and deferring grid reinforcements. Low awareness of energy community opportunities and their design among banks and investors increases the cost of capital, decreases their bank-ability and hinders development. To counteract this, authorities can:

- Channel resources and expertise towards investors and developers;
- Deploy public funding schemes like feed-in tariffs;
- Leverage national and international funds;
- Provide digital upskilling opportunities to citizens.

As the role of digitization in energy communities grows, data privacy and protection become an increasingly important issue. There are few standardized rules or obligations for data handlers and utilities in the context of energy communities [5].

1.1 Diffusion of RECs in Europe

The appearance of first renewable energy communities as they are known today is dated back to the mid-1970s, in Denmark. It was not until the 2000s, however, that their gradual diffusion in Northern Europe started to capture the attention of a wider audience. The growing popularity of RES communities then reached a peak in 2019, as the EU officially adopted a set of legislative texts known as *Clean Energy Package*, which among many other things legally recognizes energy communities as a new actor in the European energy system. The volume of literature on RECs has greatly increased over the past decade and the Figure 1.2 reflects this increasing trend [6].

The contextual factors that can play a role in the emergence and evolution of

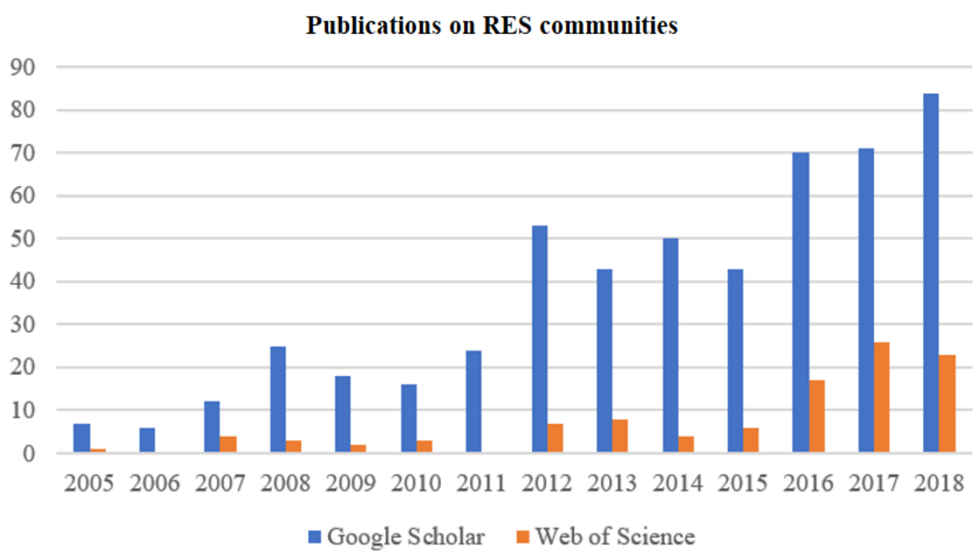


Figure 1.2: Identified publications on RECs [6]

REC projects are many and diverse. Hicks and Ison propose a classification that distinguishes between physical, technological, institutional and community factors. Specifically, *physical factors* relate to, e.g., the topography, the availability of renewable energy sources, and the existing energy infrastructure. *Technological factors* relate to, e.g., the cost of different RES technologies, the maturity and adaptability of the technology, the energy needs and the demand profile of the community. *Institutional factors* relate to, e.g., the structure of the energy market, the regulatory environment, the laws governing legal structures, renewable energy policies (especially dedicated support schemes), the culture within existing energy and other relevant institutions. *Community factors* relate to, e.g., the local history and culture, to relationships or social capital, to skills and knowledge available, to

social perceptions of and appetite for certain technologies [6].
In each country, the REC sector has its own history, more or less long and more or less successful, strongly influenced by specific contextual factors. The three countries where REC has a longer history are Denmark, Germany and UK. Other European countries where the concept of REC has been present in society for several years include Sweden, the Netherlands, Austria and Belgium. Conversely, RECs do not have a long history in Southern Europe and, even less so, in Eastern Europe, where for a long time the word community has somehow been reminiscent of the socialist past [6].
Until 2018, the fate of energy communities depended on the national sensitivity that the EU countries were able to show, in a manner proportional to their history and culture, with the result that it is almost impossible to speak of it as a unique reality characterized by easily recognizable features. More frequently, the form of aggregation that has been used is the cooperative, whose members are stakeholders directly connected to the territory, such as private citizens, public administrations or small-medium enterprises.
In 2011 *REScoop*, the European federation of renewable energy cooperatives, was founded, precisely to meet the needs of the many expanding realities (at least in the countries of Northern Europe) and to coordinate them at European level. *REScoop* currently brings together more than 1500 cooperatives, and provides for a more circumscribed definition of REC: *"a legal entity where citizens, SMEs and local authorities come together, as final users of energy, to cooperate in the generation, consumption distribution, storage, supply, aggregation of energy from renewable sources, or offer energy efficiency/demand side management services"* [7].
According to the dedicated report by the *Joint Research Center* (JRC) for the European Commission, by 2019 in Europe there were about 3500 so-called renewable energy cooperatives: a type of energy communities, which are found mostly in North-Western Europe. This number is even higher when including other types of community energy initiatives. Figure 1.3 shows an indicative number of community energy initiatives such as cooperatives, eco-villages, small-scale heating organizations and other projects led by citizen groups [8].
Energy communities can perform both traditional activities and engage in new business models. Usually, smaller scale citizen-led initiatives are mostly involved in renewable generation activities. However, an increasing number of energy communities are taking on new roles as energy providers and energy services [8].

- **Generation**: community energy projects collectively using or owning generation assets (mostly solar, wind, hydro) where members do not self-consume the energy produced but feed it into the network and sell it to a supplier;

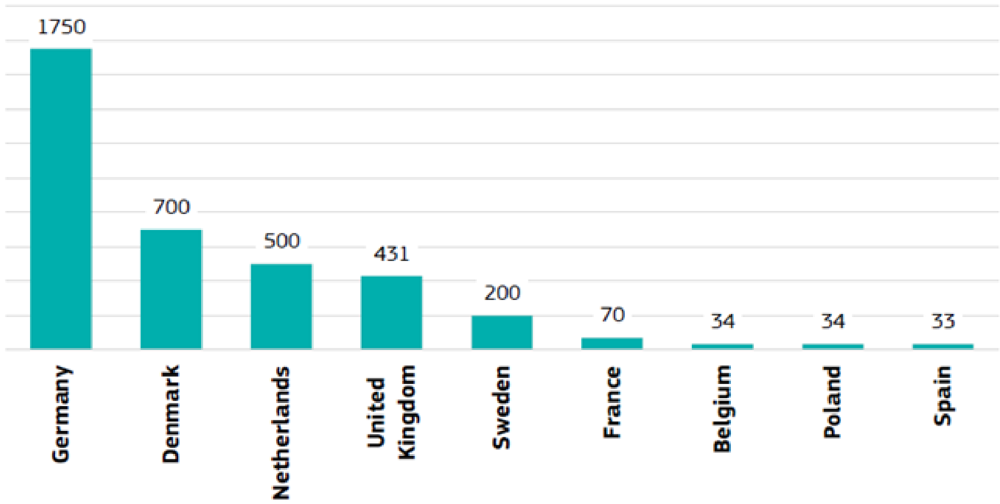


Figure 1.3: Approximate number of community energy initiatives in the nine analyzed countries [8]

- **Supply**: the sale (and resale) of electricity and gas to customers (electricity, wood pellets, biogas and others). Large communities can have a large number of retail customers in their proximity, and may also engage in aggregation activities combining customer loads and flexibility or generate electricity for sale, purchase or auction in electricity markets;
- **Consumption and sharing**: the energy produced by the community is used and shared inside the association. This includes both consumption (individual and collective self-consumption) and local sharing of energy among members;
- **Distribution**: ownership and/or management of community-run distribution networks, such as local electricity grids or small-scale district heating and (bio)gas networks;
- **Energy services**: energy efficiency or energy savings; flexibility, energy storage and smart grid integration; energy monitoring and energy management for network operations; financial services;
- **Electro-mobility**: car sharing, car-pooling and/or charging stations operation and management, or provision of e-cards for members and cooperatives;
- **Other activities**: consultation services to develop community ownership initiatives or to establish local cooperatives, information and awareness raising campaigns, or fuel poverty measures.

Figure 1.4 shows that a large majority of initiatives are engaged in energy generation, usually owning generation assets.
As previously said, the three countries characterized by a longer history in

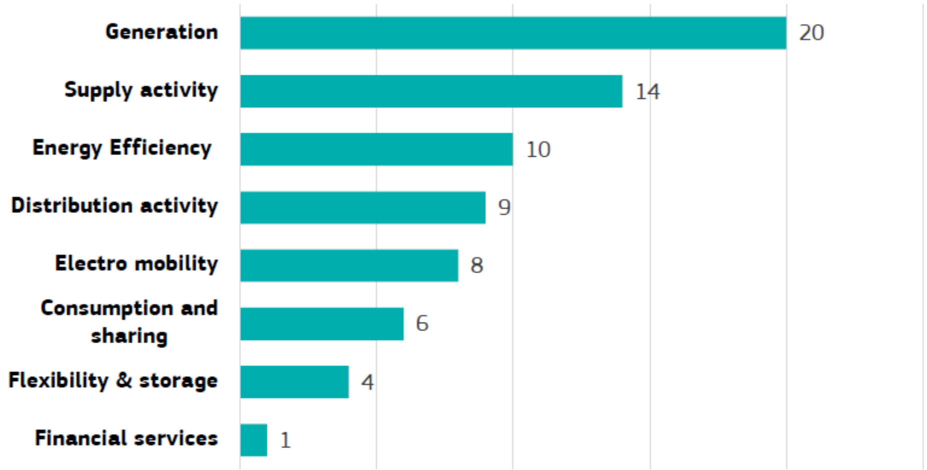


Figure 1.4: Main activities carried out by the energy communities studied by the JRC [8]

RECs are Denmark, Germany and UK. In the following is shown a short summary of the evolution of communities in that areas and a cumulative representative graph.

1.1.1 Denmark

Denmark has been a pioneer in wind energy and today remains a world leader. Denmark is also the country where the first modern REC projects were realized and, importantly, contributed in a fundamental way to the development of the wind industry. First experiences of REC projects are dated back to the mid-1970s, when the first oil crisis pushed Danish society to consider the nuclear option (never subsequently undertaken). The search for alternatives to nuclear power and the wealth of wind in the country stimulated experiments for the commercialization of wind energy, to which, especially in the beginning, an entrepreneurial civil society gave a fundamental contribution. An extraordinary diffusion of local wind energy cooperatives followed in the subsequent two decades. The success of wind cooperatives can be explained, on one hand, with the development of the national wind industry, which became an industrial policy objective pursued with effective forms of economic support, notably investment grants, tax exemptions and (later) feed-in tariffs; on the other, with the involvement of local communities.
Historically, Danish local authorities are actors in the energy sector, which is

markedly decentralized. In the early 2000s, the liberalization of the electricity market and the measures introduced by a new government less supportive of green technologies dealt a serious blow to the model of local energy cooperatives and, more generally, to the whole renewable energy sector. Funding for renewable energy was slashed and the feed-in tariff scheme was replaced by renewable portfolio standards. As a result, almost no new wind turbines were installed between 2003 and 2007 and, as Figure 1.5 shows, the number of wind cooperatives collapsed in that period. Subsequently, the number of wind turbines started to grow again, a feed-in tariff scheme was reintroduced in 2009, but ownership continued to move away from local entities to large project developers and investors. At the same time, the advantages of projects owned by the local population were made salient by a growing number of NIMBY-type protests[1] against new wind projects. In response to them, the government adopted a law that established a fund for local community development including financial support to onshore turbines, and provided that in a commercial build of new onshore turbines, at least 20% of shares must be offered to the local community.
In 2017, 4910 wind turbines existed in Denmark and about 20% of these were estimated to be locally owned by citizen cooperatives, farmers and local landowners [6].

1.1.2 Germany

Germany is a world leader in renewable energy. The range of used RES technologies is wide, but wind and solar have a prominent role. The specific contribution of citizens and communities through cooperatives and limited partnerships is also important. In Germany while the federal level sets policy targets and goals, the States decide on the implementation of projects through, e.g., the allocation of wind zoning plans and subsidy schemes, which however often are delegated to municipalities.
Germany has a long tradition of energy cooperatives and local public utilities, despite the fact that most of the second have been privatized or indeed are now owned through local cooperatives. Today wind cooperatives are fewer than solar ones but have a longer history, which started in the early 1990s thanks to the first feed-in tariff scheme, and are larger in terms of generation capacity. While declining over the years, due to increasing professionalization and commercialization in the sector, the share of wind capacity owned by citizens and local communities remains significant. By contrast, solar cooperatives, which often involve collaborations

[1]The acronym NIMBY (Not In My Back Yard) indicates the protest by members of a local community against the construction of public works with a significant impact in a territory that is perceived by them as strictly personal

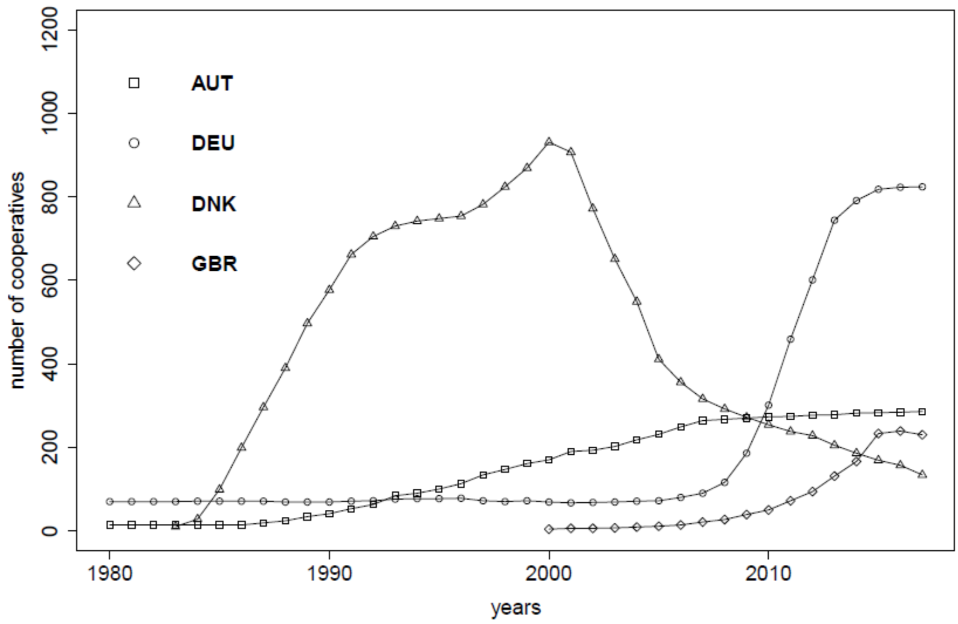


Figure 1.5: RES cooperatives in Denmark, Germany, Austria and UK [6]

between citizens and local governments, are a more recent phenomenon. Their origin coincides with the economic crisis of 2008-2009 and the consequent search for new economic models. Solar cooperatives grew very rapidly: from only four in 2007, to 200 three years later.

In Figure 1.5, the curve corresponding to Germany, which steeply increases starting in 2008 and gets flat after 2014, closely reflects the evolution of solar cooperatives. That year, the reform of the Renewable Energy Act replaced the feed-in tariff scheme with a market premium scheme, which penalized small-sized plants as being typically less competitive. The next major change in support measures was in 2016, with the shift to a tendering scheme [6].

In 2010, the energy transition process, called *Energiede*, was launched, which was divided into several fronts: drastic cut in CO_2 emissions (-80% compared to 2005) to be achieved by 2050, start of the *decommissioning* of nuclear power plants by 2022, increasing energy efficiency in the industrial sector, keeping the energy sector competitive and ensuring security of supply [9].

1.1.3 United Kingdom

After Denmark and Germany, the UK is one of the first countries in Europe where the concept of REC started to take hold. After over two decades, however, its penetration in the British electrical system remains relatively limited. In the early 1990s the electricity market was dominated by large international groups and without a significant role of local public utilities: not an ideal starting point for RECs. Apart from some experiences of community enterprises, mostly concentrated in Scotland, the first opportunities for REC projects began to appear at the turn of the millennium with the introduction of RES support schemes. The main of these, however, was a market-based mechanism that did not allow small-scale projects to benefit from it.

The Renewable Obligation scheme was initially exclusive to projects larger than 5 MW. Then, in 2004, it was extended to allow smaller plants ($>$ 50 kW), though without technology-related differentiations (this would change later, in 2009). Still, REC projects were normally not competitive. During those years, community enterprises in rural areas continued to be the primary niches for community-led renewable energy development. It is in the same period that the Scottish government started to clearly distinguish itself from the UK one in actively supporting RECs as a mean to achieve broader objectives around rural development and community empowerment. 2010 represents a turning point as it is the year a feed-in tariff scheme for renewable energy was introduced. The scheme, together with tax incentives and public loans, proved to be very effective in stimulating RES investment, including REC more specifically.

In five years, between 2009 and 2014, the total amount of installed community-owned energy capacity almost quadrupled, from 28 MW to 105 MW. Mainly thanks to the feed-in tariff, reduced investment risk meant that more diversified financial resources became available, urban RES cooperatives made their appearance as well as new shared ownership arrangements [6].

1.1.4 Examples of RECs in Europe

Middlegrunden Wind Farm

Middelgrunden Wind Turbine Co-operative is an offshore wind farm located 3 km from Copenhagen harbor. Operational since 2001, the project comprises 20 turbines of 2 MW each providing 40 MW of electricity: equivalent to 3% of the electricity needs of the capital.
The Middelgrunden co-operative was established in October 1996. A group of wind turbine enthusiasts got together to create a new co-operative combining with the Copenhagen Environment and Energy Office, who had noted that the location of Middelgrunden had been identified as a potential site for wind power in the Danish Action Plan for Offshore Wind. Together, these groups established the wind turbine co-operative and a partnership with the local utility, Copenhagen Energy. 50% of the project is owned by this local utility (which itself is part of Copenhagen municipality), whilst the other 50% is owned co-operatively by members. Initially, membership was limited only to those living within the municipal area, and by 2003 over 10000 residents had joined the co-operative.
Middelgrunden provides an interesting case study, because it is the largest community-owned wind project in the world, demonstrating how citizens can participate in and take ownership over large, complex projects. Its structure of ownership – a combination of civic participation through a co-operative, and strategic direction from the local government via its publicly owned energy company – is rare and may prove to be an interesting model for elsewhere [13]. In Figure 1.6 is shown a capture of the wind park.

Figure 1.6: Middlegrunden Wind Farm

Bioenergy Village Jühnde

Jühnde is a small village in the southern part of Lower Saxony, Germany, with a population of around 750 inhabitants. In 2005, the village opened a local bioenergy plant to supply heat and power to local residents, making Jühnde the first bioenergy village in Germany.
The system contains a 700 kW CHP generator that relies on biogas to produce electricity that is supplied to the public grid. A 550 kW woodchip boiler is used in the winter to supply heating which circulates around the local district network. During summer time, the excess heat of the CHP-plant is used for drying of wood-chips or firewood for the heating boiler to be used in winter. The original aim of the project was for the village to be self-sufficient in terms of energy consumption, and the plants now produce 70% of the villages heating demand and double its electricity demand.
The bioenergy facility is owned locally and collectively by the people of Jühnde. Residents are able to buy shares in the co-operative company that owns the facility – at present, nearly 75% of the inhabitants of Jühnde are members of this company. The development has resulted in a 60% reduction in the village CO_2 emissions because of a switch away from oil heating, and members are now provided with a comfortable, reliable and relatively cheap source of local energy. Villagers also believe that the development has contributed to the community spirit of the hamlet. The majority of crops for the plants are harvested locally, with a small shortfall of 25% purchased from regions around the village [13]. In Figure 1.7 is shown a capture of the facility.

Figure 1.7: Bioenergy Village Jühnde

Wiltshire Wildlife Community Energy

Wiltshire Wildlife Community Energy (WWCE) is an independent Community Benefit Society set up in 2012 by Wiltshire Wildlife Trust (WWT) to develop, finance and operate community owned renewable energy projects.

WWT was motivated to set up WWCE because of their commitment to protect wildlife habitats and biodiversity. WWCE has so far pursued two ground-mounted solar energy projects as well as a number of small roof-mounted schemes. The first is the Chelworth scheme, a 1 MW ground-mounted solar PV array near the village of Crickdale, near Swindon. Construction began in spring 2014 and was installed and running by June that same year. The project was funded solely from the selling of shares in WWCE through a community share offer, enabling people to invest anywhere between £500-£100000 and giving them community ownership of the project. A second, much larger solar array called Braydon Manor was originally planned to be a 5 MW scheme, then expanded to 9.1 MW, following changes in government regulations.

Both projects offer substantial community and environmental benefits. After payment to members, 80% of the remaining money is allocated to local projects through the community benefit fund of WWCE, with 20% going directly to Wiltshire Wildlife Trust [13]. In Figure 1.8 is shown a group of people during the inauguration of the PV array of Braydon Manor.

Figure 1.8: Braydon Manor PV array

Table 1.1 consists in a sort of summary containing the main features of the considered RECs in the three more advanced countries regarding this topic.

	Rural/ urban	Size/ technology	Partnership with others?	Other factors
Middlegrunden, Denmark	Urban	Large-scale wind	Joint with commercial developers	Offshore, near Copenhagen. One of the first projects
Bioenergy Village Jühnde, Germany	Rural	Biomass and other technologies - small scale but whole village	Partnership with local university	
Witshire Wildlife, England	Rural	Solar PV, medium-large scale	Partnership with commercial developer	

Table 1.1: Features of the considered RECs in the three main countries [Self - made]

1.2 Renewable Energy Communities in Italy

The *"Decreto Milleproroghe"* gave the green light to the renewable energy communities, that are considered as associations made up of energy consumers (citizens, private companies, public bodies and other subjects) that, within a geographical area, are able to produce energy from renewable sources, consume and exchange it with a view to self-consumption and self-sufficiency, entering into energetic symbiosis.
Until few years ago in Italy, self – consumption could be implemented through the *"one to one"* scheme: a Production Unit (PU) serving a Consumption Unit (CU): self-produced energy was not put on the grid and therefore self – consumption was real and immediate. To make REC operational, it is necessary to adopt a *"many to many"* scheme (different PUs and several CUs) in two possible configurations: physical and virtual self – consumption [14].
The *physical self – consumption* provides a direct private connection between the generation plant(s) and domestic users, with a single access point (POD - Point Of Delivery) to the public network. The energy produced and self-consumed actually remains within the perimeter of the private network of the building. This configuration can be summarized as follows:

- internal private condominium network with a single connection to the public network through a single fiscal meter;
- single contract for the supply of electricity to service the common and domestic users of the condominium;
- non – fiscal measurement infrastructure for accounting for utility consumption.

The *virtual self – consumption*, also referred to as "commercial" or "on an extended perimeter", involves the use of the public network for the exchange of energy between generation and consumption units, therefore each user is normally connected to the public network through its own POD. The main features of the virtual scheme are:

- unchanged network configuration: the public network ends at the *Point Of Delivery* of the individual end users, where the fiscal meter is installed;
- the electricity distributor manages the metering service;
- each end customer is free to choose his own energy supplier and to exit the scheme at any time;
- the benefits derive from commercial transactions: the responsible party appointed by the condominiums (manager of the scheme) quantifies the self-consumption share of each participant according to a calculation method

established by contractual agreements between the condominiums. The criterion on which the calculation is based can be **proportional** to the withdrawals of each user in each measured time interval, or **fixed**, for example of the thousandth type, independent of the energy consumption of individual homes.

ARERA has identified the *virtual regulation model* as the simplest and most effective to manage Collective Self-consumption and Renewable Energy Communities [14]. It should be noted that, with the same grid topology, the energy flows from a production plant will always take the path towards the point of consumption characterized by the lowest impedance, regardless of whether the grid is public or private. It is therefore not a technical distinction, but a purely regulatory one [15]. Figure 1.9 describes and compares the virtual and physical models.

The benefits that a renewable energy community can achieve are of different

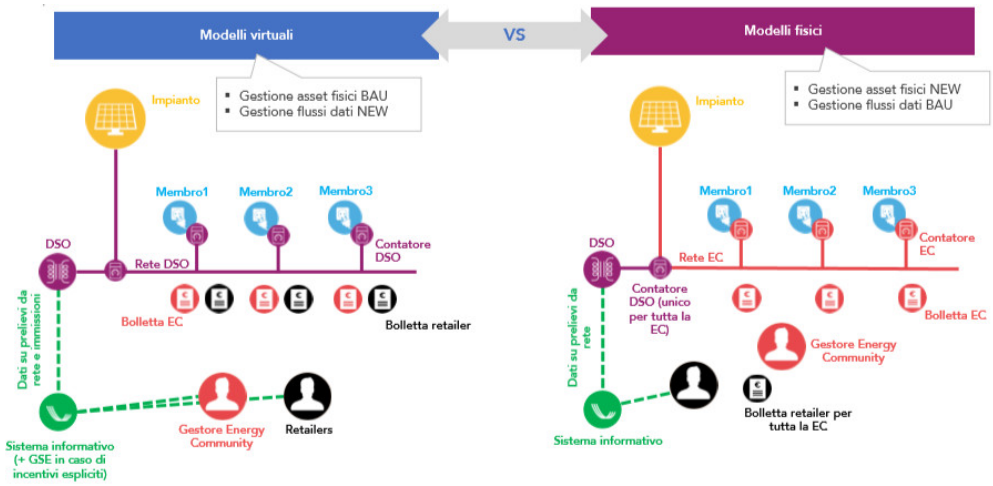


Figure 1.9: Virtual (left) Vs Physical (right) regulatory model [15]

nature and can be summarized in:

- **Environmental** benefits:
  - It collaborates in the achievement of production objectives from renewable sources;
  - It allows to reduce CO_2 emissions to produce electricity;
  - It reduces the energy dependence on imported fossil sources;
- **Social** benefits:
  - Self-production and sharing of energy among community members;
  - Creation of aggregation and development at local level;

  - Adoption of policies to support the most disadvantaged, at no cost, within the energy community itself;
  - Fight against "energy poverty";

- **Economic** benefits:
  - Cost reduction of bills thanks to an economic incentive paid by the State to the community based on self-produced and shared energy within the community itself;
  - Increase in the value of properties;
  - Participants retain their rights as end customers, including the right to choose their supplier and leave the community when they wish. Participation is open to all users under the same electrical substation, including those belonging to low-income or vulnerable families;

1.2.1 The regulatory context

According to the Article 1 of the Attached A of the *"DELIBERAZIONE 4 AGOSTO 2020 - 318/2020/R/EEL"*, a renewable energy community is a legal entity:

- which is based on open and voluntary participation, is autonomous and is effectively controlled by shareholders or members who are located in the proximity of production facilities owned by the renewable energy community;
- whose shareholders or members are natural persons, small and medium-sized enterprises (SMEs), territorial bodies or local authorities, including municipal administrations, provided that, for private companies, participation in the renewable energy community does not constitute the main commercial and/or industrial activity;
- whose primary objective is to provide community-wide environmental, economic or social benefits to its shareholders or members or to the local areas in which it operates, rather than financial profits [10].

Article 3 of [10] defines the *"Requirements for access to the shared electricity enhancement and incentive service"*. In this section is highlighted the fact that RECs are open to everyone but with some constraints. These constraints can be of different nature:

1. Topological constraints: each plant must be connected to **MV/LV electrical networks underlying the same secondary substation**. It is therefore necessary to geographically define the users that are served by the cabin. Utilities underlying different substations belong to different energy communities. However, the system does not need to be located above the building;

2. Technical constraints: only plants for the production of **electricity from renewable sources** are allowed. Only new plants or upgrades of existing plants are allowed. Each plant must have a **power not exceeding 200 kW**;

3. Temporal constraints: only plants that entered into operation between **1 March 2020** and within 60 days of the date of entry into force of the transposition of the European Directive REDII (**deadline assumed around august 2021**) are accepted.

The incentive paid by the State is calculated on the basis of the **shared electricity**, defined as the minimum, on an hourly basis, between the electricity actually fed into the grid and the electricity withdrawn from the connection points that are relevant for the purposes of the configuration [11].
For each kWh of shared electricity, the *Gestore dei Servizi Energetici* (GSE) recognizes for a period of 20 years:

- a unit fee (sum of the transmission tariff for low voltage users, equal to **7.61 €/MWh** for the year 2020, and the higher value of the variable distribution component for users other low voltage uses, equal to at **0.61 €/MWh** for the year 2020);

- a premium rate (equal to **100 €/MWh** for groups of self-consumers and **110 €/MWh** for renewable energy communities)[2].

Figure 1.10[3] represents a scheme showing the evolution of Italian law in the topic of REC.
An important subject within an energy community is the one of the **Contact Person**. In accordance with [11], he/she is defined as the subject to whom, jointly by producers and end customers, a mandate is given for the technical and administrative management of the request for access to the enhancement and incentive service, to the processing of data and to sign the related contract with the GSE to obtain the benefits provided by the aforementioned service. He/she is appointed by the community itself.
The REC must present a *statute* and a *constitutive act* that foresee that:

- the principal social objective has to be the one of providing environmental, economical or social benefits at community level to the stakeholders or to the members or to the local areas, and has not to be only an economic revenue;

[2] In Appendix A is shown how the incentive is calculated

[3] Last part of the figure is in red because it is not already approved. According to the draft of *SCHEMA DI DECRETO LEGISLATIVO RECANTE ATTUAZIONE DELLA DIRETTIVA 2018/2001/UE*, in the Article 8 is explained how the previously cited constraints will be modified

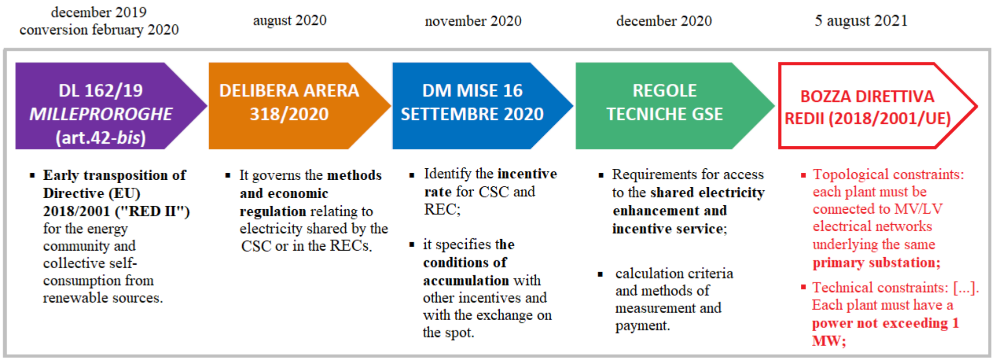


Figure 1.10: Evolution of Italian law in RECs [Self-made]

- the participation to the community has to be open to everyone and voluntary;
- the community has to be autonomous and effectively managed by the members;
- all the conditions present in the *Private law contract* have to be verified.

The relationships present inside a REC, are ruled by the *Private law contract* that presents the following characteristics:

1. provides for the maintenance of the rights of final customers, including the right to choose the most appropriate seller;
2. uniquely identifies a delegated subject responsible for the distribution of shared electricity to whom the subjects can also delegate the management of payment and collection items to the sales companies and to the GSE (the Contact Person);
3. allows subjects to withdraw at any time and exit the configuration, without prejudice to any fees agreed in the event of early withdrawal for the participation in the investments incurred, which must in any case be fair and proportionate [11].

1.2.2 Historical evolution of RECs in Italy

In Italy, before the signature of the *"Decreto Milleproroghe"*, there were already several communities and energy cooperatives located mainly in the northern area of the peninsula, some of them already active in the early decades of the twentieth century. The element that unites them is the local dimension of the renewable energy production and exchange systems [1].

- **Funes** was born in 1921 in Alto Adige with the name of "Società Elettrica Santa Maddalena". Even today, the electricity used locally is produced by three hydroelectric plants, a photovoltaic system and two biomass district heating systems. A real revolution, which has made this valley a flagship in the search for completely sustainable territories, where the role of citizens who join it, gathered in the form of a cooperative, has made the valley capable of producing, 100% renewable, more electricity than consumed. The remaining portion is fed into the national network and the revenues are reinvested in the same area, translating them into discounts on bills or investments for new plants;

- **Ewerk Prad**, a cooperative in Prato allo Stelvio, that manages 17 renewable energy plants. A model of excellence that was born in 1923. To date, it has 1350 members, which is the total number of families in the small town who, in addition to being users, are, thanks to the cooperative formula, owners of the production of electricity and gas. In this case, the savings on the bill is 30% for electricity and 20% for gas;

- The **Cooperativa Elettrica Gignod** (CEG) is located in Saint Christophe, in the Aosta Valley. The energy produced by the cooperative is sold to the members. In this way, the centrality of the mutualistic purpose is manifested in the qualification of the cooperative society and in the objectives set by the statute. In compliance with the regulations of the ARERA authority and the integrated text for historic electricity cooperatives, the CEG transfers the energy exceeding the consumption of the members to a *trader* and purchases, from the same, the energy necessary for the members if production is not enough. The cooperative manages to guarantee its self-sufficiency calculated over a period of one year;

- The **Alto But electric cooperative** was founded in Friuli in 1911. It represents the first Friulian company for the production and distribution of hydroelectric energy to be set up in the form of a cooperative. The cooperative form characterizes the work of the company on every front: production, purchase and distribution of electricity generated from renewable and conventional sources, supply of fuel gas and water resources;

- **Società Elettrica di Morbegno** (SEM) was founded in Valtellina in 1897. The company produces electricity through the exploitation of eight hydroelectric plants located in Valtellina / Alto Lario and supplies 13000 users;

- The **Melpignano cooperative** was born in Melpignano in 2011, from the collaboration between Legacoop and the municipal administration, with the aim of producing energy using photovoltaic panels placed on the roofs of public and private buildings in the city. The cooperative is responsible for installing photovoltaic systems and providing for their maintenance and management, producing energy and taking into account user demand;

- The **FTI cooperative** of Dobbiaco-San Candido was founded in 2003, managing to cover the needs of 1300 users. It represents a pioneering energy community model as regards the production of energy from renewable sources in South Tyrol. It is one of the largest plants of this type in Europe and was the first to be installed in South Tyrol;

- Founded in 2010, **Weforgren** uses three photovoltaic systems in the provinces of Lecce and Verona, shared by 462 self-producing members that produce useful energy for 1471 domestic users between the homes of self-producing members and consumers. In addition, thanks also to a mini-hydroelectric plant, greater production is guaranteed, capable of powering an additional 260 homes. Choosing to join this cooperative involved for the members, in the period 2012-2016, an average saving of 14% on the energy component of the bill compared to the rates of the *Maggior Tutela*;

- The **Energia Positiva cooperative** was born in 2015 in Nichelino, in the province of Turin. Here the shareholder can, through an Internet of Things (IoT) platform, purchase the shares of the available plants and build his own "virtual plant" with which produce clean energy. The business began by sharing three photovoltaic plants in Piedmont. In the first year of life, 70 members took part, distributed in eight Italian regions, with an average investment of about 7000 euros each; each user saved on average 350 euros per year;

- The **ÈNOSTRA cooperative** was born in 2014 in Milan to supply renewable energy to families, businesses and third sector organizations. At the moment it is able to serve 969 users, of which 922 are members, thanks to 5 photovoltaic systems installed in the Cuneo area and a 99 kW photovoltaic system located in the municipality of Sorbolo;

- The **Comunità Pinerolese** is another recent energy community project, implemented in the Pinerolo area, in Piedmont. Municipalities and companies are included in this community, and among them 8 out of 11 are *prosumers*.

> The community includes: 15 photovoltaic systems other than domestic ones; hydroelectric power plants and biogas production. Natural gas is also used, but, in this case, there is a high-efficiency cogeneration system that produces heat and electricity [1].

An interesting experiment currently under construction is the **GECO** (Green Energy COmmunity) project which, launched in July 2019, will lead, by 2023, to the creation of the energy community in Emilia Romagna, in the districts of Pilastro and Roveri. It will be realized in a virtual way, using the existing network in the areas where an electricity consumption of 430 MWh per year is currently recorded. The development area includes: a residential area of 7500 inhabitants, a commercial area of 200000 square meters which houses an agri-food park, two shopping centers, and an industrial area of over 1 million square meters. The project will promote at least 6 new plants from renewable sources, associated with storage systems, transforming companies and citizens into *prosumers*. A 200 kW plant for the agro-industrial center to be built on the car park shelter, a 20 kWe and 30 kWt biogas plant for the disposal of organic waste with storage, a 100 kW solar photovoltaic plant on more social residential buildings, 200 kW of solar power also for the Pilastro shopping center and for the neighboring condominiums. Finally two more plants, of 200 kW each, on the roofs of the Fashion Research Institute, ZR Experience and neighboring companies. All this for a total of 1 MW of new power generated by photovoltaic plants, which by 2023 will produce over 15.4 million kWh/year, with a saving of 120 MWh/year of energy, avoiding emission into the atmosphere of 58000 tons of CO_2/year [12].

Chapter 2

Constitutive act and statute

The establishment of an association takes place through the signing of a "contract" between the founding members, consisting of two documents: the constitutive act and the statute [16].

- The *constitutive act* is the document through which the founding members, gathered in the assembly, manifest and sanction their willingness to associate to pursue shared purposes; it must be signed, at the bottom, by all the shareholders present at the time of stipulation. The constitutive act must contain the following elements:
  - the indication of the day, month, year and place in which the meeting was held;
  - the details of the founding members: name, surname, residence, fiscal code;
  - the name chosen for the association;
  - the purposes (corporate purpose) and actions/services that the association will be able to implement to achieve the corporate purpose;
  - the composition of the Board of Directors (number and names of members) elected at the same time;
  - the statute attached.
- The *statute* is the document containing the rules of the association for its entire life, the rules governing relations between members and between members and the association itself. All members present at the time of signing must also sign the statute. It must contain the following elements:
  - name of the association;
  - registered office;

– purpose;
– patrimony;
– internal regulations;
– rules on administration;
– the rights and obligations of the members and the conditions for their admission;
– rules relating to the extinction of the entity;
– rules relating to the devolution of residual assets.

Once the confirmation of which subjects can be part of the community has been received from the distributor, people and entities involved can constitute the legal entity that will be characterized as the renewable energy community. Considering the fact that the purpose of the community cannot be financial profit, the most commonly used forms are those of *unrecognized associations*. Unrecognized associations can be formed with a simple fiscally registered contract, have low management costs and relatively simple organizational requirements. However, other non-profit associations such as cooperatives are also not excluded [18].
Associations can be:

1. *recognized*: they have applied for and obtained recognition;

2. *unrecognized*: they did not ask (or they asked for it but not obtained) recognition.

To obtain legal personality, a specific application must be formulated to be filed with the Prefecture. The recognition of legal personality implies that the entity is the holder of perfect patrimonial autonomy and that the corporate creditors cannot attack the assets of the individual members. In the period of time in which the association awaits recognition, it is already active but operates as an unrecognized association [17].
Since the most commonly used legal forms for RECs are the ones of *unrecognized associations*, in Appendix B (from Figure B.1 to Figure B.4) will be shown a template for the *constitutive act* and then one for the *statute*, both characteristic of this typology of association. These figures are shown in that section because are in Italian. By looking to them it is possible to understand the contents of these two essential documents for the realization of a REC.
At the end of subsection 1.2.1, the contents that the Private law contract must present have been indicated. These, in case of renewable energy communities, are an integral part of the statute and/or of the constitutive act of the same community. In substance, it is necessary to stipulate various acts for access to the service: the private contract/statute to regulate relations between the subjects that are part of

the configuration, the potential contract between the subjects that are part of the configuration and the subjects that are relevant for the configuration even though they are not part of it ("third party" producers), the mandates of both types of subjects (part of and relevant for the configuration) to the Contact Person [19].
On the GSE website it is possible to find among the documents the one of the "Mandate of producers not part of the configuration but whose plants are relevant for the purposes of the configuration of renewable energy community" [20]. This document clearly defines the relationship between the Contact Person of the REC and the representative of the *technical partner* and has to be considered in the formulation of the statute. In Appendix B (from Figure B.5 to Figure B.9) are shown captures representing this type of contract.
The figure of the *technical partner* and why it is needed within a REC will be defined at the beginning of Chapter 3, where all the types of actors that can be found will be listed.

2.1 Analysis of two available statutes of different RECs

To clarify the statement that RECs are mainly implemented as *unrecognized associations*, the following two examples made available online are now analyzed:

1. REC of Magliano Alpi;
2. REC of San Lazzaro di Savena.

Magliano Alpi founded in December 2020 its REC in compliance with the European RED-II Directive, as adopted by the Italian Government on February 28th, 2020. The REC is called “Energy City Hall” (ECH). Magliano Alpi is small rural municipality with 2230 inhabitants and other two RECs are planned in the first half of 2021. The REC-ECH is a combination of public and private POD, where the Municipality plays the role of the *prosumer*, making its PV installations available to share renewable energy.
The full version of the statute is available in [21].
Fifteen private citizens are the protagonists of the promotion of the "Energy Community", an Association of Citizens born with the aim of encouraging technologies from renewable sources and producing energy in the area thanks to them. With this goal, a 20 kW photovoltaic solar system was built on the roof of the Fantini elementary school in the Municipality of San Lazzaro di Savena. A system built thanks to the collaboration and self-financing of the citizens of the place and which today are gathered under the Energy Community association. The plant, financed through shares donated by the involved citizens of 250 euros, was then donated to the Municipality of San Lazzaro di Savena. This one, through a special agreement, self-consumes the energy produced by the plant for the school and annually gives the contributions, for the entire duration (20 years), to the Energy Community association, which in turn distributes it proportionately among its members [22].
The full version of the statute is available in [23].
By analyzing the two statutes in detail, it can be seen that they are almost identical; the only difference that can be found is that the statute of San Lazzaro di Savena presents two articles less with respect to the one of Magliano Alpi. These two appear to be:

- Article 9 of Magliano Alpi that defines all the organs present in the REC;
- Article 20 of Magliano Alpi that defines the members and functions of the C.T.S (*Comitato Tecnico Scientifico*).

Therefore, both for the case of Magliano Alpi and for the one of San Lazzaro di Savena, the structure of the statute is very similar and this is because both are formulated as *unrecognized associations*. The common root for both statutes is exactly the one shown in Appendix B (from Figure B.2 to Figure B.4), characteristic of this typology of associations.

Chapter 3

Benefit sharing within a REC

Within a REC, it is possible to identify both subjects of a public nature (for example a municipality) or of a private nature (a citizen or a SME). The configuration of subjects participating in the REC can be:

1. Pure producer subject;
2. Pure consumer subject;
3. Producer and consumer;
4. Subject neither producer nor consumer but who provides the space to position the production plant (*lessor*).

In case 4, the latter does not produce any kWh and does not contribute economically to the construction of the REC, however he/she is the owner of the installation space of the production facility. Different scenarios can be opened regarding how to remunerate subjects belonging to category 4. One possibility could be that of a retrofitting financed by the REC in the event that the roof is made of asbestos; in that case, the REC would reinvest part of the proceeds for the retrofitting but, once completed, it would not present a constant distribution of the benefits with this type of subject. In the event that the canopy of the subject 4 does not require retrofitting, a rent share should be taken into account in the internal distribution. In most cases, the energy community is the owner of the production plants but, at the same time, an external body (energy service manager) manages it. In fact, since RECs often involve public administrations, they will not have adequate technical skills and therefore the external *technical partner* will be responsible for guaranteeing the operation and maintenance of production plants and the distribution

of benefits within the community. In the event that the production plant is not owned by the REC but by the external company, the percentage of share for the latter would increase dramatically, as the depreciation of the plant should also be provided; in that case the final benefits to be shared among the members would be significantly reduced. A degree of complexity can be added to this situation outlined if OPEX foreseen for the production plant are considered. The latter, in addition to including ordinary and extraordinary maintenance, may also include aspects relating to the insurance and custody of the plant.
In Figure 3.1 is possible to see a qualitative cash flow diagram representing the situation above described. This distinction of different nature of subjects together

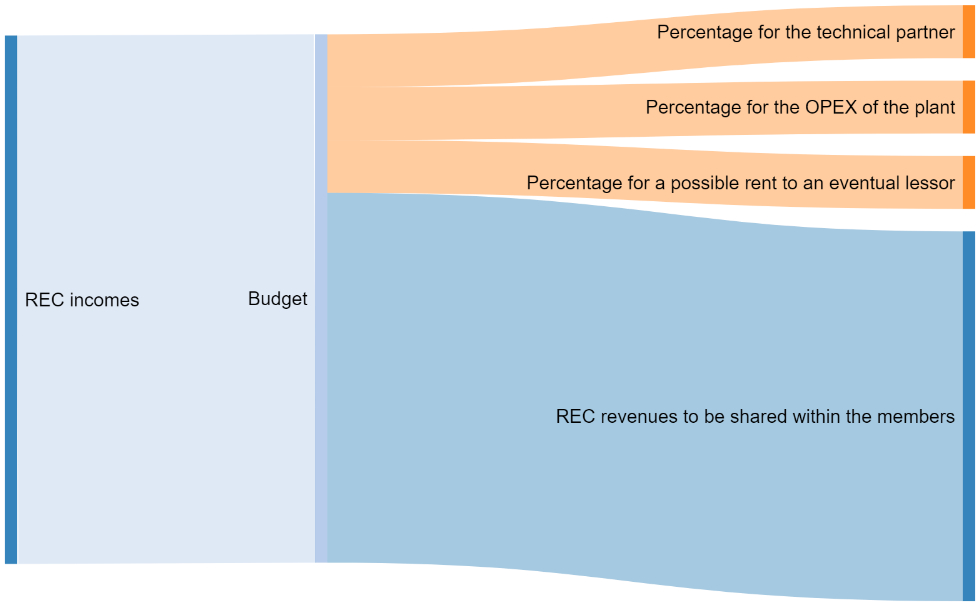


Figure 3.1: Qualitative representation of a cash flow distribution within a REC [Self-made]

with the need to sign the Private law contract between the Contact Person and members of the community, means that establishing a coherent method for distributing the proceeds is of vital importance.
In the following different methods of distribution will be analyzed and then there will be shown results for the case of Monticello d'Alba in which these methods were tested.

3.1 Case study of Monticello d'Alba

Monticello d'Alba is a village of about 2350 inhabitants, located in the Roero near the city of Alba, in the province of Cuneo characterized by a territorial extension of 10.1 km^2. The municipality is divided into the hamlets of Borgo, Soria, Casà, Sant'Antonio, Valdozza and Villa. Considering the geographical constraint placed in the decree-law regarding the extension of renewable energy communities (the points of injection and withdrawal of electricity must be on low voltage electricity grids, underlying the same MV-LV transformer substation), it was decided to focus attention on the more urbanized area of the municipality, where the probability that PODs of contiguous users meet the constraint imposed by the decree is greater [31].
The first community will be born in the hamlet Borgo, taking the opportunity of the planned energy redevelopment of the municipal gym building in via Mario Nantiat. As coordinator and *prosumer* of the Energy Community, the Municipality of Monticello d'Alba will provide a 55 kWp photovoltaic system combined with energy storage systems, which will be able to share with the Energy Community the energy produced and not self-consumed by the municipal buildings. The system will be installed on the roof of the municipal gym and will also power two Electric Vehicles (EV) charging columns, one installed in Piazza Michele Ferrero, and one in Piazza Martiri della Libertà, which can be used free thanks to the usage of the health card. At the same time, the municipal administration intends to encourage the installation of new panels to replace the old Eternit® roofs still present in the village. The energy community will leverage renewable energy projects not only to provide a return on the investment of its members, but to fund social and environmental programs [32].

3.1.1 Optimal Energy sizing: the RECOpt tool

The Community of Monticello d'Alba is made up of six users, of which five are public, belonging to the Municipality, and a private one (RSA). In the case study analyzed, the installation of a photovoltaic system with a nominal power of 55 kWp is owned by the Municipality. The Figure 3.2 is a satellite capture that shows the perimeter of the REC of Monticello d'Alba and the involved players.
The energy performances of the community are assessed using the methodology implemented in the *RECOpt* tool [34], which uses profiles (of production and consumption) in typical days, representative of a reference year, rather than annual hourly series. The *RECOpt* open-source software was developed in its original version at the Energy Department "Galileo Ferraris" of the Politecnico di Torino [35]. The tool implements an optimization procedure for the operation of a photovoltaic system, possibly combined with a storage system, in the hypothetical context of

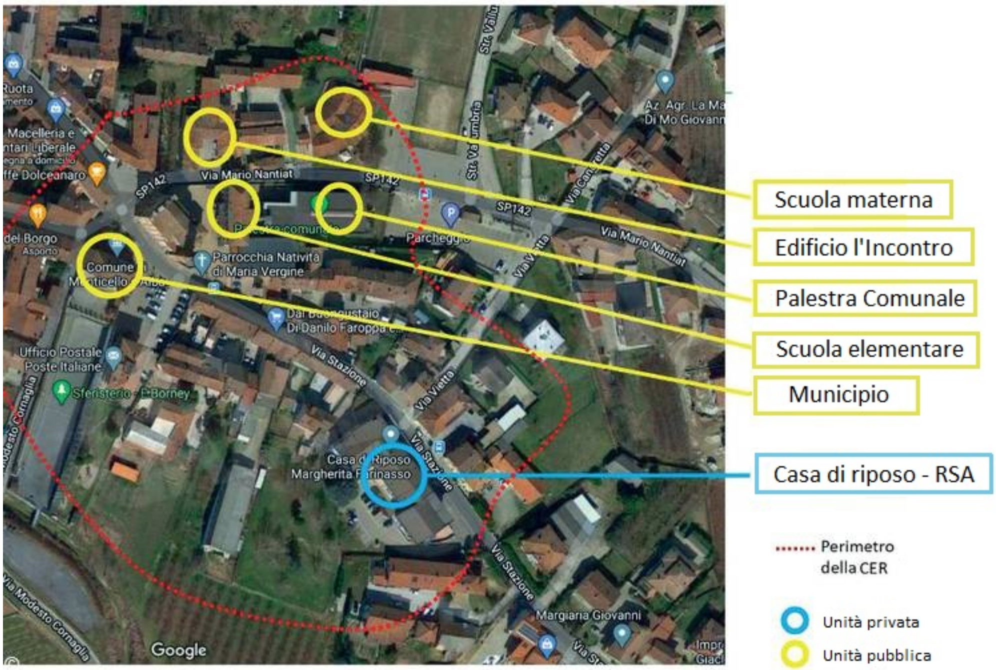


Figure 3.2: Satellite capture of the perimeter of the REC with the involved players [33]

a REC. The objective of the procedure is to maximize the shared energy and therefore the economic profit of the association. *RECOpt* is based on an hourly analysis of energy flows and aims to define the optimal sizes of PV and BESS given the electrical loads present.
The evolution of the *RECOpt* tool focused on determining the benefits distribution according to the theory of cooperative games takes the name of *RECOptGame*. After the introduction of theoretical concepts, this one will be compared with another method of distribution, the so - called *Sharing Distribution Model*[1]; it is based on the most common theory of the "thousandth table" .

[1]A benefit share generator based on the model proposed by Prof. Maurizio Repetto and, in fact, in the following figures will be indicated with RDM (Repetto's Distribution Model)

3.2 Benefit sharing through cooperative game theory

Game theory is an effective tool for addressing the interactive nature of energy sharing, as it provides general mathematical techniques for analyzing situations in which two or more individuals make decisions that will affect the well-being of the other. The game describes any situation in which the decision-making processes of the players, i.e. the participants in the game, are interconnected. If game theory is applied to energy communities:

- players are considered *rational*, since their decisions are guided solely by the desire to complete their goals, which are assumed to be the maximization of their expected payoff, described mathematically by a utility function;
- players are considered *intelligent* and it is assumed that each player is aware of the rules of the game and can think of coherent assumptions to make his own decisions [24].

Game theory is generally divided into two classes that define the level of constraint of the agreements made between players. *Cooperative games* analyze situations where commitments are fully binding and enforceable. Conversely, in *non-cooperative* (or strategic) *games* there is no obligation to fulfill these commitments. In *non-cooperative games*, players are independent and choose their own strategy: maximizing their utility function, without communicating or exchanging information with other players. *Cooperative games* are characterized by the possibility of communication between players. In particular, players decide to form coalitions with each other to improve their payoff from the game. This alliance represents an agreement that binds players to act collectively [24].
A cooperative game with a *Transferable Utility* (TU) can be represented through a couple (N, v), where $N = \{1, \dots, n\}$ is the set of players and v is the characteristic function, also known as *value function.* Specifically

$$\begin{aligned} v : \mathcal{P}(N) \simeq 2^N &\longrightarrow \mathbb{R} \\ S &\longmapsto v(S). \end{aligned} \tag{3.1}$$

The value $v(S)$ can be interpreted as the profit that the players in S can gain, regardless of the behavior of the other players $N \setminus \{i\}$, for every $S \subseteq N$.
It is defined as a solution of the game with a transferable utility (N, v), a (possible) distribution of profits for N, i.e. the coalition of all the players.
In the early days of game theory, some techniques were introduced to determine ensemble solutions. However, they did not solve the fundamental problem of determining an allocation of profits.

It is defined as a punctual solution or *value* for the game (N, v) a function

$$\begin{aligned} \psi : \mathcal{G}^N &\longrightarrow \mathbb{R}^N \\ (N, v) &\longmapsto \psi(v), \end{aligned} \tag{3.2}$$

where $\mathcal{G}^N = \{(N, v)\}$ is the set of all the games and $\psi_i(v)$, $i \in N$, is the share of profits due to the player i.
To overcome the problems of set solutions, Shapley introduced in 1953 [25] a punctual solution, called *Shapley value*. It is defined for super additive games, i.e. games (N, v) such that

$$v(S \cup T) \geq v(S) + v(T), \tag{3.3}$$

with $S \cap T = \emptyset$ e $S, T \subseteq N$. It is possible to observe that the characteristic function chosen in the considered model, that is the function that returns the revenues of the coalition, satisfies the condition 3.3. Furthermore this $v(S)$ satisfies another hypothesis: the *monotony*, and so

$$S \subseteq T \implies v(S) \leq v(T), \quad S, T \subseteq N. \tag{3.4}$$

The Shapley value is so defined as

$$\phi_i(v) = \sum_{S \subseteq N \setminus \{i\}} \frac{s!\,(n-s-1)!}{n!} \left(v(S \cup \{i\}) - v(S)\right), \tag{3.5}$$

for every $i \in N$, where $s = |S|$ is representative of the number of participants of the coalition S. Under the above assumptions, the Shapley value $\phi_i(v)$ corresponds to the expected payoff of player i. In other words,

$$\sum_{i \in N} \phi_i(v) = v(N), \tag{3.6}$$

and so, the sum of all Shapley values corresponds to the (economic) value of the total configuration.

3.2.1 Interpretation and alternative formulations of the Shapley value

The idea behind the Shapley value $\phi_i(v)$ is the consideration of the *marginal value* that each player $i \in N$ brings to the coalition $S \subseteq N \setminus \{i\}$. This contribution is defined as the change in value that the S coalition undergoes after player i joins it:

$$v(S \cup \{i\}) - v(S).$$

This contribution is weighted for each coalition by the term

$$w(S) = \frac{s!\,(n-s-1)!}{n!}, \tag{3.7}$$

which can be interpreted as the probability that a coalition of $s = |S|$ players will be formed. In fact,

$$\begin{aligned} \frac{s!\,(n-s-1)!}{n!} &= \frac{n-s}{n-s}\frac{s!\,(n-s-1)!}{n!} = \\ &= \frac{(n-s)!s!}{(n-s)\,n!} = \\ &= \frac{n-s}{\binom{n}{s}}. \end{aligned} \tag{3.8}$$

Since the 50s, alternative formulas for the Shapley value have been introduced, which can make it easier to interpret. Among them, in the paper [26], the value is defined as

$$\phi_i(v) = \sum_{S \subseteq N \setminus \{i\}} \frac{\Delta_v\,(S \cup \{i\})}{s+1}, \quad \forall i \in N, \tag{3.9}$$

where $\Delta_v\,(S \cup \{i\})$ are *Harsanyi's dividends* defined as

$$\Delta_v\,(T) = \sum_{R \subseteq T} (-1)^{|T|-|R|} v(R), \quad \forall T \subseteq N. \tag{3.10}$$

These values, which can be calculated recursively, are the basis of the Harsanyi model. The idea is to associate to each coalition S, a dividend $\Delta_v\,(S)$, which can be redistributed among members $i \in S$.
So the dividend $\Delta_v\,(T)$ consists in a measure of the net surplus given by the coalition T, calculated by discounting the surpluses already created by the sub-coalitions $R \subset T$.
Shapley himself, in his pioneering work, presents an alternative formulation. This model assumes that the total N coalition is formed by admitting players one by one. Each participant, upon his/her admission, requires his/her marginal contribution to the already admitted members. The order of participation of the various players is given randomly, assuming that all possible orders are equi-probable. The value must therefore be considered as an *a priori* assessment of the situation, based on the ignorance or disinterest of the players.
More formally, consider a permutation $\pi \in \Pi$, where $\Pi \simeq S_n$ is the group of all player permutations. It therefore becomes important to consider the value of the coalition of players preceding i in the order π; this coalition is denoted as $P(\pi, i)$.

More specifically, it is necessary to consider the contribution that i makes by joining $P(\pi, i)$.
With these formalisms, the Shapley value can be expressed as

$$\phi_i(v) = \frac{1}{n!} \sum_{\pi \in \Pi} \left[v(P(\pi, i) \cup \{i\}) - v(P(\pi, i)) \right], \tag{3.11}$$

for each player $i \in N$. Finally, it is reminded that

$$\frac{1}{n!} = \mathbb{P}(\pi), \quad \forall \pi \in \Pi, \tag{3.12}$$

is the probability of any sort. The latter formulation is sometimes reported in the literature as *bargaining model*.

3.2.2 Approximations and Extensions of the Shapley value

In [27] is explained how the calculation of the Shapley value can become problematic as the number of players n increases; however, an adequate approximation technique is not proposed, which is difficult to identify in this application context.

Truncation

A heuristic reasoning would suggest truncating the summation 3.5 considering only sub-configurations S of order $s \geq n - h$, thus realizing what can be called "approximation of the order h", $h \geq 1$. In this way the computational complexity of the problem would be considerably reduced, depending on the h order chosen. By doing so the approximation of the Shapley value becomes

$$\tilde{\phi}_i(v) = \sum_{\substack{S \subseteq N \setminus \{i\} \\ s = |S| \geq n-h}} \frac{s!\,(n-s-1)!}{n!} \left(v(S \cup \{i\}) - v(S) \right). \tag{3.13}$$

First of all it is observed that, with this methodology, the relationship 3.6 is lacking, and so

$$\sum_{i \in N} \tilde{\phi}_i(v) < v(N). \tag{3.14}$$

In other terms, values $\tilde{\phi}_i(v)$ do not correspond to the expected payoff of the player i.
However, an approximate distribution can be $q \in [0,1]^n$ normalizing these values, that is by setting, for each player i,

$$q_i = \frac{\tilde{\phi}_i(v)}{\sum_{j \in N} \tilde{\phi}_j(v)}. \tag{3.15}$$

By implementing this approximation algorithm and running tests, the following aspects were noted:

- the distribution generated with this technique is not too far from the deterministic one, but
- "small" participants are penalized;
- increasing the approximation order h does not imply a significant improvement.

Statistical sampling

Although there are some subcases of games for which the Shapley value can be easily calculated directly, the only approximations suitable for (almost) all generalizations are those based on statistical sampling [28]. These techniques allow to reduce the computational complexity of the problem from exponential to polynomial.
Considering the alternative formulation of the Shapley value based on *bargaining model* (3.11), it is possible to see that, in this model, to the order of each player π is assigned the same probability $\frac{1}{n!}$.
It is therefore possible to carry out a sampling of orders $M \subset \Pi$, with $m = |M|$ and calculate, for each player, the Shapley value as the arithmetic mean of the evaluations. More precisely, it can be estimated

$$\hat{\phi}_i(v) = \frac{1}{m} \sum_{\pi \in M} \chi_i(\pi), \quad \forall i \in N, \tag{3.16}$$

where

$$\chi_i(\pi) = v(P(\pi, i) \cup \{i\}) - v(P(\pi, i)), \quad \forall i \in N, \tag{3.17}$$

is the characteristic of the player i, always in the formulation 3.11.
Several extensions of these approximations have been studied, such as the one in [29], which allows to fix bounds and maximum error probabilities. All these, however, share the need for a significant statistical basis (eg with $|N| > 15$): they are more suitable for games with many players and a computationally undemanding $v(S)$ feature.

Weighted Shapley value

The formulation based on *bargaining model* makes it easier to build a Shapley value extension named *weighted Shapley value.*
This generalization must take into account the importance attributed *a priori* to each player. Therefore, consider a vector of weights

$$w = (w_1, \dots, w_n), \tag{3.18}$$

with $w_i \in \mathbb{R}^+$, for every $i \in N$. Once an order of players has been set $\pi \in \Pi$, its probability in this weighted model can be expressed as

$$\mathbb{P}^w(\pi) = \prod_{j=i}^{n} \frac{w_{\pi(j)}}{\sum_{l=1}^{j} w_{\pi(l)}}. \tag{3.19}$$

The weighted Shapley value can therefore be expressed as

$$\phi_i^w(v) = \sum_{\pi \in \Pi} \mathbb{P}^w(\pi) \left[v(P(\pi, i) \cup \{i\}). - v(P(\pi, i)) \right]. \tag{3.20}$$

This extension opens up some opportunities in modeling terms: weights can be introduced to force the distribution of profit in predetermined directions.

3.2.3 Interpretative analysis of the Shapley value

The Shapley value defined as in 3.5 can be rewritten in the form:

$$\phi_i(v) = \frac{1}{|n|} \sum_{s \subseteq n \setminus \{i\}} \binom{|n|-1}{|s|}^{-1} (v(S \cup \{i\}) - v(S)) \tag{3.21}$$

The v function gives the payout for any subset of the players; let S be a subset of N, $v(S)$ gives the value of that subset. For a coalition game (N, v) it is possible to use the equation to calculate the payout for player i, i.e. the Shapley value.
To get the concept clearer, an example is considered [30]. One of the production teams of a brick factory consists of four people: **A**manda, **B**en, **C**laire e **D**on. Each week together they manage to produce X amount of bricks. The business is in a rosy situation and there is a bonus that have to be distributed within the team members. To do this fairly, it is necessary to find out how much each person contributes to the production of X amount of bricks per week. There are several factors to be considered; one of them is the size of the team since a larger team will perform a higher production of bricks. Another could be the way team members collaborate with each other. Once players are defined (A, B, C and D) and also the game they are playing in (brick production), first point is to start by deciding how many of the X bricks produced can be attributed to **D**on, and so this means to calculate the Shapley value for D. The situation is the following:

$$N = \{\text{A,B,C,D}\}$$
$$i = \text{D}$$

The Shapley value formula, applied to the example under consideration, provides that it is necessary to exclude from the group of people considered the person under investigation. Hence, one must consider all possible subsets that can be formed. Excluding D from the group, they remain {A, B, C}. From this remaining group the following subsets can be formed (these are the sets that S can assume):

$$\begin{array}{cccc} & A & AB & \\ \emptyset & B & BC & ABC \\ & C & CA & \end{array}$$

So in total there are 8 possible subsets for the remaining team members. Focusing on the final part of 3.21, there is where the concept of marginal value of adding player i to the game comes into play. For any given subset S, its value will be compared with the value it has when player i is also included in it. With reference to the example, the aim is to see what is the difference in the amount of bricks produced each week if D is added to each of the 8 subsets. These 8 marginal values are displayed as:

$$\begin{array}{cccc} & \Delta v_{A,D} & \Delta v_{AB,D} & \\ \Delta v_{\emptyset,D} & \Delta v_{B,D} & \Delta v_{BC,D} & \Delta v_{ABC,D} \\ & \Delta v_{C,D} & \Delta v_{CA,D} & \end{array}$$

It is therefore necessary to observe how many bricks are produced if no one is working (i.e. the empty set $\emptyset$) and compare it to what happens if only D is working. It is also necessary to observe how many bricks are produced by AB and compare them with the quantity of bricks produced by AB together with D and so on for all the 8 possible configurations. It is therefore necessary to calculate 8 different marginal values. The summation in 3.21 says they must all be added together. However, it is necessary to scale down any marginal values before doing so. In the example considered, there is $|N|$ - 1 = 3. So, for example, if there is $|S| = 2$ then it is possible to build 3 different groups of this size: AB, BC and CA. This means that the following scale factor must be applied to each of the 8 marginal values:

$$\begin{array}{cccc} & \frac{1}{3}\Delta v_{A,D} & \frac{1}{3}\Delta v_{AB,D} & \\ 1\Delta v_{\emptyset,D} & \frac{1}{3}\Delta v_{B,D} & \frac{1}{3}\Delta v_{BC,D} & 1\Delta v_{ABC,D} \\ & \frac{1}{3}\Delta v_{C,D} & \frac{1}{3}\Delta v_{CA,D} & \end{array}$$

The goal is to know how much D contributes to the total production of the team. To do this, it was calculated how much contributes marginally in every possible configuration of the team. Adding this scale factor means averaging the effect the rest of the team members have for each dimension in the subset. This means that at this point is possible to capture the average marginal contribution of D when added to a team of sizes 0, 1, 2 and 3 regardless of the composition of these teams. It only remains to apply a further scaling factor to all marginal values before they can be added together. Divide them by the number of players participating in the game (N). At this point, the Shapley value for D can be determined

$$\phi_D(v) = \frac{1}{4} \sum \left(\begin{array}{cccc} & \frac{1}{3}\Delta v_{A,D} & \frac{1}{3}\Delta v_{AB,D} & \\ 1\Delta v_{\emptyset,D} & \frac{1}{3}\Delta v_{B,D} & \frac{1}{3}\Delta v_{BC,D} & 1\Delta v_{ABC,D} \\ & \frac{1}{3}\Delta v_{C,D} & \frac{1}{3}\Delta v_{CA,D} & \end{array} \right) \tag{3.22}$$

After doing it for the rest of the team, the contribution of each player to the amount X of bricks produced each week is known: in this way is possible to divide the bonus equally among all team members.

$$X = v(\{A, B, C, D\}) = \phi_A(v) + \phi_B(v) + \phi_C(v) + \phi_D(v) \tag{3.23}$$

3.3 Sharing Distribution Model

In this model, the share of each participant on the total income of the community is calculated by considering the hourly contribution that the participant has on production and total consumption, for an entire reference year.
This distribution must necessarily be calculated on an hourly basis and could be differentiated between:

- producers (P), who have invested in plants for the generation of renewable energy;
- storage operators (S), who have also invested in hardware to increase the sharing of the energy produced;
- users (U), that join with their consumption, thus allowing the sharing (virtual self-consumption) of the energy produced.

A simplified initial formulation is considered in which the accumulation operators are not taken into consideration. The proceeding therefore provides for a division of benefits between the two classes of producers (P) and users (U). Within the two macro-groups, each participant is rewarded with the percentage of useful energy put into play (whether produced or consumed), normalized to the whole of their class, calculated on an hourly basis. The following quantities are defined:

- hourly index $k \in \{1, \ldots, 8760\}$;
- number of producers within the REC, N_P;
- hourly production of the i-th producer, $P_i^{(k)}$, $i \in \{1, \ldots, N_P\}$;
- number of users within the REC, N_U;
- hourly consumption of the i-th user, $U_j^{(k)}$, $j \in \{1, \ldots, N_U\}$;
- hourly shared energy within the REC, $E_{sh}^{(k)}$;
- community hourly rate $v^{(k)}$;
- coefficient for sharing the income between producers and users, η (with $\eta = 1$ all incomes go to producers, and with $\eta = 0$ all incomes go to consumers).

The hourly rate linked to the production of the i-th producer can therefore be calculated as

$$q_i^{(k)} = \frac{P_i^{(k)}}{\sum_{\iota=1}^{N_P} P_\iota^{(k)}}. \tag{3.24}$$

The latter allows to calculate the (hourly) economic payment due to the i-th producer, that is

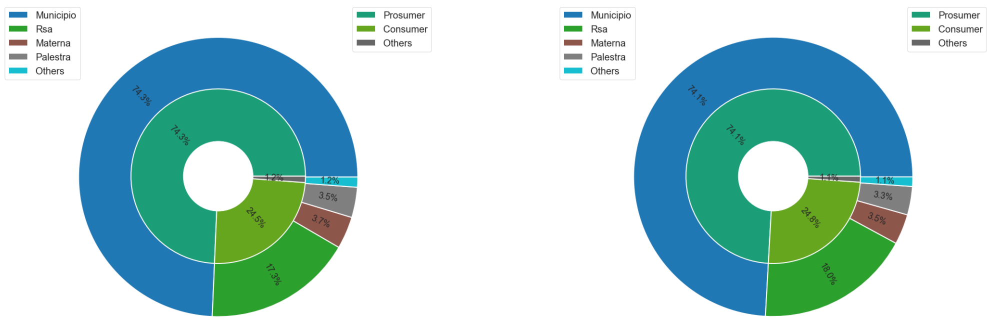
$$v_i^{(k)} = \eta \cdot v^{(k)} \cdot q_i^{(k)}. \tag{3.25}$$

The hourly payment due to the j-th user can be obtained in the same way:

$$v_j^{(k)} = (1 - \eta) \cdot v^{(k)} \cdot \frac{U_j^{(k)}}{\sum_{\lambda=1}^{N_U} U_\lambda^{(k)}}. \tag{3.26}$$

3.4 Comparison of RECOptGame and Sharing Distribution Model

In Figure 3.3a and Figure 3.3b are shown the percentages to the members of the Community of Monticello d'Alba, obtained using the *Sharing Distribution Model* and *RECOptGame*, respectively. In the first case, it was assumed to divide the total incomes in order to allocate the 70% to producers and the remaining 30% to consumers ($\eta = 0.7$[2]). In the second case, it was adopted the convention whereby configurations of a single player have a non-zero value (from now on, *Republican*[3]), which increases the value of producers to the detriment of consumers. The following figures show different pie diagrams representing the shares of the main players (*Municipio*, *RSA*, *Materna*, *Palestra*) and the remaining ones (*Incontro*, *Elementare*) are grouped in "Others" [Team 23].



(a) *Sharing Distribution Model* ($\eta = 0.7$) **(b)** *RECOptGame* (Republican)

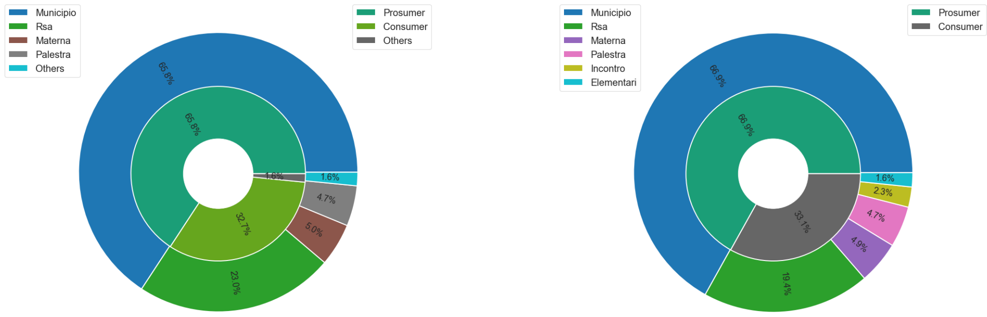
Figure 3.3: Benefit shares for the REC of Monticello d'Alba, with a 55 kW_p PV plant owned by the *Municipio* [Team 23]

In Figure 3.4a e Figure 3.4b same previously determined results are reported, respectively, with $\eta = 0.6$ in the first case and adopting the convention that

[2]This value is the result of a sensitivity analysis done on the specific case study of the REC of Monticello d'Alba. The first guess was $\eta = 0.5$ but at the end with $\eta = 0.7$ the obtained KPIs were coherent with the ones obtained with the other model. η parameter is a constraint set at the beginning of the procedure and then changed when results are determined, if not in line with the purpose. It is specific for the considered case study.

[3]This name has no political origin and is used symbolically to express the concept

single player configurations have zero value (from now on, *Democratic*[4]). The latter confers a certain value on each participant simply by being present in the community, beyond the extent of its consumption.



(a) *Sharing Distribution Model* ($\eta = 0.6$) **(b)** *RECOptGame* (Democratic)

Figure 3.4: Benefit shares for the REC of Monticello d'Alba, with a 55 kW_p PV plant owned by the *Municipio* [Team 23]

In the first set (Figure 3.3), obtained results with the two different models are practically coincident. In the second set (Figure 3.4), while the global distribution between producer and consumer remains similar[5], the distribution within the consumer group varies according to the adopted model. As already mentioned, the *Democratic* model confers a certain value on a consumer simply by being a member of the community. The *Sharing Distribution Model*, on the other hand, continues to consider actual consumption (and its distribution within the day) as the only metric for the distribution of benefits in the macro-group of consumers.
From the previous analyzes it can be concluded, first of all, that the *Sharing Distribution Model* can lead to results similar to the algorithm based on the calculation of the Shapley value, in not particularly problematic cases. To this is added the fact that the first, while needing annual series, can require calculation times much less than the second, especially as the number of players increases (calculation times vary, respectively, linearly and exponentially with the number of players). Last but not least, the optimal theoretical simplicity of the model proposed by

[4]Same reasoning of Republican but with opposite meaning

[5]In reality, the Municipality is part of the community as a prosumer and not a pure producer. However, its consumption is quite low and it can be assumed that a large part of its share is due to production

Prof. Repetto guarantees an incomparable interpretability compared to that of *RECOptGame*.
However, the algorithm on which *Sharing Distribution Model* is based, in the initial formulation, appears relatively rigid and does not respond perfectly to variations in the configuration. In fact, having to define *a priori* the percentage breakdown between production and consumption, the algorithm is not able to automatically "perceive" how much production affects the income of the community with respect to consumption and vice versa. Another problem to be solved is how to consider, in the algorithm, any operators of storage systems, whose calculation of the share would require a different implementation from the one adopted up to now. This problem is not found in *RECOptGame*, where the storage holders are treated like other players and the algorithm is able to automatically evaluate their value [Team 23].

3.4.1 Extensions of RECOptGame

In reality, inside a REC, there are typologies of subject that are difficult to refer to the model based on game theory [27]. To better evaluate the behavior of *RECOptGame*, new extensions have been developed capable of framing what can be defined as "atypical" participants:

- the *technical partner* of the REC (the one who manages the community);
- the *lessor* of the spaces dedicated to the plants.

Technical partner

A method has been designed and developed, called `find_ms_share`, which calculates the share that can be allocated to any external service manager. This method, taking as input the minimum thresholds for the KPIs of the participants, through an iterative procedure, calculates the maximum share (of the total profits) that can be allocated to the *management service* [Team 23].
Consider, by way of example, an application to the profiles of the basic configuration of Monticello d'Alba. In this case, fixing as minimums

- IRR at 6%
- PCR at 8%;
- PBT at 12 years,

is obtained, for the operator, a share of 14.5% [Team 23].

Lessor and others

It is reasonable to consider, among the various cases, that of a lessor who, while not participating directly in the REC, makes available the space for the installation of photovoltaic systems. For this situation, the allocation of a fixed rent is considered and depends exclusively on the surface used (and on a specific price). This share is calculated by reconstructing the square footage starting from the size of the photovoltaic system chosen; the algorithm then separates it from the total value of the configuration (which is on an annual basis) and calculates the KPIs net of this expense [Team 23].

It remains to plan and develop the treatment of further "pathological" series from the modeling-theoretical point of view. For example, consider the situation of a participant who, while wanting to make his property available, must first deal with the disposal of any cover in Eternit®.

Chapter 4

Evaluation of KPIs for the REC of Monticello d'Alba

Once the goodness of the distribution algorithms has been determined, it is necessary to ensure that the latter return parameters in output that are able to evaluate their convenience in the eyes of the participants of an energy community. These parameters are called Key Performance Indicators (KPIs). A KPI is a measurable value that demonstrates the effectiveness with which a company or department or sector is achieving its objectives.
To estimate performances in the REC of Monticello d'Alba, the following KPIs are determined:

- the percentage reduction in bill costs (**PCR**), for each *consumer* and *prosumer*;
- the Internal Rate of Return (**IRR**) and the Pay - Back Time (**PBT**), for *producers* and *prosumers*.

In particular, the PCR value is calculated net of depreciation and maintenance costs; the PBT also takes into account the expenses for O&M.
In the following will be determined the KPIs for the base configuration of the REC of Monticello d'Alba (the one described in section 3.1.1) and then for a new one composed by the previous six players plus two new ones.

4.1 KPIs estimation for basic configuration

Table 4.1 is representative of all the players involved with their characteristics.
In all the considered configurations are valid the economic hypothesis described in

Name	Typology	Notes
RSA	Consumer	Private user
Municipio	Prosumer	Municipal user - In the analysis, to show the behavior of the distributor, it is considered as the only owner of the system
Scuola Elementare	Consumer	Municipal user
Scuola Materna	Consumer	Municipal user
Palestra	Consumer	Consumer & Municipal user - There is a photovoltaic system installed on the roof but is not considered as a lessor as it is a municipal user
Incontro	Consumer	Municipal user

Table 4.1: Involved players in the basic configuration of the REC [Team 23]

Table 4.2. In the analysis it was decided to adopt the *Republican* convention of the

Voice	Value	Notes
CAPEX PV	900 € /kW	-
OPEX	36 € /kW	-
Discount rate	7%	-
Inflation rate	1%	FOI 2013 INSTAT
Premium Tariff	110 € /MWh	Incentive to remunerate shared energy
TRASe+Dist.	8.56 € /MWh	Refund of amounts as defined by ARERA

Table 4.2: Assumptions and starting data [Team 23]

RECOptGame model, as it was seen that the latter, compared to the *Democratic*, made it possible to obtain a more homogeneous distribution of KPIs and also because the benefit share was more consistent with respect to the contributions made [Team 23].
In Figure 4.1 all the results are reported. On the horizontal axis is represented the percentage share of the total, while on the vertical axis each involved player is considered. Since in this configuration the Municipality is the only owner of the PV plant, this one is the only player that presents IRR and PBT within its KPIs.

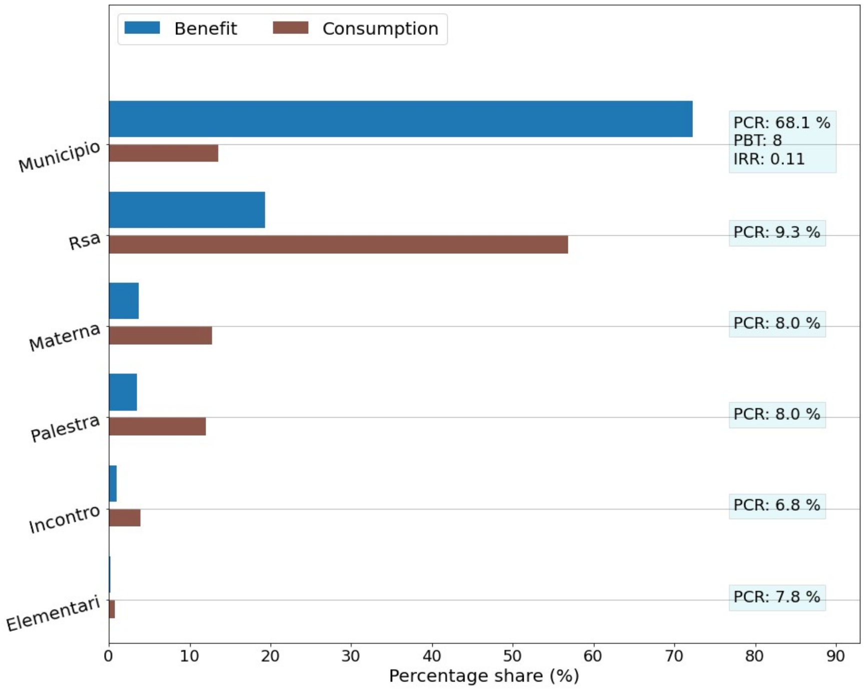


Figure 4.1: Results for basic configuration of the REC [Team 23]

All the others are consumers and so the only characteristic KPI for each of them is the PCR. Furthermore the graph shows two different columns: the brown explains the share of consumption while the blue the share of benefit that the considered player will obtain.
Obtained results are reasonable since it is coherent that the largest share of benefits belongs to the owner of the PV plant. On the consumption side, it is possible to observe that the most energy - intensive player is the RSA and again this is coherent since typical consumption profiles of a RSA are higher compared to the ones of all the involved players. For all the subjects it is possible to see the advantage of joining the REC since savings in the bill percentage (PCR) are for all of them positive.

4.2 KPIs estimation for a further developed configuration

In order to improve the effectiveness of the *RECOptGame* model, it was decided to consider a more advanced configuration which, in addition to the previous six subjects considered, analyzes the profile of two new users: a butcher and a bakery. Specifically:

- the **butcher** has a rather flat consumption profile during the day;
- the **bakery** has a very high consumption, but concentrated in the early hours of the day.

Table 4.3 is representative of all the players involved with their characteristics.
Also in this case the model works and obtained results are shown in Figure 4.2.

Name	Typology	Notes
RSA	Consumer	Private user
Municipio	Prosumer	Municipal user - Again is considered as the only owner of the system
Scuola Elementare	Consumer	Municipal user
Scuola Materna	Consumer	Municipal user
Palestra	Consumer	Municipal user - There is a photovoltaic system installed on the roof but is not considered as a lessor as it is a municipal user
Incontro	Consumer	Municipal user
Butcher	Consumer	Type of private user with a generally "flatter" consumption profile
Bakery	Consumer	Type of private user characterized by a different consumption profile and concentrated in the early hours in F3 of the day

Table 4.3: Involved players in the further developed configuration of the REC [Team 23]

The model, in accordance with what was hypothesized, does not reward the overall amount of consumption of each participant but the distribution in relation to the consumption profile. In fact, the shop of the butcher, while having lower consumption than the bakery, will obtain a higher share of income. In addition, there is an increase in the share of the Municipality due to the greater use of the energy produced by, mainly, the shop of the butcher.

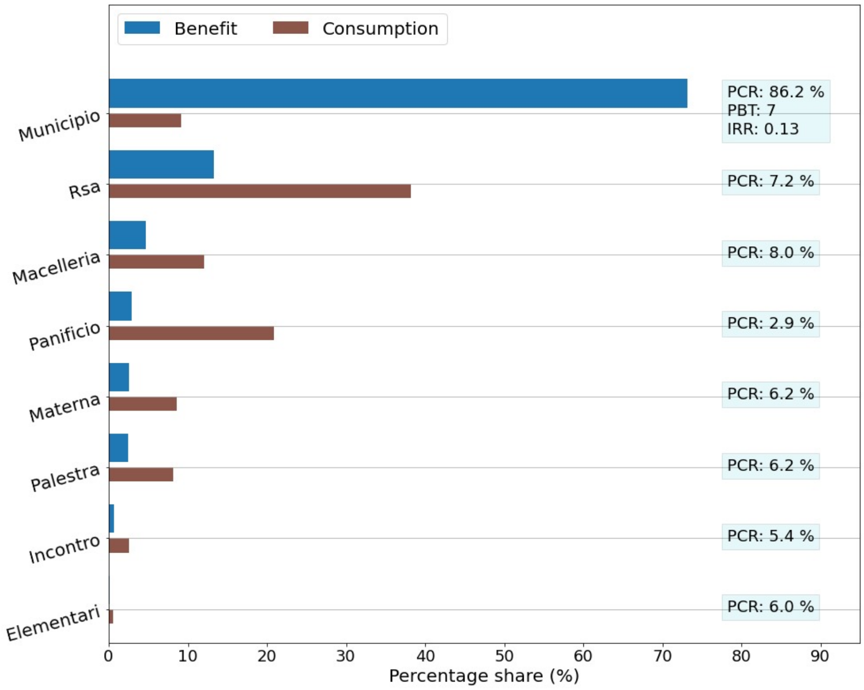


Figure 4.2: Results for further developed configuration of the REC [Team 23]

4.3 Comparison with the Sharing Distribution Model

The two case studies described in section 4.1 and in section 4.2 are now evaluated according to the *Sharing Distribution Model* (RDM) (described in section 3.3). Figure 4.3 shows the comparison of performances of the two model regarding the basic configuration of the REC. To obtain this graph, the value of η was set at

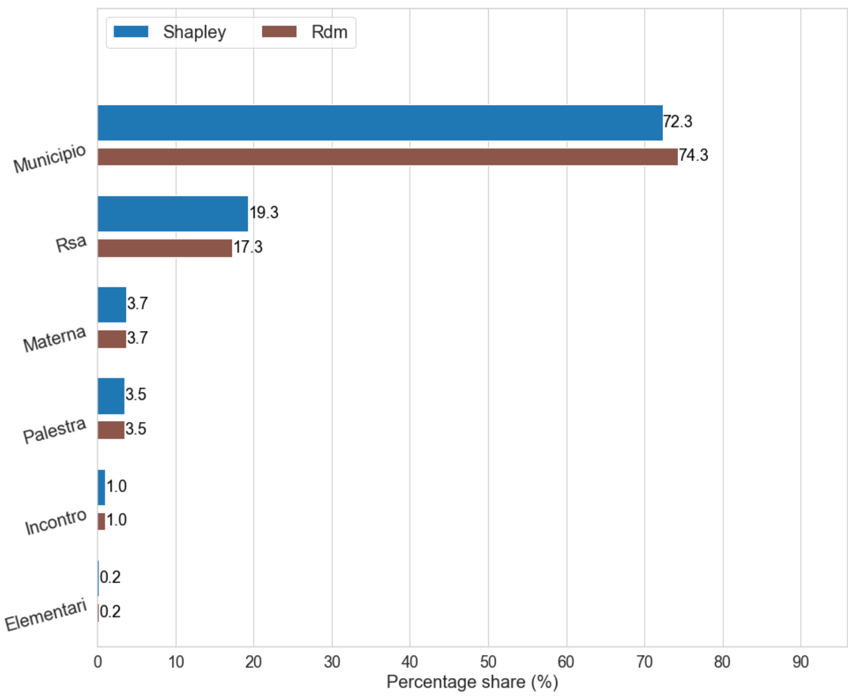


Figure 4.3: Comparison of the two model for the basic configuration of the REC [Team 23]

70% in the case of the RDM (as in section 3.4). As visible, obtained results in the output of the two models are very much in line.
The situation changes when the second case study is analyzed. Figure 4.4 shows the comparison of the performances of the two model regarding the further developed configuration of the REC. In this case it is noted that the *Sharing Distribution Model* is less sensitive to the distribution of consumption during the day.
All the previous considerations done at the end of section 3.4 are here demonstrated in the specific cases.

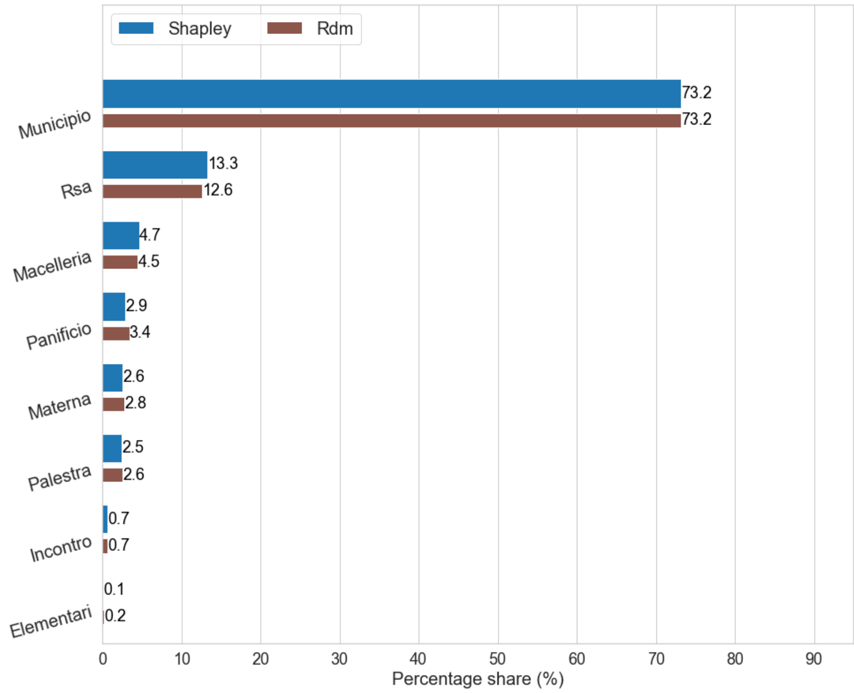


Figure 4.4: Comparison of the two model for the further developed configuration of the REC [Team 23]

Chapter 5

Demand Side Management

Increasing the share of renewable energy sources and managing total demand are seen as critical to the energy transition that will fundamentally overhaul the electricity system. A key challenge of such transition is integrating and absorbing larger shares of non-dispatchable renewable energy sources, without jeopardizing the safety and the reliability of the electric system. To this end, key solutions include the introduction of Demand Side Management (DSM).
The term DSM is used to indicate a set of actions aimed at efficiently managing the consumption of a site, in order to reduce the costs incurred for the supply of electricity, for network and for general system charges, including tax components. These optimization actions are aimed at modifying the characteristics of electricity consumption, with reference to the overall amount of consumption, time profile of consumption, contractual supply parameters (contractual power and grid connection parameters), in order to determine savings on the cost of the bill [36]. The techniques for managing user load were already studied in the 1980s, with research programs started in the USA under the name Demand Side Management.
The objectives of the DSM program consisted in obtaining variable evolution of the electrical load over time, applying some basic principles:

- *peak shaving (or clipping)*;
- *valley filling*;
- *load shifting*;
- *strategic load reduction (conservation)*;
- *strategic load growth*;
- *flexible load shape.*

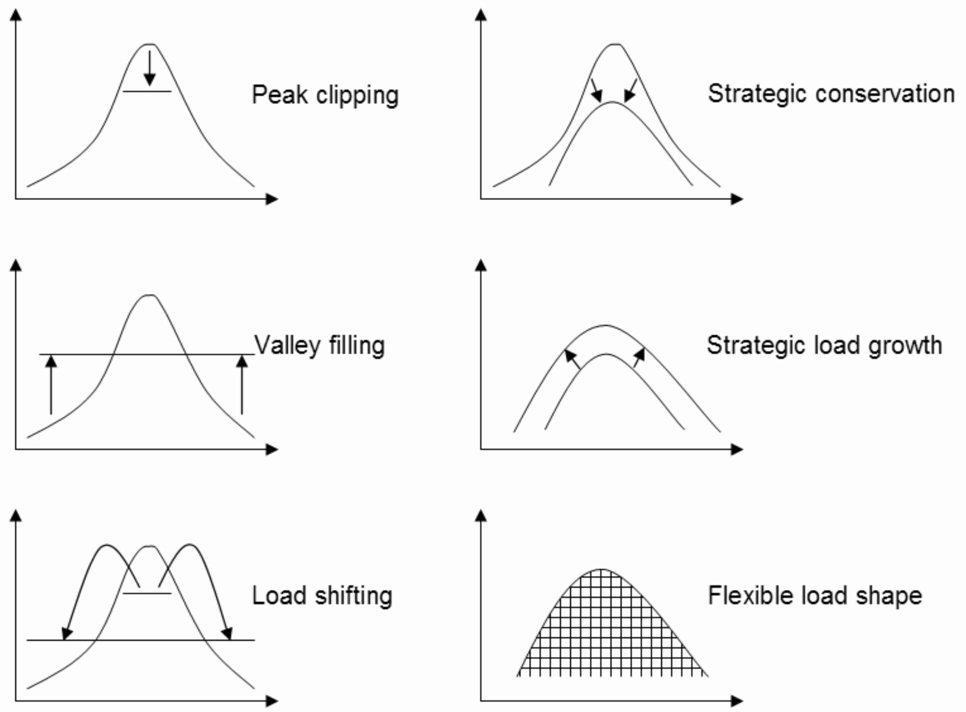


Figure 5.1: Demand Side Management concepts [39]

The Figure 5.1 explains graphically all these concepts. Such programs are different from one utility to another, as they depend on number of customers, load type (commercial, industrial or residential), benefit from that program, level of reaction of the costumer or satisfaction with the applied program, etc. However, benefits from applying are on both sides of customers and utility, so that such activities have grown over the past decades. Many utilities are implementing DSM programs and other are considering it in planning processes.
Peak clipping is aimed at decreasing the demand during peak hours, especially if the installed capacity is not enough to cover the peak demand. This is very important in the developing countries and if there is the problem with investments for the new installations and generation capacities [37].
Valley filling can be applied in order to change load curves so to obtain grater load factors in predefined time margins. In such a way the utility may increase its profit, whereas it decreases the costs per kWh of energy. Greater demand in off-peak hours is achieved by encouraging end-customer to spend energy with paying lower tariffs, or to change time schedule of the load demand distribution over the day. This is possible if some controllable devices may operate in different time intervals during the day and the chosen time interval is not relevant to the customer, e.g. for a residential or industrial consumer these might be boilers or storage heaters [37].

Load shifting is the best solution from the point of view of utility companies. With this DSM technique the part of demand is shifted from peak to off-peak hours. Customers are encouraged for this by cheaper tariff in off-peak hours [37].
Strategic conservation is also very important in power systems and, nowadays, there are many novelties announced in this field. If it is required to decrease the overall energy consumption, it may be achieved by using more efficient devices and appliances, which is very important at global level [37].
Increasing the overall energy consumption (*strategic load growth*) is useful if some utility has surplus capacity or available energy to sell with lower costs per kWh. This load building technique is achieved with the encouragement of consumers to spend electrical energy where needed for the operation of power system. There are examples of power utilities which gave customers storage heaters as great loads where this was desirable to maintain the power system capacities in the area [37].
Measures of DSM are divided between incentive programs and price-based programs.
Incentive-based programs include direct load control measures, load interruption programs, capacity markets and ancillary services. Consumers usually receive payments, bill reductions or discounts for their participation in such measures, also depending on the volume of load reduction. *Direct load control* programs provide the ability to remotely shut down equipment or machinery of participants on the basis of short notice. In *load interruption programs*, end consumers are asked to reduce consumption to a predefined value. Those who do not respond to this request incur penalties. *Capacity markets* measures are offered to those consumers who have the possibility to undertake to provide pre-specified load reductions in correspondence with system contingencies. Participants usually receive a notice the day before and are penalized if they do not respond to the load reduction request. *Ancillary services* allow consumers to make an offer on cuts in the spot market. When the offers are accepted, participants are paid the equivalent of the spot market price for their commitment to remain on stand-by [38].
Price measures are based on dynamic tariffs that vary according to the real cost of electricity. The ultimate goal of these measures is to flatten the demand curve as much as possible by offering lower prices during non-peak periods and higher prices during peak periods. These measures include two-hourly rates: *Critical Peak Pricing* (which is used for a limited number of days or hours per year during critical situations from the point of view of the system) and *Real Time Pricing* (where consumers pay prices that reflect the real cost of electricity in the wholesale market and are informed about prices on the previous day or hour) [38].
Figure 5.2 summarizes all the Demand Response (DR) programs.

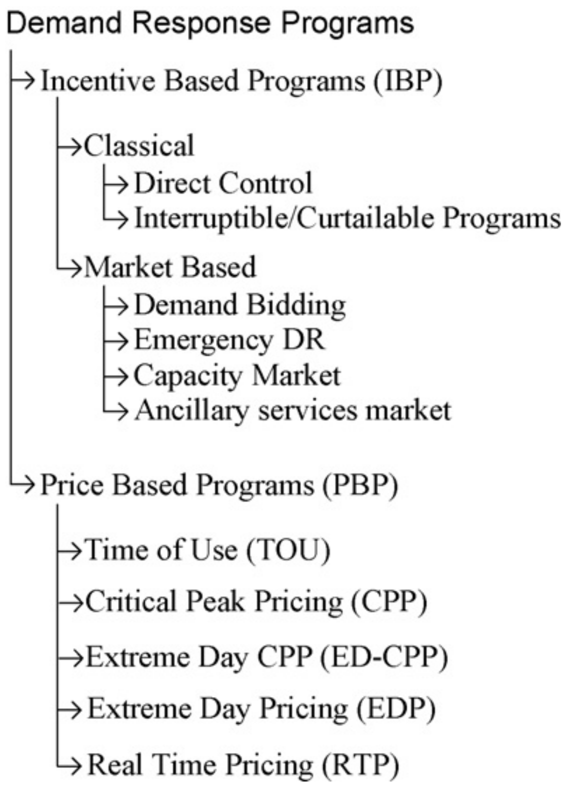


Figure 5.2: List of Demand Response programs [39]

An *aggregator* could be needed to manage the situation in a coordinated way. This entity may be the distributor, the retailer, or another subject. The aim of the *aggregator* is to collect the availability of many users with several components which consumption may be reduced or shifted in time in a flexible way. The demand side may participate in the enhancement of the operating conditions in different time horizons, also linked to the markets. The variations that correspond to the actions of users are calculated with respect to a reference (baseline) case that has to be identified, for example in a conventional way. An accurate measurement system is necessary to verify that the service requested from the user was actually provided by the user. The baseline is the reference pattern associated to a customer or a customer group:

- the *true baseline* is the pattern that a customer would have followed in the absence of a DR action;

- the *predicted baseline* is the pattern, estimated by the utility company, the customer (or customer group) would have followed in the absence of a DR event (i.e., it is the prediction of the true baseline).

The baseline may also depend on temperature and weather [39].
The performance of the DR action is assessed by calculating the difference between the actual pattern that followed the DR action and the corresponding "business as usual" baseline. The baseline and the DR outcomes have to be:

- *accurate*, in order to reflect the real curtailments due to DR changes;
- defined with *integrity*, i.e., not containing irregular data and able to discover the presence of irregular responses to avoid customers "gaming" the system;
- *simple*, enabling straightforward calculation and interpretation;
- *aligned* with the DR goals, to avoid inadvertently penalizing DR efforts.

The adjusted baseline is the adaptation of an initial baseline to the actual load pattern occurring before the start of the DR action. Specific rules have to be followed to determine the adjusted baseline [39].

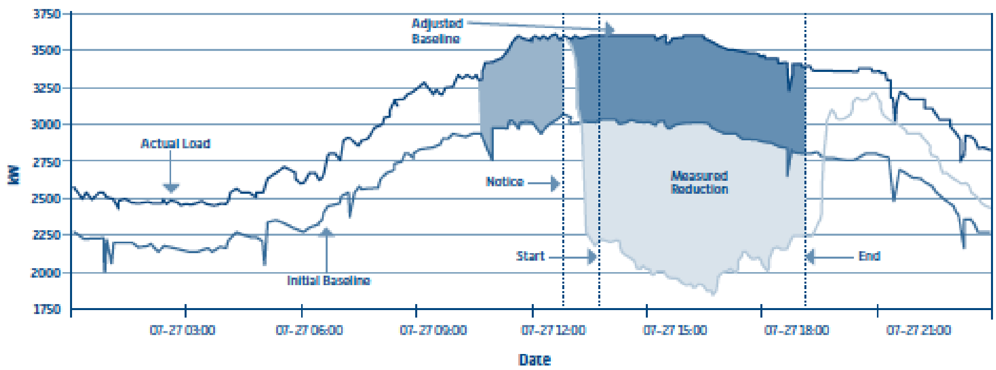


Figure 5.3: Adjusted baseline [39]

Strategic behavior to artificially create favorable conditions in the determination of the baseline, leading to economic advantages in the determination of the reward after a DR event, has to be avoided. The possibility of conducting strategic activities impacting on the baseline depends on the baseline adjustment approach and increases when the DR event is announced well in advance to the participants. For example, the user could increase the load few hours before the DR event in order to have a higher baseline on the basis of which the demand reduction will be calculated. Pre-cooling of the load is one possibility of increasing the load before the DR event, then cutting the supply to the cooling load during the DR event. These two examples explain why appropriate rules have to be established to identify and mitigate the strategic behavior.

5.1 Demand Response in Europe

The *European Energy Efficiency Directive* (2012/27/EU) [40] contains various references to the use of Demand Response techniques, e.g.:

- the article 15.4 requires to the Member States to remove the incentives that may reduce the participation of Demand Response actions to the system services, and to enhance the participation of users to energy efficiency and Demand Response;

- the article 15.8 indicates that the National Authorities (e.g., ARERA in Italy) have to encourage the resources on the demand side, as Demand Response, to participate together with the generation to the markets, and indicates that the system operators have to consider the Demand Response providers, included aggregators, in nondiscriminatory mode, on the basis of their technical possibilities, satisfying the system constraints.

The Smart Energy Demand Coalition (SEDC) Demand Response Map (Figure 5.4) provides an overview of the current regulatory framework for Demand Response in the 18 countries examined [41]. It is important to note, that frameworks are ranked in relation to each other – even for countries marked green, further improvements are still possible and necessary. The European countries that currently provide the most conducive framework for the development of Demand Response are Switzerland, France, Belgium, Finland, Great Britain, and Ireland. Nevertheless, there are still market design and regulatory issues that exist in these well-performing countries. Slovenia, Italy, and Poland are colored orange. In Slovenia and Poland, no major regulatory changes have been made within the past couple of years that would have allowed for further Demand Response participation. Notably, Italy has upgraded its status from red in the previous SEDC Demand Response Maps to orange today, as it has slowly started to take the regulatory steps needed for a solid framework for Demand Response. However, despite the gradual opening of markets, significant barriers still hinder customer participation.
The detailed assessment of regulatory conditions for Explicit Demand Response in different European markets demonstrates measurable improvements and encouraging plans. Nevertheless, the overall result still reveals multiple remaining barriers to the establishment of consumer centered Demand Response services [41].

1. The regulatory framework in Europe for DR is progressing, but further regulatory improvements are needed;

2. Restricted consumer access to DR service providers remains a barrier to the effective functioning of the market;

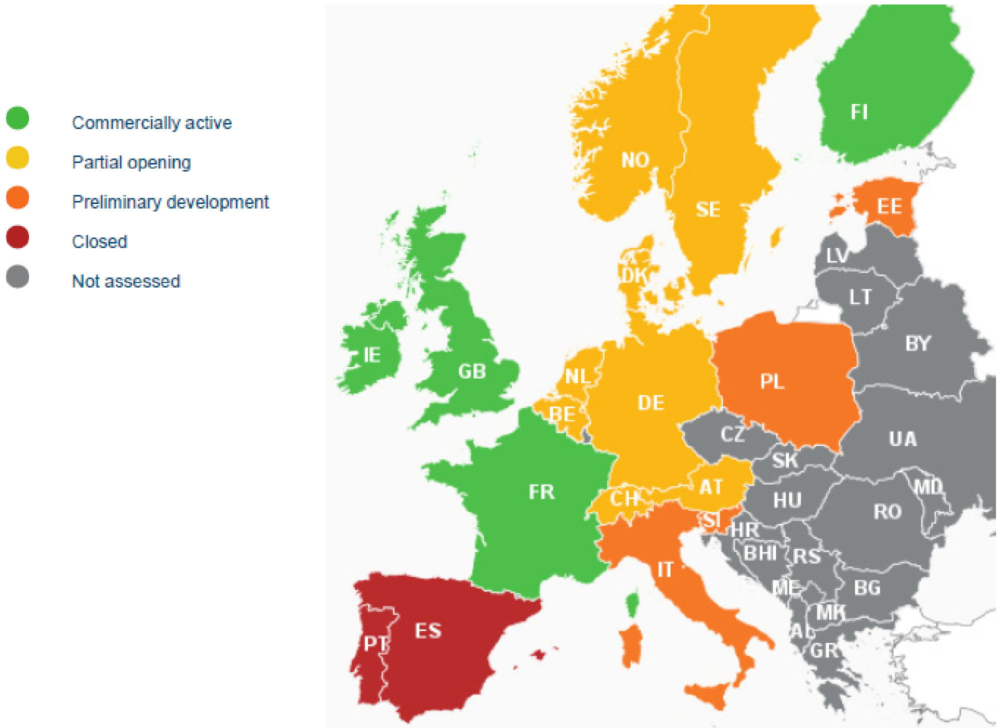


Figure 5.4: Map of Explicit Demand Response development in Europe [41]

3. Significant progress has been made in opening balancing markets to demand-side resources;

4. The wholesale market must be further opened to demand-side resources;

5. Local System Services are not yet commercially tradable in European countries.

5.2 DSM for RECs

In the past, most of the work done on the electricity generation side and consumer loads were not manageable. The flat rate pricing will not motivate consumers to schedule the appliances and electricity usage for cost minimization. The flow of electricity and data-flow (informations) are bidirectional in smart grid (SG). The data-flow between homes and utility grid is done in order to manage the optimization of each consumer and improve the entire system via peak reduction. Actually, it is impractical to ask consumers to optimize the appliance program, since they are neither system operators nor economists. For this reason, a fully automated load management system is required for consumers in order to take the benefits through the scheduling of smart appliances. The energy management system is an essential part in the SG that consumers use to manage electricity. For the best schedule of smart appliances, technical and economic constraints are considered. Community microgrid provide an opportunity for small scale distributed RES to trade energy locally. The realization of microgrid markets necessitate safe and smart information systems for their appropriate operation [42].
The cycle of execution of one possible proposed DSM strategy is daily and is divided into three parts: data collection, optimization problem resolution and agreement of plans with users. This strategy is applied to a wind-solar-diesel microgrid where the fuel consumption is considered as the cost to be minimized [43]. Figure 5.5 presents the workflow of the proposed DSM. Yellow arrows represent the data collection phase. Green arrows represent the output of the system. The optimization is executed at the Energy Management System (EMS) server.
Initially, to feed the optimization problem, data from the power plant, renewable

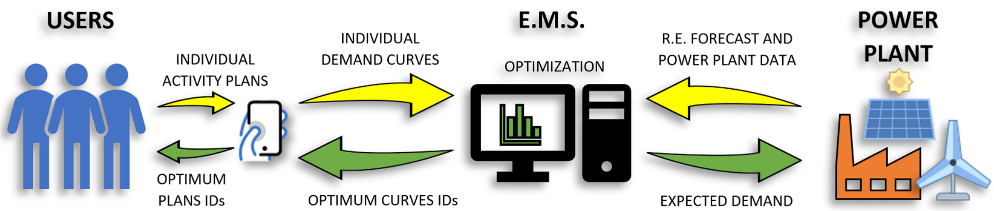


Figure 5.5: Workflow of the proposed DSM [43]

resources forecast and electric demand information are required. After data collection, the optimization algorithm is able to be executed. Once the solution is determined, users are then informed about which plan each one should choose to minimize the overall cost of energy production. After the agreement with the users, the EMS sends the expected demand curve to power plant controllers.
During the DSM initialization, the users are invited to present up to three possibilities of performing their next day activities (Plan 1, 2 or 3). Considering

the informed plans, the possible demand curves of each user are estimated and, in sequence, the optimization algorithm seeks a coordinated action of the users that minimize the cost of energy production with the minimum number of users managed. In the end, each user is informed which plan need to be followed so that the whole system is improved.
For this, the activity plan of a user is defined as a vector of z hours, containing in each hour the set of activities planned by the user. Each user presents one main plan and two alternate ones, totaling three plans. *Plan 1* is considered as the most convenient plan to the user. For elaboration of the alternate plans, the user is invited to migrate activities between morning and afternoon or within the same period. A fundamental premise is that users only present plans that are feasible.
In the proposed approach, it is considered that every hour a person can perform a set of activities, in one or more places. Whatever the place, each activity may be linked to the use of one or more equipment (loads). So, the electrical consumption related to a specific activity like "do task x at room y", may be composed by the electrical consumption promoted by one or more loads. From this method it is possible to perform the accounting of the energy consumption caused by group of activities and so estimate the demand curve related to each one of the activity plans. This information is then stored in a matrix named Matrix of Demand Curves (MDC).
The aggregate demand curve is given by the sum of demand curves of all users. Therefore, the aggregate demand curve will have its format changed according to the plans executed by each user. Each combination of plans produces an aggregate demand curve. The renewable resources data is defined as a vector of z hours, containing the forecast renewable energy for the day-ahead. The power plant parameters are constants and variables related to equipment capacities, efficiencies and consumption curves, limits and cost of operation, used to construct the power plant model.
Figure 5.6 illustrates the DSM operating cycle, beginning and ending in the user. In Figure 5.6 it is possible to visualize the vectors of the activity plans informed by the users, the concepts of activity groups per hour and estimation of the demand curves. Based on the demand curves, renewable forecast and power plant parameters, the optimization algorithm solves the problem and returns the solution to the users. The solution is a vector containing the identifier of the plan that each user needs to follow to promote the intended objectives.

Considering the solution found by the optimization algorithm, the aggregate demand curve expected for the next day is sent to the power plant operator. With this information the operator can manage the generators in a more reliable and efficient way, as simulated inside the optimization. Some or even all the generators can be turned off during specific hours of the day, which improves the gensets load factor and reduces the generators operation hours.

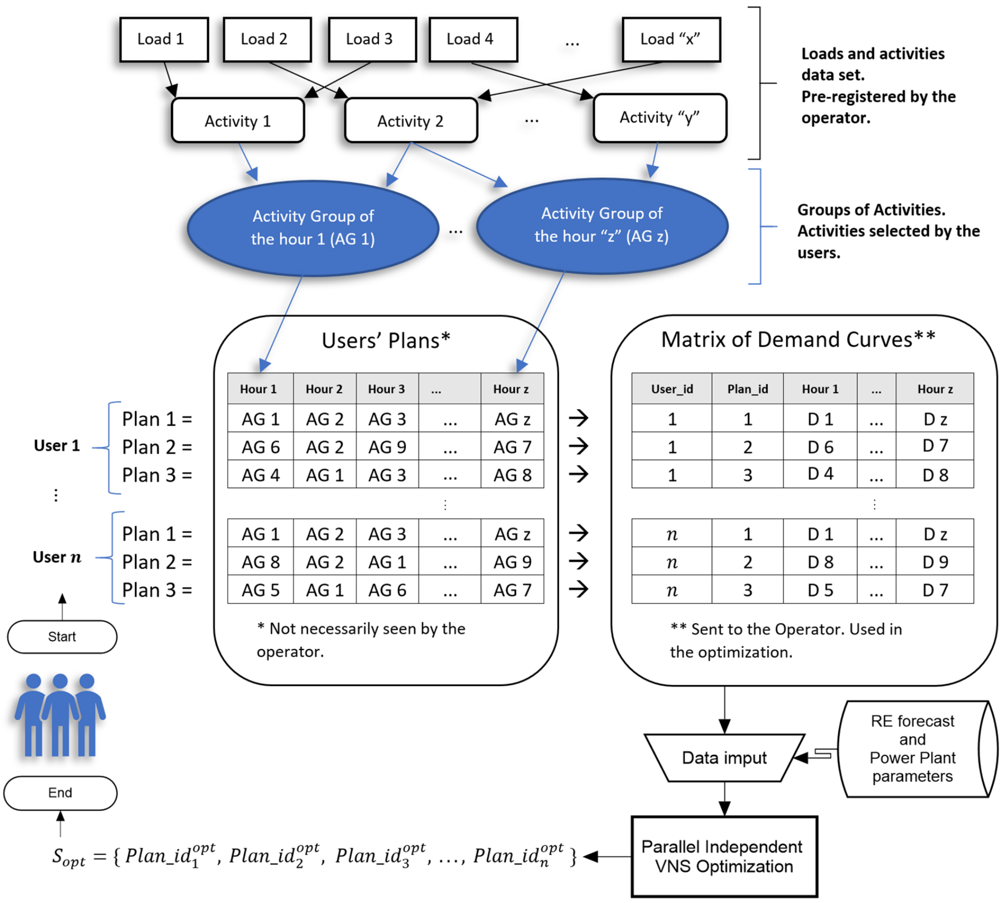


Figure 5.6: Concept of the data structure and flow for the proposed DSM, beginning and ending in the user [43]

Several techniques and methods for demand side energy management have been investigated and tested in parallel with conservation actions and rational use campaigns. Beyond the techniques, DSM systems also differ according to the methods adopted. The methods can be differed by: type of interaction with the users (individual or cooperative), approach to the optimization problem (deterministic or stochastic) and time scale (day-ahead or real time). The complexity of the optimization problem and consequently the time required depend on the number of users, techniques and methods of the DSM system. Related to DSM implementation in real scenarios, the main difficulties highlighted by the literature are to encourage human participation and to reduce the needs of installed devices [43].

Conclusions

As the COVID-19 crisis has amply demonstrated, the impact of man on the environment is having repercussions at all levels. The hard test that is being faced globally must be a warning for a future rebirth in a truly sustainable key, for the well-being of humans and for the one of the planet. The energy transition is no longer a choice but a necessity and an opportunity to create new production models and embrace new habits and behaviors more eco-sustainable. The gradual activation of local communities, through participatory processes focused on the regeneration of the local economy, gives a preview of the creation of a new socio-energy system based on the production of energy from renewable sources and on the use of local distributed energy generation plants.

Italy with the National Resilience Recovery Plan (PNRR) has decided to focus heavily on energy communities and collective self-consumption configurations; in fact, in the coming months, state funding of € 2.2 billion is planned with the aim of supporting the economy of areas at risk of depopulation. This justifies the strong interest that is being created behind the theme of energy communities and this thesis has set itself the goal of treating them in their entirety.

The starting point of the thesis was dedicated to what RECs are and why they are important in the perspective of a sustainable future, then an analysis was carried out on their historical evolution, first in Europe and then in Italy. In Italy, the evolution of the law has been deepened up to present days, listing what are the constraints that must be respected in order to join the project.

Subsequently, the section dedicated to the statutory aspect was discussed where it was explained which documents are necessary to establish a REC and what they must contain.

The variety of subjects present within a REC has been explained in order to make clear the need to formulate a Private law contract, that regulates the relationships between the Contact Person and the members of the community. To do this, it is necessary to use suitable distribution algorithms that are able to take into account all possible cases. Two algorithm based on different theories were therefore introduced: one based on the theory of cooperative games and one based on the theory of the "thousandth table".

Both algorithms were tested on the Monticello d'Alba case study, analyzed both in the original and in an updated version characterized by the addition of two users: a baker and a butcher. The choice of these two was made considering their characteristic consumption profile, much different compared to the one of a normal residential user.
KPIs were introduced in order to evaluate the goodness of the proposed algorithms and it was seen that both were suitable for the intended objective. In particular, it was emphasized that the algorithm based on game theory is more flexible as it is not bound to have to set the value of η *a priori* as is the case of the other model. On the other hand, the *Sharing Distribution Model* appears to be more robust as it is based on already established theories. A plausible future scenario could be to use both algorithms: the one based on the theory of cooperative games would be used to understand which value of η must be adopted, while the *Sharing Distribution Model* would be used to obtain all the required KPIs in output.
The final section of the thesis is dedicated to Demand Side Management. After having introduced the concept from a conceptual point of view, a brief historical evolution in Europe of this topic was analyzed. Finally, it is analyzed how DSM is central in energy communities. The role of the participant becomes active not only from a production point of view (becoming a *prosumer*) but also from an application point of view: producing/consuming energy in accordance with predetermined programs is the key to optimizing the operation of a community.
Together with the huge incentive that Italy is going to invest in RECs, one possible option to boost the diffusion is to overcome the constraint related to the installed power. If this limit is raised up to reach higher values, a lot of different technological possibilities could be implemented. Furthermore, it must be remarked that, in the present Italian situation, some critical issues in the REC creation are posed by the limitation to a single MV/LV substation. Information about the electrical distribution network can, in fact, be a hindering factor in pushing together some users that could be close in the geographical sense but distanced in the electrical way if they are supplied by different substations. Italian laws, as shown in Figure 1.10, are in fact moving towards this direction by overcoming the old constraints.
To be part of an energy community means to start from the community dimension and then take new paths towards zero km ways of energy production and consumption; it means to re-establish a relationship with the environment starting from the use of renewable sources for the realization of a sustainable economic and social system for present and future generations. Energy community means mutual support, cooperation, exchange, concepts at the basis of "living together".

Appendix A

Composition of the incentive

In the document [11], there is a specific section titled "Timely calculation criteria and method of measurements" that explains how the different voices of the incentive are estimated. There is a distinction between the two categories of *self-consumers of energy acting collectively* and *renewable energy communities*. The case of interest is the latter. Figure A.1[1] is a summary of all the involved parameters.

COMUNITÀ DI ENERGIA RINNOVABILE	
Restituzione componenti tariffarie (C_{CE})	$C_{CE} = CU_{Af,m} * E_{AC}$
Incentivazione dell'energia condivisa (I_{CE})	$I_{CE} = TP_{CE} * E_{AC}$
Ritiro dell'energia (R_{CE})	$R_{CE} = P_R$[1] $* E_{immessa}$

Figure A.1: Summary table relating to the calculation algorithms [11]

Shared electric energy (E_{AC})

The shared electric energy (E_{AC}) is equal to the minimum, calculated on an hourly basis, between the electricity fed into the grid by production plants powered by renewable sources and the electricity withdrawn through the connection points that are relevant for the purposes of a group of self-consumers or a renewable energy

[1]The recognized price (p_R) for the withdrawal of the energy fed into the network is governed by ARERA Resolution 280/07 and depends on the type of plant and any additional incentives recognized on it.

community.

$$E_{AC,m} = \sum_{h=1}^{n} E_{AC,h} \tag{A.1}$$

where

$$E_{AC,h} = \min[\textstyle\sum_{y=1}^{n} E_{effimmessapuntodiconnessioney} \ ; \ (\sum_{y=1}^{n} E_{prelevatapuntodiconnessioney} - \sum_{y=1}^{n} E_{prelevatapuntodiconnessioneyesente})]$$

- $E_{AC,m}$ = shared monthly electricity expressed in kWh;
- $E_{AC,h}$ = shared hourly electricity expressed in kWh;
- y = connection point relating to the configuration;
- $E_{effimmessapuntodiconnessioney}$ = electricity actually injected through the connection point y expressed in kWh, net of the conventional loss coefficients;
- $E_{prelevatapuntodiconnessioney}$ = electricity withdrawn through the connection point y expressed in kWh;
- $E_{prelevatapuntodiconnessioneyesente}$ = electricity withdrawn through the connection point y expressed in kWh for which the transmission and distribution tariff components are not applied.

Monthly flat-rate self-consumption fee ($CU_{Af,m}$)

The monthly flat-rate self-consumption fee, expressed in c€/kWh, is equal to the algebraic sum, rounded to the third decimal place according to the commercial criterion, of the variable unit parts, expressed in c€/kWh, of the transmission tariff ($TRAS_E$) defined for low voltage users and the higher value of the variable distribution component defined for users for other low voltage uses (BTAU) in force in the month m-th.

$$CU_{Af,m} = TRAS_E + MAX(BTAU_m) \tag{A.2}$$

Coefficient of avoided network losses (c_{PR})

The coefficient of avoided network losses (c_{PR}) is equal to:

- 1.2% in the case of shared electricity due to the production of production plants connected to the medium voltage distribution network;
- 2.6% in the case of shared electricity due to the production of production plants connected to the low voltage distribution network.

Premium rate (TP) pursuant to the Decree

The shared electricity (E_{AC}) is entitled, for a period of 20 years starting from the date of entry into commercial operation of each of the plants whose electricity is relevant for the configuration, to a premium rate equal to:

- (TP_{AC}) - 100 €/MWh in the event that the energy of the production plant is relevant for a group configuration of self-consumers;
- (TP_{CE}) - 110 €/MWh if the energy of the production plant is relevant for a configuration of a renewable energy community.

The premium rate is not considered for the shared electricity attributable to:

- the power share of photovoltaic systems that have access to the Superbonus 110% deduction;
- to the share of power share of obligation Po (provided for in paragraph 4, art. 11 of Legislative Decree 28/2011);
- to photovoltaic plants for which there is a ban on access to state incentives.

Appendix B

Italian version

L'elaborato è stato realizzato in lingua inglese. Questa appendice viene realizzata in italiano per riassumere i punti salienti di quanto spiegato nelle pagine precedenti, in modo tale che la comprensione possa risultare più chiara.
Nell'**Introduzione** viene spiegato il concetto di *energy trilemma* ovvero il raggiungimento di uno sviluppo sostenibile attraverso i tre obiettivi cardini: responsabilità sociale, responsabilità economica e responsabilità ambientale. Per raggiungere un futuro sostenibile caratterizzato da emissioni di gas serra via via sempre minori, bisogna fare in modo che questi tre obiettivi coesistano e che vengano promossi in ogni progetto che si viene a realizzare.
Le *Comunità Energetiche Rinnovabili* (CER) consistono in uno strumento nuovo e molto promettente nel panorama energetico. Esse rappresentano un buon esempio di sviluppo sostenibile in quanto soddisfano tutti e tre gli obiettivi cardini: tramite le CER viene promossa l'integrazione sociale in quanto si vanno a creare delle associazioni di cittadini, si riesce ad ottenere un taglio alle emissioni dei gas serra per via degli impianti di produzione totalmente rinnovabili e infine i membri aderenti alle CER riescono ad ottenere un risparmio in bolletta grazie agli incentivi offerti.

Il **Capitolo 1** si occupa di descrivere in generale in cosa consiste e come è strutturata una CER. Inizia spiegando quali sono state le leggi europee che si sono rivelate catalizzatrici per lo sviluppo delle comunità energetiche, ovvero il *Clean Energy Package* e più specificatamente la *Direttiva su norme comuni per il mercato interno dell'energia elettrica* insieme alla *Revisione della direttiva sulle energie rinnovabili.* Viene poi fatta una distinzione tra il ruolo sempre più emergente del *prosumer* e quello classico di consumatore, ovvero il primo non si limita più a svolgere passivamente il ruolo di consumatore ma partecipa attivamente nelle varie fasi di produzione. La Figura 1.1 illustra visivamente questa differenza di ruoli.
Viene sottolineato come questo accentramento della figura del cittadino nel mondo

energetico sia un aspetto positivo che va di pari passo con quanto espresso nel *Green Deal*: il piano strategico formulato dagli Stati membri dell'Unione Europea per fronteggiare i cambiamenti climatici.
Le CER variano da una comunità all'altra: alcune ospitano semplicemente impianti di generazione eolica e solare, mentre altre sono un sistema completamente bilanciato e autosufficiente che funziona come una microgrid; alcune hanno un'impronta locale, mentre altre coprono un'area geograficamente più ampia. Le comunità energetiche possono anche cooperare con gli operatori di sistema per aumentare la resilienza della rete energetica sfruttando appieno l'elevato numero di famiglie attive coinvolte. Uno dei loro obiettivi principali è infatti quello di spostare il consumo energetico nei momenti in cui le risorse locali si stanno generando.
La **sezione 1.1** si occupa della diffusione storica delle CER in Europa. Il primo progetto che può rifarsi ad una comunità energetica come intesa oggigiorno, è datato a metà degli anni '70 in Danimarca. Come anticipato, il catalizzatore per lo sviluppo delle CER in Europa è stato il *Clean Energy Package* e infatti la Figura 1.2 mostra come il numero di pubblicazioni scientifiche trattanti questa tematica è andato via via crescendo in maniera esponenziale.
La penetrazione delle CER nel mondo energetico è influenzata da fattori di diversa natura: *fisici*, *tecnologici*, *istituzionali* e *comunitari*. Infatti ogni Paese ha la propria storia, più o meno lunga e più o meno fortunata, fortemente influenzata da questi specifici fattori contestuali. I tre paesi in cui le CER presentano una storia più duratura sono Danimarca, Germania e Regno Unito.
In accordo con il report del JRC, nel 2019 vi erano circa 3500 cooperative energetiche rinnovabili. La Figura 1.3 mostra come questi sono suddivisi nei vari Stati analizzati dal report.
La sezione 1.1 continua poi analizzando in dettaglio l'evoluzione storica delle comunità energetiche nei tre Stati europei più avanzati in materia: la Danimarca, la Germania e il Regno Unito. La Figura 1.5 è rappresentativa di come il numero di cooperative è evoluto nel corso degli anni per queste tre nazioni. Successivamente le tre comunità energetiche più rappresentative per l'Unione Europea sono state analizzate nel dettaglio (*Middlegrunden Wind Farm* per la Danimarca, *Bioenergy Village Jühnde* per la Germania e *Wiltshire Wildlife Community Energy* per il Regno Unito. La Tabella 1.1 riassume le caratteristiche principali di ciascun progetto analizzato.
La **sezione 1.2** si concentra sull'evoluzione delle CER in Italia. Il *Decreto Milleproroghe* è stato quello che, in tempi recenti, ha consentito il forte interessamento e, conseguentemente, lo sviluppo delle comunità energetiche.
Viene spiegato come sino a pochi anni fa in Italia, in merito all'autoconsumo, la configurazione prevalente era quella di *"uno a uno"* dove vi era un'unità di produzione combinata ad un'unità di consumo: l'energia autoprodotta non veniva immessa in rete e quindi l'autoconsumo era reale e immediato. Con lo sviluppo

delle CER si è passati ad una configurazione *"molti a molti"* dove vi sono diverse unità di produzione combinate a diverse unità di consumo. Questo può avvenire secondo due modalità: autoconsumo fisico o virtuale.
ARERA ha individuato nel modello di regolazione virtuale il più semplice ed efficace per gestire l'Autoconsumo Collettivo e le CER. Si precisa che, a parità di topologia di rete, i flussi energetici provenienti da un impianto di produzione seguiranno sempre il percorso verso il punto di consumo caratterizzato dall'impedenza più bassa, indipendentemente dal fatto che la rete sia pubblica o privata. Non si tratta quindi di una distinzione tecnica tra le due possibili configurazioni, ma puramente normativa. La Figura 1.9 rappresenta visivamente la distinzione tra autoconsumo fisico e virtuale.
La sezione 1.2 poi prosegue svolgendo un'analisi dettagliata sul contesto legislativo riguardante le CER in Italia. In accordo con l'Articolo 1 dell'Allegato A della *"Deliberazione 4 Agosto 2020 – 318/2020/R/EEL"* una comunità energetica rinnovabile è un soggetto giuridico:

- che si basa sulla partecipazione aperta e volontaria, è autonomo ed è effettivamente controllato da azionisti o membri che sono situati nelle vicinanze degli impianti di produzione detenuti dalla comunità di energia rinnovabile;

- i cui azionisti o membri sono persone fisiche, piccole e medie imprese (PMI), enti territoriali o autorità locali, comprese le amministrazioni comunali, a condizione che, per le imprese private, la partecipazione alla comunità di energia rinnovabile non costituisca l'attività commerciale e/o industriale principale;

- il cui obiettivo principale è fornire benefici ambientali, economici o sociali a livello di comunità ai propri azionisti o membri o alle aree locali in cui opera, piuttosto che profitti finanziari.

L'Articolo 3 dell'Allegato A della *"Deliberazione 4 Agosto 2020 – 318/2020/R/EEL"* definisce i *"Requisiti per l'accesso al servizio di valorizzazione e incentivazione dell'energia elettrica condivisa"*. In questa sezione viene evidenziato il fatto che le CER sono aperte a tutti ma con alcuni vincoli. Tali vincoli possono essere di diversa natura:

1. Vincoli topologici: ogni impianto deve essere connesso alle **reti elettriche MT/BT sottostanti la stessa cabina secondaria**. Occorre quindi definire geograficamente le utenze servite dalla stessa cabina. Le utenze sottese a cabine diverse aderiscono a diverse comunità energetiche. Non è invece necessario che l'impianto si trovi sopra l'edificio;

2. Vincoli tecnici: sono ammessi solo **impianti di produzione di energia elettrica da fonte rinnovabile**. Sono ammessi solo impianti di nuova

realizzazione o potenziamenti di impianti esistenti. Ciascun impianto deve avere una **potenza non superiore a 200 kW**;

3. Vincoli temporali: Vengono accettati solo impianti entrati in esercizio tra il **1° marzo 2020** ed entro 60 giorni successivi alla data di entrata in vigore del recepimento della Direttiva europea RED II (termine ipotizzato attorno ad **agosto 2021**)

L'incentivo corrisposto dallo Stato è calcolato sulla base dell'**energia elettrica condivisa**, definita come il minimo, su base oraria, tra l'energia elettrica effettivamente immessa in rete e l'energia elettrica prelevata dai punti di connessione rilevanti ai fini della configurazione. Per ogni kWh di energia elettrica condivisa, il *Gestore dei Servizi Energetici* (GSE) riconosce per un periodo di 20 anni:

- un corrispettivo unitario (somma della tariffa di trasmissione per le utenze in bassa tensione, pari a **7.61 €/MWh** per l'anno 2020, e del valore più elevato della componente variabile di distribuzione per le utenze altri usi in bassa tensione, pari a **0.61 €/MWh** per l'anno 2020);
- una tariffa premio (pari a **100 €/MWh** per i gruppi di autoconsumatori e **110 €/MWh** per le comunità rinnovabili).

La Figura 1.10 è rappresentativa del quadro normativo italiano e riassume tutte le leggi che si sono succedute riguardanti le CER.
Un soggetto importante all'interno di una comunità energetica è il **Referente**. È definito il soggetto al quale, congiuntamente da produttori e clienti finali, viene conferito mandato per la gestione tecnica ed amministrativa della richiesta di accesso al servizio di valorizzazione e incentivazione, al trattamento dei dati e alla sottoscrizione del relativo contratto con il GSE per ottenere i benefici previsti dal predetto servizio. È nominato dalla comunità stessa.
Le ripartizioni presenti all'interno di una CER sono regolamentate dal *Contratto di diritto privato*, il quale presenta le seguenti caratteristiche:

1. prevede il mantenimento dei diritti di cliente finale, compreso quello di scegliere il proprio venditore;
2. individua univocamente un soggetto delegato responsabile del riparto dell'energia elettrica condivisa a cui i soggetti possono, inoltre, demandare la gestione delle partite di pagamento e di incasso verso le società di vendita e il GSE;
3. consente ai soggetti di recedere in ogni momento e uscire dalla configurazione, fermi restando eventuali corrispettivi concordati in caso di recesso anticipato per la compartecipazione agli investimenti sostenuti, che devono comunque risultare equi e proporzionati.

La sezione 1.2 si conclude svolgendo un'analisi sull'evoluzione storica delle CER in Italia. Si parte dalle prime forme di associazioni sino a giungere alle più moderne comunità. Infine viene citato il progetto GECO, ad oggi in fase di realizzazione, il quale porterà alla nascita della CER in Emilia Romagna.

Il **Capitolo 2** tratta il fondamentale aspetto statutario di una comunità energetica. La costituzione di un'associazione avviene mediante la sottoscrizione di un "contratto" tra i soci fondatori, costituito da due atti: l'atto costitutivo e lo statuto.

- L'*atto costitutivo* è il documento tramite il quale i soci fondatori, riuniti in assemblea, manifestano e sanciscono la loro volontà di associarsi per perseguire finalità condivise; esso deve essere firmato, in calce, da tutti i soci presenti al momento della stipula. L'atto costitutivo deve contenere i seguenti elementi:
  - l'indicazione del giorno, mese, anno e luogo nel quale è stata svolta l'assemblea;
  - gli estremi dei soci fondatori: nome, cognome, residenza, codice fiscale;
  - la denominazione scelta per l'associazione;
  - le finalità (oggetto sociale) e le azioni/servizi che l'associazione potrà mettere in atto per raggiungere lo scopo sociale;
  - la composizione del Consiglio Direttivo (numero e nomi componenti) eletto contestualmente;
  - lo statuto in allegato.
- Lo *statuto* è il documento contenente le regole dell'associazione nella sua vita, le norme che disciplinano i rapporti tra gli associati e tra soci e associazione stessa. Tutti i soci presenti al momento della sottoscrizione devono sottoscrivere anche lo statuto. Esso deve contenere i seguenti elementi:
  - denominazione dell'associazione;
  - sede legale;
  - scopo;
  - patrimonio;
  - norme sull'ordinamento interno;
  - norme sull'amministrazione;
  - i diritti e gli obblighi degli associati e le condizioni per la loro ammissione;
  - norme relative all'estinzione dell'ente;
  - norme relative alla devoluzione del patrimonio residuo.

Una volta ricevuta dal distributore la conferma di quali soggetti possono far parte della comunità, le persone e gli enti coinvolti possono costituire l'entità giuridica che si caratterizzerà come comunità energetica rinnovabile. Considerato che lo scopo della comunità non può essere il profitto finanziario, le forme più comunemente utilizzate sono quelle delle associazioni non riconosciute. Le associazioni non riconosciute possono essere costituite con un semplice contratto fiscalmente registrato, hanno bassi costi di gestione e requisiti organizzativi relativamente semplici. Tuttavia, non sono escluse anche altre associazioni senza scopo di lucro come le cooperative.
Le associazioni possono essere:

- *riconosciute*: hanno chiesto e ottenuto il riconoscimento;
- *non riconosciute*: non hanno chiesto (oppure lo hanno chiesto ma non ottenuto) il riconoscimento.

Per ottenere la personalità giuridica occorre formulare un'apposita domanda da depositare presso la Prefettura. Il riconoscimento della personalità giuridica comporta che l'ente sia titolare di un'autonomia patrimoniale perfetta e che i creditori sociali non possano aggredire il patrimonio dei singoli associati. Nel periodo di tempo in cui l'associazione attende il riconoscimento, essa è già attiva ma opera come associazione non riconosciuta.
Poiché le forme giuridiche più comunemente utilizzate per le CER sono quelle delle associazioni non riconosciute, la Figura B.1 mostra un template per l'atto costitutivo e poi, dalla Figura B.2 alla Figura B.4, ne viene mostrato uno per lo statuto, entrambi caratteristici di questa tipologia di associazione. Le parti evidenziate in giallo sono note o possibili variazioni e devono essere eliminate nella versione finale.
Successivamente, dalla Figura B.5 alla Figura B.9, vengono mostrati degli estratti del *Contratto di Mandato*, firmato tra il Referente della CER e il rappresentante della ditta esterna che ha lo scopo di amministrare dal punto di vista tecnologico la comunità. La figura del partner tecnologico e i motivi per cui è necessario all'interno di una CER saranno definiti all'inizio del Capitolo 3, dove verranno elencati tutti i tipi di attori che si possono trovare.
La **sezione 2.1** si occupa di analizzare nel dettaglio gli statuti, messi a disposizione in rete, di due comunità energetiche appartenenti alla categoria di associazioni non riconosciute: la CER di Magliano Alpi e la CER di San Lazzaro di Savena. Si può notare come i rispettivi statuti siano pressoché identici e che presentino come radice comune quanto mostrato nei template.

Atto costitutivo dell'associazione
Denominata ___________________________________

L 'anno xxxx il mese di xxxxxxxxxxxx il giorno xxx in xxxxxxxxxxxxxxxxxx xxxxxxxxxx (Padova), presso la sede sociale in via xxxxxxxxxxxxxxxxx, xxx presenti i signori:

______________________________ nato a ________________________ il_______ residente a___________________ cap _____ in via______________ codice fiscale ____________________

______________________________ nato a ________________________ il_______ residente a___________________ cap _____ in via ______________ codice fiscale ____________________

______________________________ nato a ________________________ il_______ residente a___________________ cap _____ in via ______________ codice fiscale ____________________

______________________________ nato a ________________________ il_______ residente a___________________ cap _____ in via ______________ codice fiscale ____________________

______________________________ nato a ________________________ il_______ residente a___________________ cap _____ in via ______________ codice fiscale ____________________

Mediante quest'atto, convengono e stipulano quanto segue:

ART. 1 E' costituita fra i presenti, nel rispetto dell'art. 36 e sgg. del Codice Civile, l'associazione avente la seguente denominazione: ____

ART. 2 L' associazione ha sede in: ____________________________________ Via ____

ART.3 L'associazione ha come scopo di: ______________________________ ____
(riportare finalità indicate da Statuto)

ART. 4 L'associazione ha durata illimitata nel tempo.

ART. 5 L'associazione avrà come principi informatori, analizzati dettagliatamente nell'allegato Statuto sociale che fa parte integrante del presente Atto costitutivo: assenza di fini di lucro, esclusivo perseguimento di finalità di solidarietà sociale, democraticità della struttura, elettività, gratuità delle cariche associative, sovranità dell'assemblea, divieto di svolgere attività diverse da quelle istituzionali ad eccezione di quelle economiche marginali.

ART. 6 I comparenti stabiliscono che, per il primo mandato triennale, il Consiglio Direttivo sia composto da _______ membri e nominano a farne parte i signori:
____
____
____

A presidente viene eletto/a il Signore/la Signora ________________________.
Per le altre cariche vengono eletti __________________________

ART. 7 - Le spese del presente atto, annesse e dipendenti, si convengono ad esclusivo carico dell'associazione qui costituita.
Il primo esercizio sociale chiuderà il _______________.

È parte integrale del presente atto lo statuto - definito su XX articoli di seguito specificati, steso su XXX fogli dattiloscritti.

Letto firmato e sottoscritto.

Firme dei costituenti:
Sig. __________________________
Sig. __________________________
Sig. __________________________
Sig.___________________________
Sig. __________________________

Figure B.1: Template per *atto costitutivo* di un'associazione non riconosciuta [16]

ART. 1 – (Denominazione e sede)

1. E' costituita, nel rispetto dell'art. 36 e sgg. del Codice Civile l'associazione denominata:

   << ………......... >>
   con sede in via / piazza ……………………………………......…., nel Comune di ……………………………………..

   Il trasferimento della sede legale non comporta modifica statutaria, ma l'obbligo di comunicazione agli uffici competenti.

ART. 2 - (Finalità)

1. L'associazione è apartitica, non ha scopo di lucro e svolge attività di promozione e utilità sociale.
2. Le finalità che si propone sono in particolare:
   (specificare sia le finalità generali dell'associazione sia quelle specifiche, nonché le modalità per raggiungere lo scopo sociale)
   a)
   b)
   c)

ART. 3 - (Soci)

1. Sono ammesse all'Associazione tutte le persone fisiche che ne condividono gli scopi e accettano il presente statuto e l'eventuale regolamento interno.
2. L'organo competente a deliberare sulle domande di ammissione è l'Assemblea
   (*oppure** il Consiglio Direttivo).
   Il diniego va motivato. Il richiedente, nella domanda di ammissione dovrà specificare le proprie complete generalità impegnandosi a versare la quota associativa.
3. Ci sono 3 categorie di soci:
   <u>ordinari</u>: sono coloro che versano la quota di iscrizione annualmente stabilita dall'Assemblea,
   <u>sostenitori</u>: sono coloro che oltre alla quota ordinaria, erogano contribuzioni volontarie straordinarie,
   <u>benemeriti:</u> sono persone nominate tali dall'Assemblea per meriti particolari acquisiti a favore dell'Associazione.
4. L'ammissione a socio è a tempo indeterminato, fermo restando il diritto di recesso.
5. L'associazione prevede l'intrasmissibilità della quota o contributo associativo ad eccezione dei trasferimenti a causa di morte e la non rivalutabilità della stessa.

ART. 4 - (Diritti e doveri dei soci)

1. I soci hanno diritto di eleggere gli organi sociali e di essere eletti negli stessi.
2. Essi hanno diritto di essere informati sulle attività dell'associazione e di essere rimborsati per le spese effettivamente sostenute nello svolgimento dell'attività prestata.
3. I soci devono versare nei termini la quota sociale e rispettare il presente statuto e l'eventuale regolamento interno.
4. Gli aderenti svolgeranno la propria attività nell'associazione prevalentemente in modo personale, volontario e gratuito, senza fini di lucro, anche indiretto, in ragione delle disponibilità personali.

ART. 5 - (Recesso ed esclusione del socio)

1. Il socio può recedere dall'associazione mediante comunicazione scritta all'Assemblea
   (*Oppure ** al Consiglio direttivo).
2. Il socio che contravviene ai doveri stabiliti dallo statuto può essere escluso dall'Associazione.
3. L'esclusione è deliberata dall'Assemblea con voto segreto e dopo avere ascoltato le giustificazioni dell'interessato.
   (*Oppure ** E' ammessa la decisione dell'organo direttivo con possibilità di appello entro 30 gg all'assemblea).
   E' comunque ammesso ricorso al giudice ordinario.

Figure B.2: Template per *statuto* di un'associazione non riconosciuta - da Art. 1 a Art. 5 [16]

ART. 6 - (Organi sociali)

1. Gli organi dell'associazione sono:
   - Assemblea dei soci,
   - Consiglio direttivo,
   - Presidente,
   - Collegio dei Revisori dei Conti (*organo eventuale.*),
   - Collegio dei Probiviri (*organo eventuale*).
2. Tutte le cariche sociali sono assunte a titolo gratuito.

ART. 7 - (Assemblea)

1. L'Assemblea è l'organo sovrano dell'associazione ed è composta da tutti i soci.
2. E' convocata almeno una volta all'anno dal Presidente dell'associazione o da chi ne fa le veci mediante avviso scritto da inviare almeno 10 giorni prima di quello fissato per l'adunanza e contenente l'ordine del giorno dei lavori;
3. L'Assemblea è inoltre convocata a richiesta di almeno un decimo dei soci o quando il Consiglio direttivo lo ritiene necessario.
4. L'Assemblea può essere ordinaria o straordinaria. E' straordinaria quella convocata per la modifica dello statuto e lo scioglimento dell'associazione. E' ordinaria in tutti gli altri casi.

ART. 8 - (Compiti dell'Assemblea)

1. L'assemblea deve:
   - approvare il rendiconto conto consuntivo e preventivo;
   - fissare l'importo della quota sociale annuale;
   - determinare le linee generali programmatiche dell'attività dell'associazione;
   - approvare l'eventuale regolamento interno;
   - deliberare in via definitiva sulle domande di nuove adesioni e sulla esclusione dei soci;
   - eleggere il Presidente e il Consiglio Direttivo;
   - deliberare su quant'altro demandatole per legge o per statuto, o sottoposto al suo esame dal Consiglio direttivo.

ART. 9 - (Validità Assemblee)

1. L'assemblea ordinaria è regolarmente costituita in prima convocazione se è presente la maggioranza degli iscritti aventi diritto di voto; in seconda convocazione, da tenersi anche nello stesso giorno, qualunque sia il numero dei presenti, in proprio o in delega.
2. Non è ammessa più di una delega per ciascun aderente.
   (oppure * Non sono ammesse più di tre deleghe per ciascun aderente).
3. Le deliberazioni dell'assemblea ordinaria vengono prese a maggioranza dei presenti e rappresentati per delega, sono espresse con voto palese tranne quelle riguardanti le persone e la qualità delle persone (o quando l'Assemblea lo ritenga opportuno).
4. L'assemblea straordinaria approva eventuali modifiche allo statuto con la presenza di 3/4 dei soci (*Oppure* * con la presenza dei 2/3 dei soci *Oppure* * con la presenza della metà più uno dei soci) e con decisione deliberata a maggioranza dei presenti; scioglie l'associazione e ne devolve il patrimonio col voto favorevole di ¾ dei soci.

ART. 10 - (Verbalizzazione)

1. Le discussioni e le deliberazioni dell'assemblea sono riassunte in un verbale redatto dal segretario e sottoscritto dal presidente.
2. Ogni socio ha diritto di consultare il verbale e di trarne copia.

Figure B.3: Template per *statuto* di un'associazione non riconosciuta - da Art. 6 a Art. 10 [16]

ART. 11 - (Consiglio direttivo)

1. Il consiglio direttivo è composto da numero…… *(precisare il numero dei componenti che deve essere dispari non inferiore a tre)* membri eletti dall'assemblea tra i propri componenti.
2. Il consiglio direttivo è validamente costituito quando è presente la maggioranza dei componenti. (Nel caso in cui il consiglio direttivo fosse composto da soli tre membri, è validamente costituito quando sono presenti tutti). Esso delibera a maggioranza dei presenti.
3. Il Consiglio direttivo compie tutti gli atti di ordinaria e straordinaria amministrazione non espressamente demandati all'Assemblea; redige e presenta all'assemblea il rapporto annuale sull'attività dell'associazione, il rendiconto consuntivo e preventivo.
4. Il consiglio direttivo dura in carica per n. ……. anni *(stabilire la durata)* e i suoi componenti possono essere rieletti per n. ...... mandati *(stabilire il numero massimo dei mandati)*.

ART. 12 - (Presidente)

1. Il Presidente ha la legale rappresentanza dell'associazione, presiede il Consiglio direttivo e l'assemblea; convoca l'assemblea dei soci e il Consiglio direttivo sia in caso di convocazioni ordinarie che straordinarie.

ART. 13 - (Risorse economiche)

1. Le risorse economiche dell'associazione sono costituite da:
   a. quote e contributi degli associati;
   b. contributi di privati,
   c. eredità, donazioni e legati;
   d. altre entrate compatibili con la normativa in materia
2. L'associazione ha il divieto di distribuire, anche in modo indiretto, utili e avanzi di gestione nonché fondi, riserve o capitale durante la vita dell'ente, in favore di amministratori, soci, partecipanti, lavoratori o collaboratori e in generale a terzi, a meno che la destinazione o la distribuzione non siano imposte per legge, ovvero siano effettuate a favore di enti che per legge, statuto o regolamento, fanno parte della medesima e unitaria struttura e svolgono la stessa attività ovvero altre attività istituzionali direttamente e specificamente previste dalla normativa vigente.
3. L'associazione ha l'obbligo di reinvestire gli eventuali utili e avanzi di gestione esclusivamente per lo sviluppo delle attività funzionali al perseguimento dello scopo istituzionale di solidarietà sociale.

ART. 14 - (Rendiconto economico-finanziario)

1. Il rendiconto economico-finanziario dell'associazione è annuale e decorre dal primo gennaio di ogni anno. Il conto consuntivo contiene tutte le entrate e le spese sostenute relative all'anno trascorso. Il conto preventivo contiene le previsioni di spesa e di entrata per l'esercizio annuale successivo.
2. Il rendiconto economico-finanziario è predisposto dal Consiglio direttivo e approvato dall'assemblea generale ordinaria con le maggioranze previste dal presente statuto, depositato presso la sede dell'associazione almeno 20 gg. prima dell'assemblea e può essere consultato da ogni associato.
3. Il conto consuntivo deve essere approvato entro il 30 aprile dell'anno successivo alla chiusura dell'esercizio sociale.

ART. 15 - (Scioglimento e devoluzione del patrimonio)

1. L'eventuale scioglimento dell'Associazione sarà deciso soltanto dall'assemblea con le modalità di cui all'art. 9.
2. L'associazione ha l'obbligo di devolvere il patrimonio dell'ente non commerciale in caso di suo scioglimento per qualunque causa, ad altro ente non commerciale che svolga un'analoga attività istituzionale, salvo diversa destinazione imposta dalla legge con finalità analoghe o ai fini di pubblica utilità, sentito l'organismo di controllo di cui all'articolo 3, comma 190, della legge 23 dicembre 1996, n. 662, e salvo diversa destinazione imposta dalla legge;

ART. 16 - (Disposizioni finali)

Per tutto ciò che non è espressamente previsto dal presente statuto si applicano le disposizioni previste dal Codice civile e dalle leggi vigenti in materia.

Firmato:

Sig. ________________________
Sig. ________________________
Sig. ________________________
Sig. ________________________
Sig. ________________________

Figure B.4: Template per *statuto* di un'associazione non riconosciuta - da Art. 11 a Art. 16 [16]

CONTRATTO DI MANDATO (*)

— Servizio di valorizzazione e incentivazione dell'energia elettrica condivisa —
comunità di energia rinnovabile

tra

Il sottoscritto[1] *(nome)* ______________________ *(cognome)* ______________________ (codice fiscale ______________________), nato/a il ___/___/_____ a[2] ______________________ (___), residente nel Comune di [3] ______________________ (___), in via/viale/piazza/largo ______________________, n. ________, CAP __________, rappresentante del/della[4] ______________________ con sede[5] nel Comune di ______________________ (___), in via/viale/piazza/largo ______________________, avente codice fiscale ______________________, Partita IVA ____________________,

- produttore dell'impianto di produzione / sezione di impianto identificato/a dal codice CENSIMP[6] IM_ ____________ e codice sezione[7] SZ_ __________________, collegato/a al punto di connessione identificato dal codice POD IT__________________, alimentato/a da fonti rinnovabili, entrato/a in esercizio in data ___/___/_____[8], con potenza pari a[9] ___________kW,
- non ibrido/a e alimentato da combustibile/i principale/i[10] ______________________,
- che[11] sistemi di pompaggio,

nella qualità di produttore non appartenente alla configurazione di comunità di energia rinnovabile;

— *mandante* —

[1] Inserire nome e cognome della persona fisica, ovvero del titolare della ditta individuale, ovvero del soggetto rappresentante nel caso di persona giuridica
[2] Inserire il comune del luogo di nascita. In caso di nascita all'estero, inserire la Nazione di nascita
[3] Inserire il comune di residenza. In caso di residenza all'estero, inserire Nazione, Città estera, Indirizzo
[4] Nel caso di persona giuridica indicare la ragione sociale
[5] In caso di sede all'estero indicare Nazione, Città estera, Indirizzo
[6] Inserire il codice Censimp dell'impianto di produzione presente sul portale GAUDI' di TERNA
[7] Da inserire solo nel caso di potenziamenti.
[8] Inserire la data di entrata in esercizio dell'impianto/sezione.
[9] Inserire il dato della potenza attiva nominale dell'impianto/sezione.
[10] Indicare il tipo di combustibile principale, da inserire nel solo caso di impianti termoelettrici.
[11] Inserire *presenta* o *non presenta*.

Figure B.5: Prima parte del Contratto di Mandato [20]

Il sottoscritto[12] *(nome)* ____________________________*(cognome)* ________________________ (codice fiscale ____________________________), nato/a il ____/____/______ a[13]________________________(___), residente nel Comune di [14]____________________ (___), in via/viale/piazza/largo__________________________, n.__________, CAP ___________, rappresentante del/della[15] ____ con sede[16] nel Comune di ______________________________(___), in via/viale/piazza/largo __________________________, avente codice fiscale ________________________, Partita IVA ____________________, nella qualità di comunità di energia rinnovabile

— *mandatario Soggetto Referente* —

PREMESSO CHE

— l'art. 42-*bis* del Decreto legge del 30 dicembre 2019, n. 162, convertito con modificazioni dalla L. 28 febbraio 2020, n. 8, ha definito modalità e condizioni per l'attivazione dell'autoconsumo collettivo da fonti rinnovabili e per la realizzazione di comunità di energia rinnovabile, introducendo la disciplina transitoria per l'attuazione dell'art. 21 della direttiva 2018/2001 sulla promozione dell'uso dell'energia da fonti rinnovabili;

— con la deliberazione 318/2020/R/eel del 4 agosto 2020 e il relativo Allegato A, l'Autorità di Regolazione per l'Energia Reti e Ambiente (nel seguito anche, ARERA), nel dare attuazione al comma 8 dell'art. 42-*bis* del Decreto legge del 30 dicembre 2019, n. 162, cit., ha dettato la «*regolazione delle partite economiche relative all'energia elettrica oggetto di autoconsumo collettivo o di condivisione nell'ambito di comunità di energia rinnovabile*»;

— con il decreto del Ministro dello Sviluppo Economico del 16 settembre 2020 è stata individuata la tariffa incentivante da riconoscere agli impianti a fonti rinnovabili inseriti nelle configurazioni per l'autoconsumo collettivo da fonti rinnovabili;

— con le Regole Tecniche per l'accesso al servizio di valorizzazione e incentivazione dell'energia condivisa, verificate positivamente dall'ARERA e pubblicate sul proprio sito istituzionale, il GSE ha dettagliato le condizioni e le modalità per la presentazione dell'istanza di accesso, le modalità di comunicazione ai Referenti delle configurazioni che beneficiano del servizio di valorizzazione e incentivazione dell'energia condivisa, puntuali criteri di calcolo dei vari corrispettivi e contributi, le modalità di profilazione dei dati di misura e di utilizzo.

LE PARTI STIPULANO E
CONVENGONO QUANTO SEGUE

[12] Inserire nome e cognome della persona fisica, ovvero del titolare della ditta individuale, ovvero del soggetto rappresentante nel caso di persona giuridica
[13] Inserire il comune del luogo di nascita. In caso di nascita all'estero, inserire la Nazione di nascita
[14] Inserire il comune di residenza. In caso di residenza all'estero, inserire Nazione, Città estera, Indirizzo
[15] Nel caso di persona giuridica indicare la ragione sociale
[16] In caso di sede all'estero indicare Nazione, Città estera, Indirizzo

Figure B.6: Seconda parte del Contratto di Mandato [20]

Articolo 1
Oggetto del mandato

1. In osservanza delle disposizioni di cui all'art. 42-bis del Decreto legge del 30 dicembre 2019, n. 162, convertito con modificazioni dalla L. 28 febbraio 2020, n. 8, nonché delle regole, degli obblighi e delle condizioni previsti dal decreto del Ministro dello Sviluppo Economico del 16 settembre 2020, dalla deliberazione ARERA 318/2020/R/eel del 4 agosto 2020, e dal relativo Allegato A, e dalle Regole Tecniche del GSE, il mandatario si obbliga al compimento di tutte le attività e di tutti gli atti giuridici prodromici alla presentazione al GSE dell'istanza di accesso al servizio di valorizzazione e incentivazione dell'energia elettrica, così come al compimento di tutte le attività e di tutti gli atti giuridici successivi all'eventuale accesso al predetto servizio.
2. In particolare, a titolo meramente esemplificativo e non esaustivo, il mandatario si obbliga:

a) ad accertare che: *a.1.)* ciascun impianto di produzione, la cui energia elettrica immessa rileva ai fini della determinazione dell'energia elettrica condivisa, sia entrato in esercizio a seguito di nuova realizzazione dall'1 marzo 2020 ed entro i sessanta giorni solari successivi alla data di entrata in vigore del provvedimento di recepimento della direttiva 2018/2001; *a.2.)* ciascun impianto di produzione la cui energia elettrica immessa rileva ai fini della determinazione dell'energia elettrica condivisa abbia una potenza non superiore a 200 kW e sia connesso su reti elettriche di bassa tensione sottese alla medesima cabina secondaria a cui la configurazione si riferisce;

b) a comunicare al GSE anche l'elenco dei produttori degli impianti non facenti parte della configurazione ma la cui energia rileva ai fini della configurazione, specificando il codice identificativo di ciascun punto di connessione (codice POD);

c) ad allegare all'istanza di accesso al servizio di valorizzazione e di incentivazione dell'energia elettrica condivisa: *c.1.)* il presente contratto di mandato senza rappresentanza; *c.2)* una dichiarazione sostitutiva di certificazione e dell'atto di notorietà, resa ai sensi del d.P.R. 28 dicembre 2000, n. 445, in ordine al rispetto del requisito di cui alle lett. a.1) e a.2), da parte di tutti gli impianti di produzione facenti parte o che rilevano ai fini della configurazione;

d) a stipulare con il GSE, in caso di accoglimento dell'istanza, il contratto per il servizio di valorizzazione e incentivazione dell'energia elettrica condivisa;

e) ad informare i clienti finali e i produttori facenti parte o i cui impianti rilevano ai fini della configurazione di comunità di energia rinnovabile delle verifiche e dei controlli da parte del GSE;

f) a consentire al GSE, nell'ambito delle attività di controllo, l'accesso agli impianti di produzione e alle unità di consumo che rilevano ai fini dell'energia condivisa dai soggetti facenti parte ella configurazione di comunità di energia rinnovabile;

g) a comunicare al GSE ogni variazione riguardante la composizione della configurazione, nonché tutte le modifiche che possano incidere sul calcolo dei contributi e dei requisiti;

h) ad acquisire ogni potere necessario alla trasmissione e gestione dei dati, anche di natura personale, per conto del mandante, con ogni cura di provvedere al loro aggiornamento e relativa comunicazione al GSE;

i) ad acquisire dal mandante e, quindi, a fornire al GSE, mediante l'utilizzo del portale informatico appositamente predisposto (e sempre che non siano già disponibili sul sistema GAUDÌ) i dati relativi all'/agli impianto/i di produzione del mandante indicato/i nel presente contratto, perché l'energia da questi prodotta e immessa in rete rilevi nella configurazione ai

Figure B.7: Terza parte del Contratto di Mandato [20] fini della valorizzazione e incentivazione dell'energia condivisa;

j) a dare per conto del mandante, avendo ricevuto pieno consenso a tal riguardo, la disponibilità per la partecipazione alle campagne di misura e monitoraggio condotte dalla società Ricerca sul Sistema Energetico S.p.A. (nel seguito, RSE) ai sensi all'articolo 42-*bis*, comma 7, del Decreto legge del 30 dicembre 2019, n. 162, convertito con modificazioni dalla L. 28 febbraio 2020, n. 8 e, a tal fine, a consentire, per conto del mandante, alla società RSE qualora la configurazione di comunità di energia rinnovabile a cui il mandante appartiene dovesse far parte del campione scelto per le suddette campagne,
- l'installazione di strumenti di misura dell'energia elettrica prodotta o immessa dagli impianti di produzione del mandante facenti parte della configurazione o di quella assorbita o rilasciata da eventuali accumuli,
- l'acquisizione, per il tramite del GSE, dei dati ottenuti dal GSE tramite il Sistema GAUDI' di Terna S.p.A. e delle misure fornite al GSE dai Gestori di Rete in relazione ai predetti impianti di produzione,
- l'acquisizione per il tramite del GSE e l'utilizzo dei dati afferenti al mandante forniti nell'ambito delle dichiarazioni rese dal mandatario al GSE;

k) a richiedere la risoluzione di eventuali convenzioni di scambio sul posto in essere con il GSE e in capo al mandante, afferenti agli impianti di produzione che rilevano ai fini della configurazione.

2. Il mandatario ____________________[17] ad immettere in rete l'energia prodotta da impianti di produzione del mandante che rilevano ai fini della configurazione e conseguentemente a richiedere la risoluzione di eventuali convenzioni di ritiro dedicato in essere con il GSE ad essi afferenti e in capo al mandante.

3. Le attività e gli atti giuridici di cui ai commi precedenti sono posti in essere dal mandatario con la diligenza richiesta dall'art. 1710 c.c.

Articolo 2
Responsabilità del mandatario nei confronti del GSE
e degli altri soggetti istituzionali

1. Nei confronti del GSE, dell'ARERA e del Ministero dello Sviluppo Economico, il mandatario è l'unico responsabile dei ritardi, delle omissioni, delle violazioni, delle elusioni, delle irregolarità e di ogni anomalia, comunque qualificabile, che dovesse essere accertata sia con riferimento alle condizioni previste per l'adesione dei clienti finali/produttori alla configurazione di comunità di energia rinnovabile, sia con riferimento ai requisiti previsti per gli impianti di produzione dell'energia elettrica condivisa.

2. Nel caso in cui il GSE dovesse accertare la sussistenza di una delle fattispecie di cui al comma 1, eventuali recuperi e/o decurtazioni troveranno applicazione nei soli confronti del mandatario.

3. Resta fermo l'eventuale diritto del mandatario di rivalersi nei confronti dei membri della configurazione.

[17] Inserire "*si obbliga inoltre*" oppure "*non ha mandato*".

Figure B.8: Quarta parte del Contratto di Mandato [20]

Articolo 3

Mancato rinnovo e revoca del mandato

1. In caso di mancato rinnovo del mandato alla scadenza del termine di durata e in caso di revoca, il mandatario è tenuto ad informare tempestivamente il GSE[18], indicando anche il nominativo e i riferimenti del nuovo mandatario.
2. In caso di morte o di sopravvenuta incapacità del mandatario, l'informazione di cui al comma 1 deve essere resa al GSE dal mandante, anche con comunicazione congiunta da parte di tutti i clienti finali/produttori facenti parte della configurazione di comunità di energia rinnovabile, ovvero dal nuovo mandatario.

In caso di mancato rinnovo del mandato alla scadenza del termine di durata da parte del mandante, il mandatario è tenuto ad informare tempestivamente il GSE.

Articolo 4

Clausola di rinvio

1. Per quanto non espressamente previsto si applicano le norme di legge, di regolamento, nonché le previsioni degli atti di regolazione vigenti.

Allegati - Documenti di identità dei sottoscrittori

In fede

Luogo e data .... *Firma del mandante* ....

Firma del mandatario Soggetto Referente ....

[18] Fatta eccezione per la revoca disposta per giusta causa, l'art. 3, comma 1, dovrà ritenersi valido soltanto qualora non sia pattuita la irrevocabilità del mandato e sempre che la durata del mandato non corrisponda a quella dell'intero periodo di incentivazione.

Figure B.9: Quinta parte del Contratto di Mandato [20]

Il **Capitolo 3** tratta l'argomento centrale della tesi, ovvero la ripartizione dei benefici all'interno della comunità. All'interno di una CER è possibile identificare sia soggetti di natura pubblica (ad esempio un comune) sia di natura privata (un cittadino o una PMI). I soggetti che vi possono aderire possono essere:

1. Soggetto produttore puro;
2. Soggetto consumatore puro;
3. Soggetto sia produttore che consumatore;
4. Soggetto nè produttore nè consumatore ma che mette a disposizione lo spazio per la locazione degli impianti produttivi.

Quest'ultima tipologia di soggetto non produce alcun kWh e non contribuisce economicamente alla realizzazione della CER, tuttavia è proprietario dello spazio di installazione dell'impianto produttivo. Si possono aprire diversi scenari in merito alle modalità di remunerazione dei soggetti appartenenti alla categoria 4. Una possibilità potrebbe essere quella di un retrofitting finanziato dalla comunità, nel caso in cui la tettoia sia realizzata in amianto; in tal caso la CER reinvestirebbe parte del ricavato per il retrofitting ma, una volta completato, non presenterebbe una distribuzione costante dei benefici con questo tipo di soggetti. Nel caso in cui la tettoia del soggetto 4 non necessiti di retrofitting, nella ripartizione interna dei proventi si dovrebbe tener conto di una quota di canone.
Nella maggior parte dei casi, la comunità energetica è proprietaria degli impianti di produzione ma, allo stesso tempo, è gestita da un ente esterno (partner tecnologico). Infatti, poiché le CER coinvolgono spesso le pubbliche amministrazioni, esse non presenteranno competenze tecniche adeguate e quindi il partner tecnologico avrà la responsabilità di garantire l'esercizio e la manutenzione degli impianti di produzione e la distribuzione dei benefici all'interno della comunità. Nel caso in cui l'impianto produttivo non fosse di proprietà della CER ma della società esterna, la percentuale di quota per quest'ultima aumenterebbe notevolmente, in quanto sarebbe previsto anche l'ammortamento dell'impianto; in tal caso i benefici finali da ripartire tra i soci sarebbero significativamente ridotti. A questa situazione delineata si può aggiungere un grado di complessità se si considerano gli OPEX previsti per l'impianto produttivo. Questi ultimi, oltre a comprendere la manutenzione ordinaria e straordinaria, possono comprendere anche aspetti relativi all'assicurazione e custodia dell'impianto. La Figura 3.1 mostra un qualitativo diagramma raffigurante le possibili voci di spesa presenti all'interno di una CER.
Questa distinzione di diversa natura dei soggetti unitamente alla necessità di sottoscrivere il Contratto di diritto privato tra Referente e membri della comunità, fa sì che sia di vitale importanza stabilire una coerente modalità di distribuzione dei proventi.

La **sezione 3.1** si occupa di introdurre il caso studio dove verranno applicati i due algoritmi di ripartizione dei proventi, ovvero la comunità energetica di Monticello d'Alba. La Figura 3.2 mostra un'immagine satellitare raffigurante il perimetro di estensione della CER. Sono identificati i sei soggetti partecipanti: il Municipio, la Scuola elementare, la Scuola materna, la Palestra, l'Incontro e la RSA.
Uno dei modelli adottati consiste in un'evoluzione del tool *RECOpt* elaborato dall'Energy Department "Galileo Ferraris" del Politecnico di Torino. L'evoluzione prende il nome di *RECOptGame* ed è basata sulla teoria dei giochi cooperativi. Il secondo modello adottato prende il nome di *Sharing Distribution Model* ed è basato sulla più comune teoria della "tabella millesimale".
La **sezione 3.2** spiega la teoria dei giochi cooperativi applicata al caso delle comunità energetiche. La teoria dei giochi è uno strumento efficace per affrontare la natura interattiva della condivisione dell'energia, poiché fornisce tecniche matematiche generali per analizzare situazioni in cui due o più individui prendono decisioni che influenzeranno il benessere dell'altro. Il gioco descrive qualsiasi situazione in cui i processi decisionali dei giocatori, cioè i partecipanti al gioco, sono interconnessi. Se la teoria dei giochi viene applicata alle comunità energetiche:

- i giocatori sono considerati *razionali*, poiché le loro decisioni sono guidate unicamente dal desiderio di completare i loro obiettivi, che si presume siano la massimizzazione del loro payoff atteso, descritto matematicamente da una funzione di utilità;

- i giocatori sono considerati *intelligenti* e si presume che ogni giocatore sia consapevole delle regole del gioco e possa pensare a presupposti coerenti per prendere le proprie decisioni.

La teoria dei giochi è generalmente suddivisa in due classi che definiscono il livello di vincolo degli accordi presi tra i giocatori. I *giochi cooperativi* analizzano situazioni in cui gli impegni sono pienamente vincolanti e applicabili. Viceversa, nei giochi *non cooperativi* (o strategici) non vi è alcun obbligo di adempiere a questi impegni. Nei giochi *non cooperativi*, i giocatori sono indipendenti e scelgono la propria strategia: la massimizzazione della propria funzione di utilità, senza comunicazione o scambio di informazioni con altri giocatori. I *giochi cooperativi* sono caratterizzati dalla possibilità di comunicazione tra i giocatori. In particolare, i giocatori decidono di formare coalizioni tra di loro per migliorare il proprio payoff dal gioco. Questa alleanza rappresenta un accordo che vincola i giocatori ad agire collettivamente.
La sezione 3.2 prosegue svolgendo un'analisi teorica del parametro chiave di questa teoria: il valore di Shapley (riportato nell'equazione 3.5). Da d'ora in avanti ci si addentra sempre di più nell'illustrazione matematica e, essendovi parecchie formule nelle sottosezioni presenti, la trattazione può essere facilmente compresa anche in lingua inglese. L'ultima sottosezione (Analisi interpretativa del valore di Shapley)

serve per fornire un esempio applicativo su come avviene la ripartizione di benefici seguendo questo metodo basato sulla teoria dei giochi cooperativi.
La **sezione 3.3** è dedicata alla descrizione del secondo modello adottato, il cosiddetto *Sharing Distribution Model*. In questo modello, la quota di ciascun partecipante sul reddito totale della comunità è calcolata considerando il contributo orario che l'operatore ha sulla produzione e sui consumi totali, per un intero anno di riferimento.
Tale distribuzione deve essere necessariamente calcolata su base oraria e può essere differenziata tra:

- produttori (P), che hanno investito in impianti per la generazione di energia rinnovabile;
- operatori accumulo (S), che hanno altresì investito in hardware per aumentare la condivisione dell'energia prodotta;
- utilizzatori (U), che aderiscono con il loro consumo, permettendo così la condivisione (autoconsumo virtuale) dell'energia prodotta.

Si considera una formulazione iniziale semplificata in cui non vengono presi in considerazione gli operatori di accumulo. Il procedimento prevede quindi una ripartizione dei proventi tra le due classi di produttori (P) e utilizzatori (U). All'interno dei due macro-gruppi, ogni partecipante viene ricompensato con la percentuale di energia utile messa in gioco (sia essa prodotta o consumata), normalizzata al complesso della propria classe, calcolata su base oraria.
La **sezione 3.4** è dedicata al paragone tra i due modelli utilizzati (*RECOptGame* e *Sharing Distribution Model*). Nella Figura 3.3a e nella Figura 3.3b sono mostrate le quote percentuali dei membri della Comunità di Monticello d'Alba, ottenute utilizzando lo *Sharing Distribution Model* e *RECOptGame*, rispettivamente. Nel primo caso è stato ipotizzato di suddividere i proventi totali in modo da allocarne il 70% ai produttori ed il 30% ai consumatori ($\eta = 0.7$). Nel secondo caso, è stata adottata la convenzione per cui configurazioni di un solo player hanno comunque valore non nullo (identificata con il nome *Repubblicana*), che va ad aumentare il valore dei produttori a discapito dei consumatori.
Nella Figura 3.4a e nella Figura 3.4b sono riportati gli stessi risultati calcolati, rispettivamente, con $\eta = 0.6$ nel primo caso e adottando la convenzione per cui configurazioni di un solo player hanno valore nullo (identificata con il nome *Democratica*). Quest'ultima conferisce un certo valore ad ogni partecipante per il solo fatto di essere presente nella comunità, al di là dell'entità dei propri consumi.
Nel primo set (Figura 3.3), i risultati ottenuti con i due modelli sono praticamente coincidenti. Nel secondo set (Figura 3.4), mentre la distribuzione globale tra produttore e consumatori resta simile, la distribuzione interna al gruppo dei consumatori varia a seconda del modello utilizzato. Come già detto, infatti, il

modello basato sul valore di Shapley, in convenzione *Democratica*, conferisce ad un consumatore un certo valore per il solo fatto di essere membro della comunità. Lo *Sharing Distribution Model*, invece, continua a considerare i consumi effettivi (e la loro distribuzione all'interno della giornata) come unico metro per la ripartizione dei benefit nel macro-gruppo dei consumatori.
Dalle analisi precedenti si può concludere, in prima battuta, che l'algoritmo di divisione dei benefit *Sharing Distribution Model* può portare a risultati simili all'algoritmo basato sul calcolo del valore di Shapley, in casi non particolarmente problematici. A ciò si aggiunge il fatto che il primo, pur avendo bisogno di serie annuali, può richiedere tempi di calcolo molto inferiori rispetto al secondo, sopratutto all'aumentare del numero di giocatori (i tempi di calcolo variano, rispettivamente, linearmente ed esponenzialmente col numero di giocatori). Non ultima, l'ottimale semplicità teorica del modello proposto dal Prof. Repetto ne garantisce un'interpretabilità imparagonabile rispetto a quella di *RECOptGame*.
Tuttavia l'algoritmo su cui si basa lo *Sharing Distribution Model*, nella formulazione iniziale, appare relativamente rigido e non risponde perfettamente a variazioni nella configurazione. Infatti, dovendo definire a priori la ripartizione percentuale tra produzione e consumo, l'algoritmo non è in grado di "percepire" automaticamente quanto la produzione influisce sui proventi della comunità rispetto al consumo e viceversa. Un altro nodo da sciogliere è come considerare, nell'algoritmo, eventuali operatori di sistemi di accumulo, il cui calcolo delle quote richiederebbe un'implementazione diversa da quella operata finora. Questo problema non si riscontra invece in *RECOptGame*, dove i possessori di accumuli sono trattati al pari degli altri giocatori e l'algoritmo è in grado di valutarne automaticamente il valore.
La sezione 3.4 si conclude spiegando le estensioni del modello *RECOptGame*. Viene spiegato come questo algoritmo sia capace di trattare correttamente la ripartizione per soggetti "non convenzionali" come quello del *partner tecnologico* e quello dell'*affittuario degli spazi per gli impianti produttivi*. La presenza di soggetti di questo tipo all'interno di una CER era stata descritta all'inizio del Capitolo 3.

Il **Capitolo 4** mostra i risultati ottenuti per la CER di Monticello d'Alba, sia per la configurazione base e sia per una più evoluta data dall'aggiunta di due nuovi player. I risultati sono stati ricavati sulla base dei KPI di interesse, ovvero:

- il risparmio percentuale in bolletta (**PCR**), per ogni *consumatore* e *prosumer*;
- l'Internal Rate of Return (**IRR**) e il Pay - Back Time (**PBT**), per i *produttori* e i *prosumer*.

In particolare, il valore del PCR è calcolato al netto degli ammortamenti e dei costi di manutenzione; il PBT tiene conto anche delle spese di O&M.

La **sezione 4.1** è dedicata alla CER di Monticello d'Alba nella sua configurazione base. La Tabella 4.1 riassume tutti i soggetti coinvolti indicandone le loro caratteristiche principali. La Tabella 4.2 invece mostra le ipotesi iniziali adottate per ricavare i risultati; queste ipotesi saranno valide per entrambi le configurazioni della CER.
Nell'analisi si è deciso di adottare la convenzione *Repubblicana* del modello *RECOptGame*, in quanto si è visto che quest'ultima, rispetto alla *Democratica*, permetteva di ottenere una distribuzione più omogenea dei KPI e anche perché si è visto che la quota di benefit è più consistente rispetto ai contributi versati.
Nella Figura 4.1 vengono mostrati i risultati. Sull'asse orizzontale è rappresentata la quota percentuale sul totale, mentre sull'asse verticale si considera ogni giocatore coinvolto. Poiché in questa configurazione il Comune è l'unico proprietario dell'impianto fotovoltaico, esso risulta essere l'unico player che presenta IRR e PBT all'interno dei propri KPI. Tutti gli altri sono consumatori e quindi l'unico KPI caratteristico per ciascuno di essi è il PCR. Inoltre il grafico mostra due diverse colonne: quella marrone spiega la quota di consumo mentre quella blu la quota di beneficio che otterrà il giocatore considerato.
I risultati ottenuti sono ragionevoli in quanto è coerente che la quota maggiore dei benefici spetti al proprietario dell'impianto fotovoltaico. Dal lato dei consumi è possibile osservare che il player più energivoro è l'RSA e anche questo è coerente poiché i profili di consumo tipici di una RSA sono più alti rispetto a quelli di tutti gli attori coinvolti. Per tutti i soggetti è possibile notare il vantaggio di aderire alla CER poiché il risparmio in percentuale in bolletta (PCR) è per tutti positivo.
La **sezione 4.2** è invece dedicata alla CER di Monticello d'Alba nella sua configurazione più evoluta. Al fine di migliorare l'efficacia del modello *RECOptGame*, si è deciso di considerare una configurazione più avanzata che, oltre ai precedenti sei soggetti considerati, analizzi il profilo di due nuovi utenti: un macellaio e un panettiere. Nello specifico:

- il **macellaio** ha un profilo di consumo piuttosto piatto durante la giornata;
- il **panettiere** ha un consumo molto elevato, ma concentrato nelle prime ore della giornata.

La Tabella 4.3 riassume tutti i soggetti coinvolti indicandone le loro caratteristiche principali. I risultati sono mostrati in Figura 4.2.
Il modello, in accordo con quanto ipotizzato, non premia l'ammontare complessivo dei consumi di ciascun partecipante ma la distribuzione in relazione al profilo di consumo. Infatti la bottega del macellaio, pur avendo consumi inferiori rispetto al panificio, otterrà una quota di reddito maggiore. Inoltre, si registra un aumento della quota del Comune dovuto al maggior utilizzo dell'energia prodotta principalmente per via della bottega del macellaio.

La **sezione 4.3** si occupa di valutare i KPI per le due configurazioni della CER di Monticello d'Alba secondo lo *Sharing Distribution Model*.
La Figura 4.3 mostra il confronto dei due modelli nel caso della configurazione base della CER. Per ottenere questo grafico, il valore di η è stato fissato al 70% nel caso dell'RDM (come nella sezione 3.4). Come si vede, i risultati ottenuti nell'output dei due modelli sono molto in linea.
La situazione cambia quando viene analizzato il secondo caso di studio. La Figura 4.4 mostra il confronto delle prestazioni dei due modelli relativamente alla configurazione più evoluta della CER. In questo caso si nota che lo *Sharing Distribution Model* è meno sensibile alla distribuzione dei consumi durante la giornata. Tutte le precedenti considerazioni fatte alla fine della sezione 3.4 sono qui dimostrate nei casi specifici.

Il **Capitolo 5** è dedicato al tema del Demand Side Management. Con il termine DSM si indica un insieme di azioni volte a gestire in modo efficiente i consumi di un sito, al fine di ridurre i costi sostenuti per la fornitura di energia elettrica, per la rete e per gli oneri generali di sistema, comprese le componenti fiscali. Tali azioni di ottimizzazione sono finalizzate a modificare le caratteristiche del consumo di energia elettrica, con riferimento all'ammontare complessivo dei consumi, al loro andamento temporale e ai parametri contrattuali di fornitura (parametri contrattuali di potenza e di connessione alla rete), al fine di determinare risparmi sul costo della bolletta.
Le tecniche per la gestione del carico di utenza sono riassunte in Figura 5.1. Il Capitolo 5 prosegue analizzando in dettaglio la logica di funzionamento di ciascuno dei possibili principi di base.
Le misure del DSM si dividono tra programmi di incentivazione e programmi basati sul prezzo. La figura 5.2 riassume tutti i programmi di Demand Response (DR).
Potrebbe essere necessario un *aggregator* per gestire la situazione in modo coordinato. Questo ente può essere il distributore, il rivenditore o un altro soggetto. L'obiettivo dell'*aggregator* è raccogliere la disponibilità di molti utenti con più componenti i cui consumi possono essere ridotti o spostati nel tempo in modo flessibile. Il lato della domanda può partecipare al miglioramento delle condizioni operative in diversi orizzonti temporali, anche legati ai mercati. Le variazioni che corrispondono alle azioni degli utenti sono calcolate rispetto a un caso di riferimento (baseline) che deve essere identificato, ad esempio in modo convenzionale. È necessario un accurato sistema di misurazione per verificare che il servizio richiesto all'utente sia stato effettivamente erogato dall'utente. La baseline è il modello di riferimento associato a un cliente o ad un gruppo di clienti:

- la *vera baseline* è il percorso che il profilo di consumo avrebbe seguito in assenza dell'azione data dal DR;

- la *baseline predetta* è il percorso stimato dalla società di servizi che il profilo di consumo del cliente (o del gruppo di clienti) avrebbe seguito in assenza di un evento di DR (è quindi la previsione della vera baseline).

Le prestazioni dell'azione di DR vengono valutate calcolando la differenza tra il percorso effettivo che ha seguito l'azione di DR e la baseline corrispondente al caso "business as usual".
La baseline modificata consiste nell'adattamento di una baseline iniziale al modello di carico effettivo che si verifica prima dell'inizio dell'azione DR. Devono essere seguite regole specifiche per determinare la baseline modificata. La Figura 5.3 mostra visivamente quanto detto.
La **sezione 5.1** esegue un'analisi storica su come le tecniche di DR si sono evolute in Europa. La Figura 5.4 fornisce una panoramica dell'attuale quadro normativo per la Demand Response nei 18 paesi esaminati. I paesi europei che attualmente forniscono il quadro più favorevole per lo sviluppo del Demand Response sono Svizzera, Francia, Belgio, Finlandia, Gran Bretagna e Irlanda. Tuttavia, in questi paesi con buone prestazioni, esistono ancora problemi di progettazione del mercato e normativi. Slovenia, Italia e Polonia sono di colore arancione. In Slovenia e Polonia, negli ultimi due anni non sono state apportate modifiche normative di rilievo che abbiano consentito un ulteriore grado di sviluppo per il Demand Response. In particolare, l'Italia ha aggiornato il suo status da rosso nelle precedenti mappe di DR ad arancione oggi, poiché ha lentamente iniziato a intraprendere le misure normative necessarie in modo da ottenere un solido scenario per la Demand Response.
La **sezione 5.2** spiega come le tecniche precedentemente introdotte del DSM possono essere applicate nelle CER. Viene proposto il ciclo di esecuzione di una possibile strategia DSM giornaliera e suddivisa in tre parti: raccolta dati, risoluzione dei problemi di ottimizzazione e accordo dei piani con gli utenti. Questa strategia viene applicata ad una microgrid eolica-solare-diesel dove il consumo di carburante è considerato come il costo da minimizzare. La Figura 5.5 presenta il flusso di lavoro della strategia DSM proposta. Le frecce gialle rappresentano la fase di raccolta dei dati. Le frecce verdi rappresentano l'output del sistema. L'ottimizzazione viene eseguita sul server Energy Management System (EMS).
Dopo la raccolta dei dati, l'algoritmo di ottimizzazione può essere eseguito. Una volta determinata la soluzione, gli utenti vengono quindi informati su quale piano ciascuno dovrebbe scegliere per ridurre al minimo il costo complessivo della produzione di energia. Dopo l'accordo con gli utenti, l'EMS invia alla centrale la curva di domanda attesa.
Durante l'inizializzazione del DSM, gli utenti sono invitati a presentare fino a tre possibilità per svolgere le attività del giorno successivo (Piano 1, 2 o 3). Il piano di attività di ciascuno di essi è definito come un vettore di z ore, contenente in ogni ora l'insieme delle attività pianificate. Ogni utente presenta un piano principale e due

alternativi, per un totale di tre piani. Il *Piano 1* è considerato il più conveniente. Per l'elaborazione dei piani alternativi, l'utente è invitato a migrare le attività tra mattina e pomeriggio o nello stesso periodo. Una premessa fondamentale è che gli utenti presentino solo piani fattibili.

La curva di domanda aggregata è data dalla somma delle curve di domanda di tutti gli utenti. Pertanto, la curva di domanda aggregata avrà il suo formato modificato in base ai piani eseguiti da ciascun utilizzatore. Ogni combinazione di piani produce una curva di domanda aggregata. La Figura 5.6 illustra il ciclo di funzionamento del DSM, con inizio e fine nell'utente. In Figura 5.6 è possibile visualizzare i vettori dei piani di attività comunicati dagli utenti, i concetti di gruppi di attività e la stima delle curve di domanda. Sulla base delle curve di domanda, delle previsioni rinnovabili e dei parametri della centrale elettrica, l'algoritmo di ottimizzazione risolve il problema e restituisce la soluzione agli utenti. La soluzione è un vettore contenente l'identificatore del piano che ogni utente deve seguire per promuovere gli obiettivi prefissati. Considerata la soluzione trovata dall'algoritmo di ottimizzazione, la curva di domanda aggregata prevista per il giorno successivo viene inviata al gestore della centrale. Con queste informazioni l'operatore può gestire i generatori in modo più affidabile ed efficiente, come simulato all'interno dell'ottimizzazione. Alcuni o addirittura tutti i generatori possono essere spenti durante determinate ore del giorno, il che migliora il fattore di carico dei gruppi elettrogeni e riduce le ore di funzionamento dei generatori.

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[Team 23] Works and publications realized by the so - called "Team 23", a working group of which I was a part during my internship experience at *EGEA S.p.A*, whose purpose was to deal with the issue of benefit sharing.