

Energy Communities and key features emerged from Business Models Review

Gianpaolo Iazzolino, Nicola Sorrentino, Daniele Menniti, Anna Pinnarelli,

Monica De Carolis, Luca Mendicino.

Department of Mechanical, Energy and Management Engineering (DIMEG)

University of Calabria - Rende, Cosenza, Italy

gianpaolo.iazzolino@unical.it; nicola.sorrentino@unical.it; daniele.menniti@unical.it; anna.pinnarelli@unical.it;

decarolism@gmail.com; luca.mendicino@unical.it

Abstract

Climate emergency has changed the way of supplying energy, replacing fossil fuels in favour of a transition to renewable sources crucial for the system decarbonisation. This change has led to a review of the electricity consumption and distribution model. Recently end-users connected to distribution grids have taken an increasing active role in the electrical power system. Such a situation highlights how the combination between distributed generation-active user, through the concept of energy self-consumption that turns in energy sharing for a 'collective' form, allowed by virtual self-consumption, seems to be a good solution to achieve both climate targets and solve technical issues related to renewables penetration. Aggregation of end-users which produce and self-consume their energy within the same geographical perimeter express a new way to use renewable energy represented by the energy communities. The paper identifies the key elements that effect a business model for energy sharing by residential end-users equipped with small-scale renewable generation plants. In addition the simulation analysis investigate the feasibility from the aggregator point of view as well as the individual end-users evaluating also a minimum size for a viable renewable energy community.

Keywords: Energy Community, Energy Business Models, Prosumagers, Aggregators, collective Self-Consumption, Energy Sustainability

I - INTRODUCTION

Renewable energy sources (RES) have gained globally increasing importance, which will continue to grow in the coming years. During the last two decades, the energy landscape has faced a deep

change due to the continuous introduction of RES generation plants, such as photovoltaics (PVs) and wind turbines which have caused difficulties to manage their intermittent generation and as a consequence the balance of the entire power grid. For this reason, in order to guarantee the required balancing that the entire electrical system needs, on the one hand, distributed generation of energy communities in combination with storage systems have been labelled as a solution to provide local energy self-sufficiency, reducing the effort of conventional power plants; on the other hand, owing to the possibility of coupling with storage systems and demand response programs it can be used as a way to provide safety and grid services.

Recent studies, as the one performed by CE Delft of Blommerde, Kampman and Afma (2016), has estimated that, by 2050 almost half of all EU households might be involved in producing renewable energy. It is estimated that 37% of them will take part in energy communities, even more could provide demand flexibility with their electric vehicles, smart loads or stationary batteries.

The European federation of citizens' groups and cooperatives for renewable energy sources and energy efficiency (*REScoop.eu*) records a visible expansion of energy communities, counting across Europe around 3,000 aggregations.

For the first time, the European Commission has recognised the role that energy communities might play in the energy framework proposed with the Clean Energy for all Europeans package (CEP, 2015) as reported by the publication of the Directorate-General for Energy (2019). It estimates that by 2030 more than 50 GW of wind power and more than 50 GW of solar power could be owned by energy communities, representing respectively 17% and 21% of total installed capacity.

The meaning of the term "Energy Community" (EC) is really flexible and varied as it can involve different configurations, type of actors, used technologies and it is subject to the complexity network infrastructures management. As in general, an EC involves groups of citizens, social entrepreneurs, public authorities and community organisations who directly participate in the energy transition by jointly investing in producing, selling and distributing renewable energy.

Thanks to distributed energy technologies and consumer empowerment, ECs are an effective and cost-efficient way to meet citizens' energy needs and expectations regarding energy sources, services and local participation (EU Commission, 2018). Individuals and companies play an active role in the system due to the increase in the decentralization of electricity production allowing development of new business models. As decentralized configuration becomes more and more common, renewable energy based generation plants are more widespread in the electrical network. Renewable sources may be predicted but not controllable, so maintaining the balance between electricity generation and consumption is nowadays a difficult task to be achieved by an electric power system operator.

In this regard, it is important to separate individual self-consumption from the concept of collective self-consumption. Simple self-consumption is related to the single end-user who produces renewable energy for his own energy needs and can store (within defined bounds represented by the single house) or sell energy to the market. Collective self-consumption conversely, is based on a virtual model in which a group of end-users are able to produce, store and sell energy with other end-users that might be also in the same building (pure collective self-consumption definition). Regarding to ECs in general, it is known also as community self-consumption is referred to a broader context where a group of end-users are connected to the same Medium-Low Voltage (MV-LV) transformer substation (same distribution grid) but geographically distant from each other.

The regulatory requirements on self-consumption have outlined the path for the new concept of Renewable Energy Communities (REC). The current result is a long process that began during the years of greater development of RES but a strong push at the European level took place with the communication from the European Commission (2015) to the European Parliament (2016) delivering a 'New Deal' for energy Consumers. Within this document, the active participation of end-users in the electricity markets and the electricity exchange among end-users, is clearly established. In Europe, the main regulations that outline the path of energy communities have taken place very recently, between 2018 and 2019, with the aim of being definitively implemented by 2021.

The most important regulation that focuses on ECs in Europe was deployed with the review for 2030 of the renewable energy directive 2018/2001 of the European Parliament and the Council (also known as REDII) on promotion of the energy use from renewable sources in which detailed measures have been implemented with articles 21 and 22 (European Commission, 2018).

The role of the entity REC is legally recognized, defined as an entity that owns and develops projects aimed at the use of RES that have the rights to produce, consume, store and share energy; furthermore, accessing the electricity markets. The EC model development is based on a complex regulatory framework that temporarily prevents private networks for residential users in favour of a greater exploitation of the public distribution networks.

The ECs do not generally have their own distribution network but, for obvious reasons of natural monopoly, they exploit the public distribution network since it allows the widest possible market participation by strengthening local contexts.

The presence of a public electricity network capable of reaching all end-users guarantees a higher quality of the service and it represents an enabling feature which plays a very important role.

Within but also outside the EU, the ECs are a consolidated phenomenon and their development were encouraged by an effective financing system, by a clear regulatory framework specifying role of utilities, local authorities and consumers and by an adequate promotion and information. Building on the regulatory framework at the European level, each country has developed its own legal framework (Hannoset et al., 2019):

- **France** has consolidated high experience with citizen and community initiatives. A framework for “Communauté d’Energie Renouvelable” (CER) or ‘Renewable Energy Communities’ is introduced by the French Energy and Climate Law⁴³ (article 6bis A). The concept and associated rights and responsibilities are integrated in Book II “Demand-side Management and the Development of Renewable Energy of the French Energy Code”.
- In **Germany** citizen participation in the energy transition has a strong tradition. Ownership of renewable energy by single owners or communities dates back to the early 1970. Energy

communities in Germany takes a variety of legal forms. The German Renewable Energy Source Act 2017 (EEG), section 3 (15) defines the concept of “Bürgerenergiegesellschaft” or ‘Citizens’ Energy Company’.

- The **Netherlands** is another country with a rich history in energy cooperatives. Today several energy associations and cooperatives exist in the country. Article 7a of the Dutch Electricity Act 1998 provides the possibility for pilot community energy projects to experiment with developments in relation to production, transport and supply of decentralized generated sustainable electricity as well as grid ownership through derogation from the Dutch Electricity Act.
- **Portugal** has a tradition of energy cooperatives owning and managing distribution grids, operating in individual municipalities and autonomous regions. Portugal has recently adopted the Decree-Law No. 162/2019 aiming at promoting and facilitating self-consumption and renewable energy communities by removing obstacles and creating conditions for the establishment of innovative solutions.
- **Italy** released several legal acts in order to allow the ECs to be more diffused. The regulation Authority for energy, networks and environment sector (ARERA) with the decision of April 1st 2020 proposes the regulatory model for self-consumers acting collectively and for “Renewable Energy Communities”. Other decisions were implemented over 2020. On December 2020 the technical rules for accessing shared electrical energy services were established. Since the beginning of 2021 the first renewable energy communities and collective self-consumption were deployed.
- **Spain**, following approval of European Directive REDII, was the first country to introduce the possibility of collective self-consumption, in the same year, with royal decree law 15/2018. This opened up the possibility of sharing energy without the need for a private distribution grid.
- **Denmark** is a notable example of collective investment in renewables since 1970. Its foresight allowed the country to reach 80% of wind turbines installed under community ownership by 2013: and today the renewable energy capacity of Denmark has thus become one of the highest in the

world. Since 2012, Denmark has also made significant progress in the photovoltaic sector. The federal government deals with matters associated with energy and definition of agreements with utility companies for connection to the grid. However, these companies are not just partners, but rather co-owners of the projects. Since 2009, the Danish Renewable Energy Act has reduced the portion reserved to co-operatives to 20% of new wind-power generation projects.

Outside the EU, many other experiences of energy communities have already been carried out or they are emerging, for instance:

- In **Australia** a significant reform package is under consideration by the Australian Energy market Commission (AEMC) to streamline the participation of DER in the National Energy Market (NEM). Although Australia is a world leader in the installation of rooftop solar and solar conditions are the best if compared to many other countries, growing of energy communities is still in the beginning phase. The federal government also has two agencies that provide grants or funding to renewable energy sector:
 - The Australia Renewable Energy Agency (ARENA) which played a key role in the last decade in the development of utility-scale renewable sector.
 - The Clean Energy Finance Corporation (CEFC) which is a dedicated financier to renewable and green projects.

Since 2012 the agency ARENA started with the model of Community-Owned Renewable (CoR) projects very similar to the REC. Despite there is no precise regulation in this regard, there are several emerging projects by private agencies who propose to the government figures of making consumers self-sufficient through pilot projects. It is worth to underline the Community Power Agency (CPA) that partners with communities, government and industry to develop projects and research designed to create a clean, affordable and accessible energy future for everyone. Another peak body is the Coalition for Community Energy (C4CE) for the growing community energy sector in Australia

Community energy projects have spread as they did in the UK, particularly along the coast and in areas poorly served by the national grid and today, there are more than 100 energy communities across the country. Currently, ARENA (Australian Renewable Energy Agency) has assigned funds to support shared-energy programmes nationally. These programmes will be even more valuable for their contribution to identifying a solution for supply stability, which has seen a crisis in recent years after catastrophic events (such as the 2016 tornadoes).

- In **California** they are becoming disruptive experiences following a law of 2002 that made it possible to set up the Community Choice Aggregations (CCAs) also known as municipal aggregation. CCAs, are programs that allow local governments to procure power on behalf of their citizens, businesses and municipal accounts from an alternative supplier while still receiving transmission and distribution service from their existing utility provider. CCAs are an attractive option for communities that want more local control over their electricity sources, more green power than is offered by the default utility and lower electricity prices. The ECs often guarantee lower rates than electricity supply companies. In such a way, 160 cities and counties in the USA have grouped into 19 CCAs, serving 10 million users who are progressively subtracting market from the electric utilities that fear losing 60-80% of their electricity demand in the next 8-10 years. Furthermore, ECs encourage procurement from renewable sources and are decisive in achieving the ambitious climate goals. In fact, since the 2000s, they have become established as a new paradigm for citizen engagement in the energy transition, supported and facilitated by the liberalization of the energy markets. Given the existence of several possible EC configurations, the purpose of the paper is to investigate if one of the community configuration guarantees a greater probability of success considering that it is necessary to adapt the model to the EC context in which it has to be applied. General aspects of ECs related to their spreading out have also been investigated. The main contributions of the paper are:

- to illustrate a comprehensive and detailed explanation of the EC model and general aspects.

In this regard the paper introduces a rich state of the art by explaining the topic carefully;

- to illustrate a comparison among business models for ECs that use renewables. In this regard the paper shows how the topic emerged in different countries and how it developed in recent years;
- to describe the different kinds of R&D projects in the field of the ECs focusing on the scenarios that can be useful for the EC business model;
- to fill the gap in the literature providing which features are important in the EC business model and which of them prevent and support the implementation of ECs;
- how the highlighted features affect a business model focused on small scale residential end-users that share energy within an EC. By mean of a standard framework as the Canvas the paper clarifies the value proposition to perform a subsequent cost-benefit analysis;
- to fill the lack of detailed simulation with results on the research topic giving information about the effective size of ECs;
- to provide useful suggestions for end-users, investors, aggregators and national regulators to favour the spreading out of ECs.

The paper is organized as follows: in section II a state of the art about REC with a set of the main European projects and aspects related to regulatory at European level are presented; Section III focuses on the self-consumption of virtual communities; while section IV proposes a business model configuration for RECs and CECs; Section V presents a more detailed cost-benefit analysis for a possible EC configuration; finally, the paper concludes with a discussion of the general results and possible future suggestions for EC regulatory authorities.

II - STATE OF THE ART

As underlined by the growing literature of Becker and Kunze (2014), Bauwens (2016), Hicks and Ison (2018), since the end of the 1980s with different timelines, regarding renewable energy sources new forms of collective involvement have emerged worldwide and in Europe. The sociological literature has carefully analysed how development since the 2000s and the term "community

renewable energy" has been established to describe it internationally as reported by Walker and Devine-Wright (2008).

The ECs, challenge the current paradigm of centralized production and move towards a more flexible system suitable for managing the intermittence that characterizes RES. As confirmed by the increasing literature of Steinke, Wolfrum and Hoffmann (2013), Braff, Mueller, and Trancik (2016), Helm and Mier (2019) in order to overcome problem of intermittence, a possible solution is represented by energy storage to satisfy both demand and costs reduction. The coupling between shared renewable energy systems and spreading out of energy storage systems, in particular, electrochemical batteries, is becoming one of the most disruptive influences within the electricity sector as stated by Agnew and Dargusch (2015). Small-scale solar installations are rapidly increasing on distribution grids and the coupling with electrochemical storage systems such as lithium batteries (or similar) will become standard by the 2030s as depicted in Figure 1 reported by *BNEF*. Owing to the continuous scale-up of electric vehicles and the electric vector in residential consumption, demand for renewable energy increases and it will drive down the cost of batteries. As costs fall, batteries can be increasingly used to store solar power. In case of expensive electricity markets, e.g. the spot markets that frequently attract speculators, prices are known to the public almost as soon as deals are transacted and thus energy prices are subject to large price variations (Gil-Alana et al., 2020).

In such energy markets where prices are very unstable, battery energy storage systems (BESSs) for solar installations already make economic sense. In addition if it is considered the decrease of generating capacity able to offer services to the grid, that can be provided with BESSs, it will not be long before that energy storage becomes a standard technology and by 2030 will be as ubiquitous as rooftop solar installation is today.

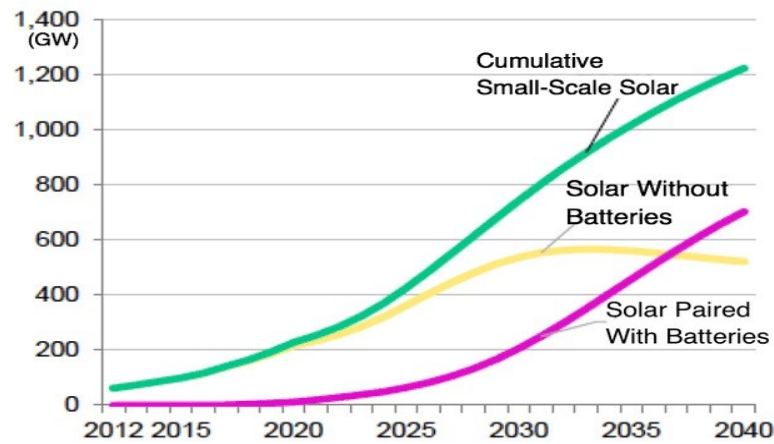


Figure 1: PV and BESs development

(source: Bloomberg New Energy Finance - BNEF)

Increasing energy consumption simultaneously when the generation by RES is available, is the most suitable solution to increase energy matching and as a consequence energy self-consumption. Within a well-defined area, the energy absorbed by a group of end-users facilitates the total self-consumption increase. In fact, with more than one end-user the chances of consuming energy when renewable generation is available increases the collective self-consumption. Group of end-users aggregated in EC also positively affect the related costs, for instance, Parra et al. (2015) showed how the Levelized Cost Of Electricity (LCoE) can achieve a possible reduction value between 29% and 44% with a transition from a single family to a five-families community.

As shown by Fares and Webber (2017), inefficiency of domestic energy storage can lead to an increase in electricity consumption and indirectly to an increase in emissions.

On the other hand, the best situation is returned when the use of energy is coupled with BESSs that allow end-users to exploit energy produced in different time periods or when generation is not available. Such approach for a single end-user, is generally performed by a Battery Management System (BMS) that optimizes energy usage and operations. In a community approach, energy management platforms take particular emphasis since allow energy storage and energy consumption to be optimized based on economic evaluation and energy trading actions. Nowadays, energy ICT platforms are effective implementation tools to manage and control ECs.

Regarding the economic and social sustainability, several start-ups have emerged as confirmed by the work of Iazzolino, De Carolis, and Clemeno (2019) and an increasing number of R&D projects aim to a market structure and business models for prosumers in EC as reported by Sousa et al. (2019).

A deep review of recent business models as enablers of the increasing prosumers' role and of enabling technologies to properly sustain new prosumer driven markets is provided in Botelho et al. (2021).

Several start-ups were developed by R&D projects that address community energy trading by focusing on the following business areas:

(i) Peer-to-peer energy surplus exchange (Mello et al., 2020), where prosumers can exchange the energy that excess their energy consumption with neighbours (e.g. *LO3 Energy*, *SonnenCommunity*, *Hive Potenza*, *OneUp*, *Power Ledger* are some of companies that perform such kind of energy operations); (ii) Energy provision/matching where prosumers can directly choose local renewable generation (e.g. are the companies *Vandebron*, *Electron*, *Piclo*, *Dajie*, *Powerpeers*).

Moura and Brito (2019) have investigated different models already put into practice by citizens, entrepreneurs, technology companies and conventional utilities. These models can help gather knowledge from experience to let us understand trends and also the challenges surrounding the energy exchanges and EC concept, allowing better information to shape policies and EC regulatory design. These sets of different case study models, show a multitude of ideas, benefits and limitations the energy system might have to face.

As shown in *Table 1*, some projects developed within different regulatory frameworks may (or may not) legally consider a prosumer aggregation policy, virtual metering mechanism or even a self-consumption policy.

Table 1: Example of several R&D projects reported in the literature

PROJECT NAME	MAIN OBJECTIVES
<i>P2P-SmartTest</i> :	It deals with distributed control with advanced ICT technologies to enable local markets on the distribution network.
<i>EMPower</i> :	It is related to a development of a real-time platform based on cloud technology to perform measurement and trading within a local community (local control).

NRGcoin :	Development of a blockchain-based virtual currency and smart contracts for small prosumers trading in P2P markets.
Enerchain :	Development of a P2P trading platform to supplement or replace the wholesale electricity market (market design proposals).
Community First Village :	Building a self-sufficient community for the homeless.
PeerEnergy Cloud :	Cloud-based energy trading for excessive production.
Smart Watt s:	ICT to control consumption in a safe way.
NOBEL :	ICT for the energy brokerage among consumers.
Energy Collective :	Distribution of local P2P markets in Denmark.
P2P3M :	P2P prototype Energy trading / sharing platform.
CleanEnergyCollective :	Energy generation shared by man of virtual metering. It develops programs such as RooflessSolar which allows users to invest in medium-scale solar systems for self-consumption or SolarPerks, in which the user does not make any investment but pays for the purchased energy.
SOM Energia :	Pproject of 2MWp Solar plant
Piclo :	The UK's first online marketplace for renewable energy that allows you to buy and sell energy directly at agreed prices.
Sonnen :	Is a community of Sonnen battery owners who participate in peer-to-peer energy trading through an "aggregator" and virtual metering scheme.
ComESto :	Integration of different energy storage systems and generation from renewable sources to encourage the active participation of end-users, owners of small civil users, in the wholesale and retail energy markets.

The case study of some demonstrative projects in Germany and Australia led by Müller and Welpé (2018), discusses what makes the projects similar. In addition to the value proposition that drives the increase of self-consumption is the funding solution which often derives from public subsidies.

Some projects use the public distribution network, despite highlighting important regulatory barriers and aiming at a target represented by families who can potentially own PV generators on the rooftops of their homes. In such a case, families bear the costs of ICT systems or applications so that end-users can manage self-consumption when they are away from home. Some other projects are aimed at the integration of determined user groups and the difference in customer segments is also reflected in the infrastructure.

Storage projects that target single households with existing PV plants do not manage the PVs since they are the property of the end-users.

Conversely, for the categories of other projects, it is the aggregator that manages the energy production systems such as PVs and BESSs but this configuration requires a substantial financial capital available.

ECs have to overcome several barriers, of an economic, financial, legislative and legal nature, which hinder their development and growth as reported by Gorroño-Albizu, Sperling, and Djørup (2019),

Mirzania et al. (2019). From the cited study of Müller and Welpé (2018) which investigates the barriers that the pilot projects are facing on the energy market it seems that no social, cultural or behavioural obstacles arise. The main barrier derives from the lack of an adequate regulatory framework for the use of the public distribution network, which slows down the adoption of shared models, and from the costs of technological systems that reduce the possibility of obtaining a sufficiently profitable business model.

The energy model based on EC promises positive solutions but there are several barriers that make the implementation difficult. They can be summarized in four categories: technological, socio-economic, environmental and institutional barriers.

Table 2: Detail of barriers related to the implementation of the community model

A - Technological	B - Socio-Economic	C - Environmental	D - Institutional
1. Intermittent generation from RES and load fluctuation; 2. Low energy efficiency; 3. Costs and duration of Storage that compromise recovery times; 4. Local balancing between generation and load (local 'matching' degree); 5. Flexibility of demand within the community and impact on the largest energy systems (regional and national); 6. Reliability of the network and load (general decrease in demand but increase in power peaks). 7. Rapidity of technological Development . 8. Costs of technologies.	1. User awareness of their role in the electricity market; 2. High propensity of users to remain passive (consumers); 3. Economic incentives to invest in technologies; 4. Willingness to pay extra for locally produced green energy; 5. Lack of access to energy; 6. Cost-benefit problems for the same actor (between who makes the investment and who gets the benefits); 7. Energy poverty (in developed countries it relates to low-income users who cannot afford energy to cover their needs or increase it); 8. Security of energy supply at local level; 9. High initial costs and financing of the initiatives.	1. Awareness of climate-related issues and objectives to be achieved; 2. Incentive to considerably reduce emissions for users; 3. Management of waste and product reusability (BESSs recycling); 4. Problems related to public or private spaces for the installation of systems owned by the energy community (photovoltaic and / or wind systems require a lot of space, especially if the reference context is the city).	1. Lack of trust and motivation of users; 2. Energy democracy (creation of decentralized structures); Transformation of the system into a decentralized system which entails the related problems for the network operators; 3. Ownership of the model; local participation both private and public; 4. Lack of suitable legislation, incentives and support schemes; 5. Governance of the local distribution network, difficulty in management of the self-regulation and EC Sizing; 6. Management of the contractual relationship with users of the energy community.

The slowdown in the development local ECs is not much related to the lack of new available technologies for controlling resources as to the start-up phase of the energy community. Up to now there have been an undetailed legislation and contractual arrangements, which regulate the

relationships between the EC manager and the aggregated end-users. The main difficulties identified for the development of ECs are represented in the following points:

- 1) High initial investment costs (A.8-B.9) related to the transformation of end-users in active users (from consumer to prosumer or prosumager) and the start-up phase of the local EC;
- 2) Socio-cultural barrier (B.1-C1) that refers to the users' awareness about electricity market and climate issues;
- 3) Regulatory barriers (D.4-D.5) that regulate EC management in detail;
- 4) Contractual schemas (D.6) suitable for managing the relationship between the EC manager and the end-users.

Regarding the barriers in 1) represent a limit that must necessarily be exceeded if the medium and long-term goals set for the enhancement and growth of renewable energy and energy efficiency are to be achieved. In this sense, European government is investing huge resources (e.g. Recovery fund resources) in scientific and applied research to develop new products and technologies that favour the rational use of energy, the development of countries based on a green economy based on low carbon emissions. Investment costs is an economic barrier and represents an important topic of the business model since the construction of distributed or centralised RES plants as solar or wind turbines require relevant amount of financial resources. A direct obligation of end-users in RES plant construction limits a lot the development therefore it is preferable a solution where a third party is involved in the business model and it is accountable for the RES plant construction.

A suitable approach to overcome the limit the hardness to find financial resources could be based on the crowdfunding or thorough the capital of a large investor able to set up the generation plant that get all or part of the revenues until the generation plant is fully repaid. After that it could be left fully available to the end-users. In such a case, the large investor gets back the financial resources invested plus an amount that remunerates the capital.

The certainty of the profitability of capital is therefore fundamental and it derives from the quality of the technologies and the continuity of the incentive regulations and authorization. Tax deduction (B.3) or incentive on emission reduction (C.2) might be another relevant part of regulation that could play a key role in payback time reduction and foster the ECs development as provided in the regulatory frameworks for energy communities.

As for the socio-cultural barriers in 2) We can also find a barrier in the culture of people. Energy efficiency in terms of savings, often comes into conflict with the cultural elements of a population. Energy consumption is an identifying element that refers to specific local identities. In fact, for example lighting of a house expresses, prestige, comfort, the ostentation of well-being. In the same way the lighting of a city and its monuments, represents the urban lifestyle and prosperity of a city. For these reasons often the sources of renewable energy and energy efficiency are associated in the collective ideas with a minimalist lifestyle, conditioned by savings, limitations and sacrifices. It is necessary to implement information actions aimed at raising awareness and making known by dispelling useless and empty prejudices, which are often at the basis of the so-called ‘NIMBY’ phenomenon. In this regard, incentive regulations to local ECs can avoid NIMBY’ phenomena.

The barriers in 3) are represented by political barriers, in fact that national regulations are late in transposing European and international directives, as well as the necessary elements to inform and guarantee businesses and citizens on the effectiveness of the investments. It would be desirable that national legislative platform was in step with the times of the European and global one. These discrepancies affect national and regional energy planning through delays, slowness, inhomogeneity of procedure. Sizing criteria is another issue to overcome in developing energy communities but regulators at the moment do not provide suggestion about type and number of end users to make an EC feasible. Nowadays an important limit is represented only by the aggregation perimeter which is a defined geographical limit under which it is possible to aggregate end-users delegated to each country. For example in the Italian case, currently, perimeter is represented by the same MV-LV

transformer substation. Some end-users might be suitable to share their electricity but could be connected to different MV-LV transformer substation therefore should be allowed to aggregate users under the same HV-MV transformer substation to facilitate the energy sharing within the ECs. A lot of studies suggest abandoning electrical criteria of the MV-LV substation in favour of a geographical criterion.

Finally, regarding the last relevant barrier in 4) there are no specific instructions on how to manage internal actions among the community members and the EC management entity. General recommendations are only referred to provide environmental, social and economic benefits that must be reported in the internal EC statute and regulations, rather than the distribution of profits.

III - FROM SELF-CONSUMER TOWARDS COMMUNITY SELF-CONSUMPTION

Producing and absorbing energy on-site is the best choice to put into practice exploiting of the available resources locally (physical self-consumption). Up to date, self-consumption has always been considered as an individual matter, only allowed in the presence of a single end-user with on-site generation plant and consumption. Physical configuration is also well known as ‘behind the meter’.

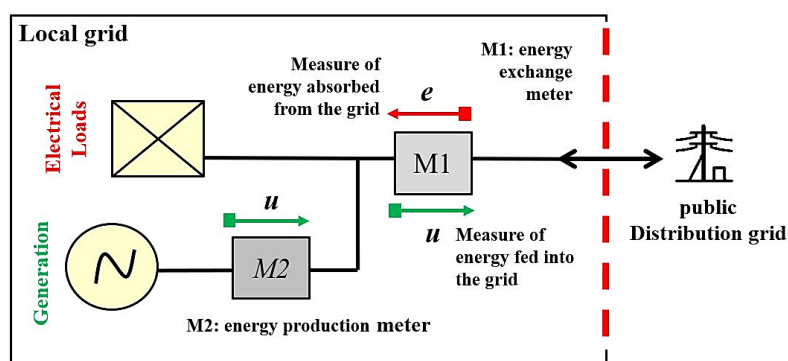


Figure 2: Behind the meter configuration (source: figure of own production)

With the new approach based on energy communities, the physical configuration as showed in Figure 2, is moving towards the new concept of ‘virtual’ self-consumption. Supported by recent technological developments of smart metering, the virtual self-consumption is the energy generated,

fed into the grid and simultaneously absorbed by different end-users within the same portion of the distribution grid. It is considered equal to the on-site self-consumption, increasing collective advantages and several benefits for the local distribution grid.

In general, in a specific time interval, the community self-consumption is given by the minimum value between the sum of all end-users' consumption and the total renewable generation of the same EC. Considering Figure 2, the generated energy fed into the external grid which is, in the same time interval, absorbed by a different end-user of the EC, is considered as a virtual self-consumption and a take part in the calculation of the energy sharing of the EC.

Energy sharing is also a model where citizens intentionally can exchange locally produced power with one another (peer-to-peer) or external markets.

European Directive 2018/2001 (REDII) defines peer-to-peer trading of renewable energy as: *“The sale of renewable energy between market participants by means of a contract with pre-determined conditions governing the automated execution and settlement of the transaction, either directly between market participants or indirectly through a certified third-party market participant, such as an aggregator.”* New smart metering devices and ICT energy platforms make it easier to understand and calculate the energy sharing related to virtual self-consumption, matching the produced energy and end-users consumption within the same section of the distribution grid, under the same MV-LV transformer substation.

In Spain, for example, the concept of proximity consumption has been already introduced today. In other words, the REC might be seen as a unique large consumer made-up of a set of several end-users, which establish an 'enclave' within which there is a sort of renewable energy sharing produced by RES. Aggregated users in a community have the opportunity to join together in order to facilitate the installation of renewable generation plants for the production of energy from RES. Thus, end-users can also share the self-produced energy excess and make it available to the aggregation, as long as all the users involved are connected to the same public low voltage distribution network. The main objective of the aggregations is to increase both individual and community self-consumption acting

on electrical behaviour or installing storage system that allow simple consumer to become consumagers and, the active-users prosumers to become prosumagers.

In particular development of BESS determined the rise of this new figure, the consumager, which plays an important role for the community (or collective) self-consumption since it does not produce energy but when it is required by the community (e.g. through a signal sent by enabling technology) it can absorb energy, increasing the percentage of community self-consumption.

After all, end-users' aggregations in ECs aim the target to provide a social mission with respect to a financial scope, which consists in providing environmental, economic and social benefits to their participants and to the related geographical area, without losing outside the EC the renewable energy produced. Despite the possible configurations of ECs might be different (for example, a large generation plant for several users or, small size distributed generation plants directly connected to the single end-users) main focus is on the configuration type composed by a multitude of small prosumers aggregated by a third party that takes the role of REC management entity, thus the aggregator.

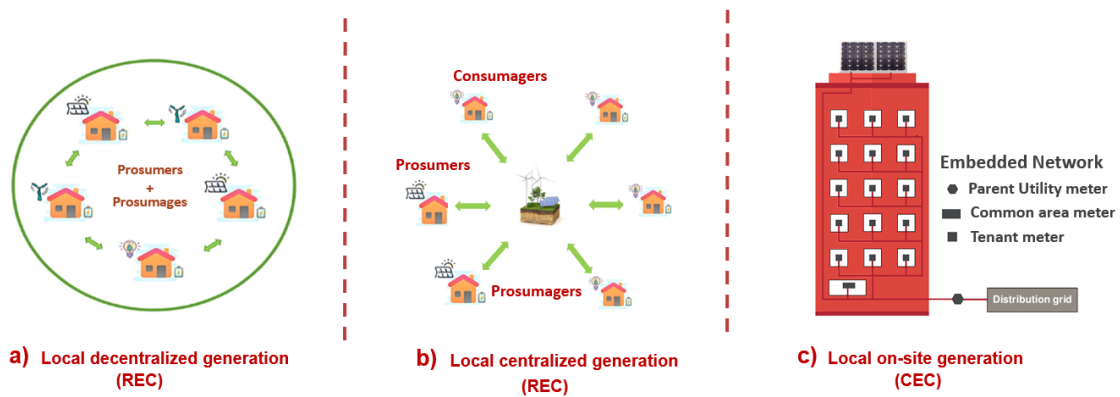


Figure 3: Possible EC configurations (source: figure of own production)

With regard to the REC model, as showed in Figure 3 different configurations exist.

The configuration labelled with a) refers to the EC where the produced energy comes from several small generation plants spread-out within the community and each facility is installed on the users' location which participate to the EC.

The configuration labelled with b) refers to the EC where the produced energy comes from the only or few large generation plant within the community and the REC plant is considered as a single producer. In such a configuration the facility is connected to the same MV-LV transformer substation. The configuration labelled with c) refers to the EC where the group of end-users that participate to the community are physically grouped in a single building that is equipped with a generation plant. In such a configuration energy sharing is facilitated due to the proximity between energy consumption and energy generation allowing, in case of right sizing of facilities, the concept of net-zero energy systems (Voss et al., 2016).

Another configuration considered by the European directive of internal electricity markets 2019/944 (European Commission, 2019) is recognized as Citizen Energy Communities (CEC) configuration. In such a configuration, similar to c) in Figure 3 where several end-users are located in a single building or spread out on a larger area, the property of the distribution grid could be private.

Despite CECs are as quite relevant as RECs mainly in the closed distribution networks, in reality this approach shows several problems if compared with RECs where the grid management is delegated to a DSO. Basically a CEC is quite similar to a REC with the difference that the connection among the aggregated users within the energy community is realized through a private distribution network while in a REC each user has its own point of connection and share electricity with other end-users through the public distribution grid. The CEC can manage directly its distribution network and therefore has no distribution fees. It has the rights to organize within the energy community the sharing of electricity produced by the generation plants owned by the community and other rules and it can be seen as an active user respect to the public grid. REC model is really similar but users are physically distributed and connected with public distribution grid (regardless if concentrated in a single building or on a larger area). In a perspective view regarding the future electricity services that energy communities can provide to the power grid, interest towards REC and CEC is deeply increasing as reported by the regulation 2019/943 on the internal electricity market. Internal

electricity markets will help the power system to become more and more self-sufficient requiring less and less contribution by large power plants.

In fact, these configurations are an input to the Local Energy Communities (LECs) and the respective Local Energy Markets (LEMs), whose development was favourably considered at the global level. In fact, the execution of LEMs incentivize the development of RECs and community self-consumption, stimulating competition and energy costs reductions.

In line with the view of adapting to European legislation about ECs, the possibility of creating LECs is particularly favourable for encouraging self-production and local distribution of energy in a context that points towards energy self-sufficiency and Zero-Power Systems (ZPSs) where the quantity of energy produced locally by the community in a given time interval is completely self-consumed.

In maximizing community self-consumption, users' energy excess is used to meet the other end-users' energy needs in order to minimize the exchange of energy outside the geographical perimeter of the EC with the main electricity grid (see Figure 4). In this way, the total community self-consumption is the minimum value between the total load and the total generation within the energy community, increases.

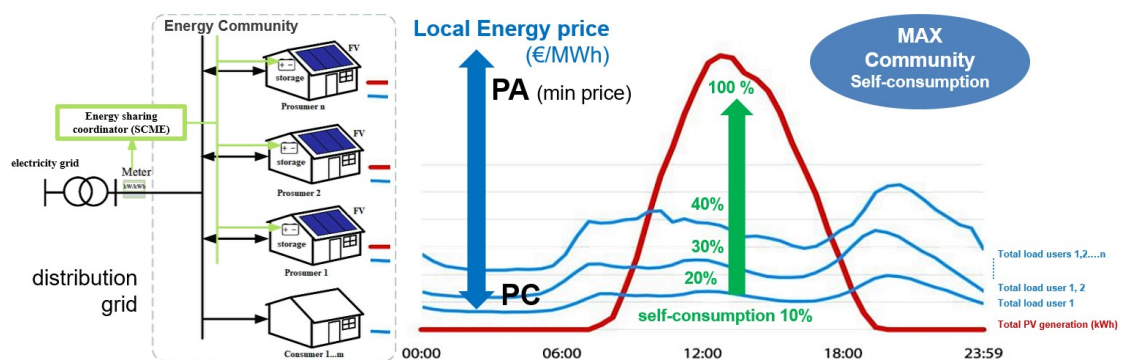


Figure 4: Single and community self-consumption

(source: figure of own production)

While the original concept of energy community aims to maximize collective self-consumption to gain environmental, economic and social benefits, the current market context aims to attain economic-financial objectives as well. Recent concept of the energy community, following the needs of RES

integration within the electricity system also aims to associate additional services related to the conscious use of energy by individual end-users. The ECs when managed in an aggregate way, can provide an important contribution to the distribution grid to which they are connected such as the congestion management on the distribution network described by regulation 2019/943 of the European Commission (2019) and voltage regulations.

IV – THE PROPOSED BUSINESS MODEL

With the aim of attracting more users and thus increasing profitability (generating higher revenues and sharing the investment costs) innovative business models have been proposed in the literature. For example, the summary of the different four scenarios proposed by Tang et al. (2019) is based on business models with energy sharing and it shows an economic analysis on photovoltaic systems but is combined with distributed battery storage system and contains important considerations on the overall economy of the shared energy storage systems. An energy sharing model is proposed where the existence of two types of end-users returns four types of different scenarios:

In *Figure 5*, a) and b) show the concept of physical self-consumption without the use of ESS (S1) or with the use of ESS (S2); in addition, scenarios consider separately the different clusters of end-users, large consumers (or prosumers) and small consumers (or prosumers) which operate independently for local consumption and do not provide any energy sharing. In c) with the same approach, S3 considers each cluster equipped with ESS that exchanges energy only among the users of the same cluster. Finally in d) the mechanism of EC is applied where energy generation is shared among different types of users and can reduce the electricity costs of the whole energy community, for simplicity there is no ‘clusterization’ of users. In particular, S4 improves the self-consumption ratio because the energy exchange among different types of end-user increases the opportunity for the members of the community to absorb the total generation. It indicates also a possible way to mitigate the financial charges associated with the ‘feed-in tariff’ schemas.

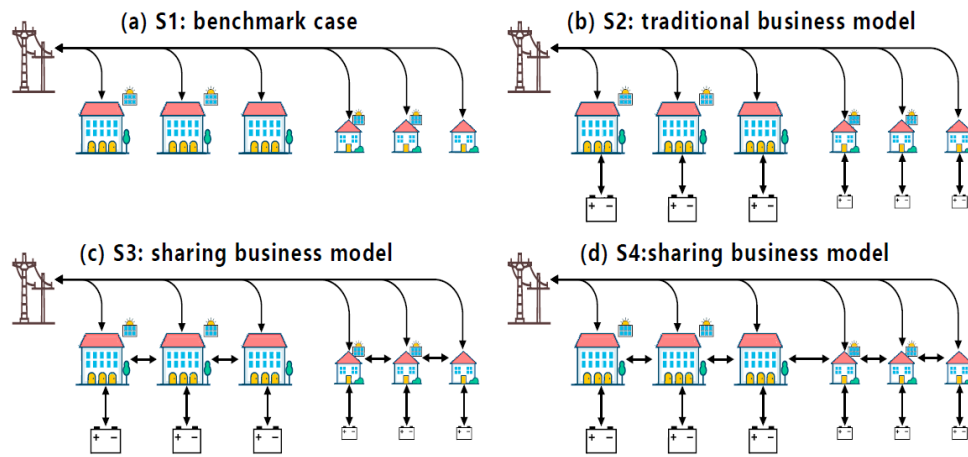


Figure 5: Schematic illustration of the different possible scenarios

The architecture of the model is determined by available technologies, regulatory and market frameworks, as well as the technical standards adopted for the distribution networks. In this case, a coordinator that represents the legal entity of the community is required: it may be considered as Aggregator or a facilitator.

As part of the proposed business model, taking into consideration one of the mentioned scenarios, householders belong to the energy community, which is represented by all the residential end-users connected under the same MV-LV transformer substation, sharing energy among them as depicted in *Figure 6*.

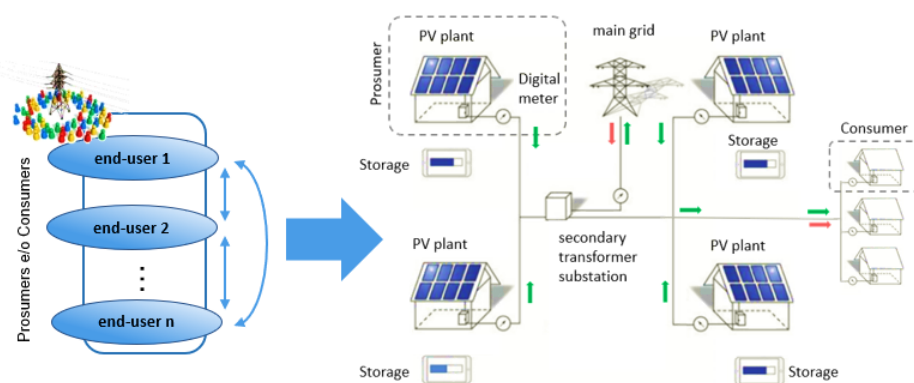


**Figure 6: Electricity sharing among end-users of the same type, as in case c) or (S3)
(source: figure of own production)**

Within the above mentioned physical configurations, an energy service entity or EC manager as the Aggregator, needs to calculate per each time step (e.g. hourly basis) the energy shared within the

community by means of the information given by the local metering devices that belong to the DSO as shown in the following *Figure 7*. In addition to the DSO information used to calculate the total community self-consumption, the smart metering devices interfaced with the ICT platform can be used to evaluate, with an internal agreement and rules, the contribution of each member to the total community self-consumption

As cited by Menniti et al. (2020) in ‘*Management model of Nanogrid-based Community Energy Storage*’ the operation of the local energy market might be managed by an Aggregator or its related entities. Regarding the grids, DSO manages the public distribution grid as normal and the Transmission System Operator (TSO) the related transmission grid.

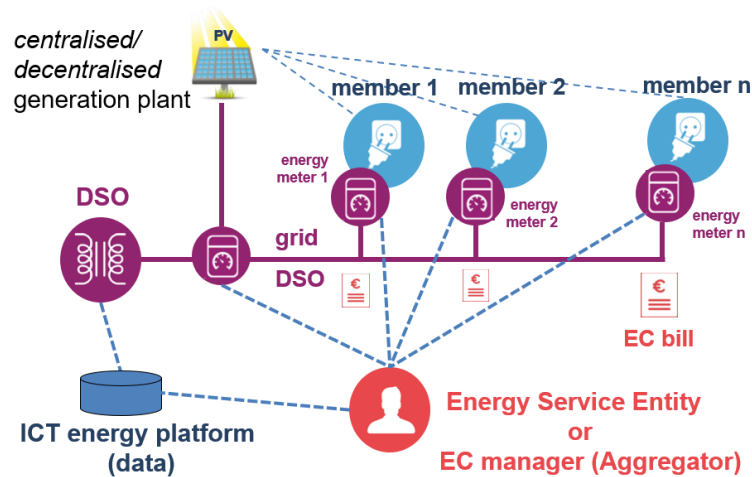


Figure 7: EC framework to evaluate energy sharing among community members

For the energy injected and consumed on the DSO distribution grid, the end-user remains free to keep his own electricity supplier (ESP) regardless of the entry or exit of the community at any time. On the other hand, as regards the internal relations with the REC (distribution of benefits, contributions, etc.) they are regulated by a private agreement and there are no regulatory models imposed for the internal management of the energy community.

Financial Benefits:

On the energy produced and self-consumed within the perimeter of aggregation, a benefit contributions is provided that can be of four types:

- *Direct incentive*, on the shared electricity within the Energy Community. The shared energy is the amount of energy produced and not used locally thus fed into the grid, which is instantaneously absorbed by another member of the community. The value of the incentive is established by each country which determines a variable amount on the kWh produced and consumed within the EC in the same time interval;
- Remuneration of energy fed into the distribution network valued at wholesale national market price;
- Indirect contribution, intended as the return of transmission tariff components included in the distribution components;
- Contribution to grid losses, only in the CEC configuration schemas and as a function of the voltage level.

Network Benefits:

The energy injected and consumed on the same distribution grid perimeter gets benefits that go over the financial meaning. The benefits of the system owing to self-consumption in any of its possible recognized forms are related to the reduction of network losses, connection to the network, networks development, or dispatching.

To date, network losses are the only real and valid recognized benefit. Other benefits are hypothetical, still being studied and analysed by researchers on Energy Systems (Koirala et al., 2016). The recognized reduction of network losses, is due to the reduction of power flows on the network to the production of electricity geographically close to the consumption point compared to the case of production geographically and electrically distant from consumption. This effect is enhanced in the current regulation through the flat-rate increase of the electricity fed into the MV-LV networks by applying a coefficient that estimates the losses as a function of the voltage level of the network. For instance, in Italy the coefficient is 2.3% in the case of MV plants and 5.2% in the case of low voltage LV connected plants.

For connection to the grid, the energy produced and simultaneously consumed on site could optimize the use of the MV-LV transformer substation by reducing management and maintenance costs. Distribution networks are generally sized to guarantee the required power for each connection point. For this reason self-consumption prevent the upgrade of existing networks, thanks to the reduction of the maximum power peak required at the connection points and prevent the creation of new networks. Self-consumption could also reduce dispatching costs but there is no certainty on this aspect currently, in fact for this reason the TSO (e.g. Terna in Italy) in sizing the secondary reserve necessary to operate the system safely considers the total internal load including self-production.

Use of the public network in the model involves particular features, cost and revenues items which must be taken into consideration within the proposed business model of the energy community. For the proposed business model, all the actors involved, the value proposition and other key elements were identified as reported in the following *Table 3* and *Table 4*.

Table 3 - Most important features of the proposed business model

Energy sharing among residential users by mean of the public distribution network	
Value proposition	Increase in community self-consumption (or collective self-consumption)
Customer segment	Prosumers - prosumages in a proximity context (relevance of the geographical position) with the presence or nor of consumers-consumagers (depending on the adopted configuration)
Communication channel for customers	Electricity supplied through the public distribution grid, energy information through (virtual) smart metering, management and monitoring platforms, enabling technologies
Customers Relations	On site and virtually through the management and monitoring platforms
key resources	RES generation plants, battery storage systems, smart meters, enabling technologies
key activities	Storage of renewable energy produced by users and instant generation-consumption
key Partners	DSO for public distribution network use, Aggregator, TSO and Aggregator.
Revenues streams	Supply of energy in self-consumption and / or from the grid, margin on energy exchanged within the energy community, rent use/sale of technology, other grid services.
Costs structure	CAPEX and OPEX for asset installation, energy management costs, software platform costs, network charges, taxes and duties.

A study on the main actors involved operating in the proposed business model and their interests in achieving an energy integrated system was carried out.

Positive and negative features related to the several business models analysed during the research activity have been taken into consideration to define improvements within the proposed business model in the following. To understand the value created by the proposed business model, the 'Canvas' framework was used and applied to the proposed business model. Canvas framework represents a method to understand the business operation which otherwise would be rather complex to understand. Through the analysis of nine standard blocks provided by the framework, the items that contribute to the overall sustainability of the model were identified and briefly summarized below.

Table 4 - Framework Canvas applied to the proposed business model

Framework Canvas		<i>Designed for: Power Cloud project. Application of the model for an Integrated Community Energy System (ICES).</i>		Designed by: Luca Mendicino
<u>Key partner</u>  - Consumers; - Prosumers; - Consumagers; - Prosumagers; - Energy Suppliers; - Other energy producers. - Aggregators; - DSO; - TSO. (Meaning: Anyone who helps the energy community increase its business)	<u>Key activities</u>  - Local generation; - Energy consumption; - Energy Storage; - Instant consumption; - Collective purchases; - Operation & Maintenance. (Meaning: What are the main activities that create value within energy community?)	<u>Offered value</u>  - Renewable energy; - Avoided costs; - Burden reduction; - Revenues in energy efficiency; - Pollution reduction; - Energy self-sufficiency; - Community self-consumption (Meaning: What are the products and services offered by the energy community that create value for customer segments?)	<u>Customers Relations</u>  - Monitoring platform; - Energy supply service; - Transformation into prosumers users; - Participation to the electricity market. (Meaning: What are the products and services offered by the energy community that create value for customer segments?)	<u>Customers segments</u>  - Final end-users; - Consumers ; - Consumagers; - Prosumers; - Prosumagers; - DSO; - TSO. (Meaning: For whom are we creating value? Who are the most important customers?)
<u>Costs structure</u>  - Financial investment (capex) to install technology on end-users' locations; - Operation and maintenance (opex); - Guarantee costs toward network operators; - IT platform management costs for the Energy Community; - Network charges, tax & duties. (Meaning: Which are the costs to realize the Business Model?)		<u>Revenues streams</u>  - Energy supply to the Community (self-consumption + additional energy consumption); - Participation to the electricity markets (MGP, Balancing, Capacity, Flexibility); - Rent use/sale of technology; - Grid services/ancillary services. (Meaning: which price mechanisms allow Business Model create value for customer segments?)		

V - ENERGY COMMUNITY COST-BENEFIT ANALYSIS

This paper section aims to define the general features of the proposed renewable energy community making the necessary assumptions of the simulation to evaluate the sustainability. In detail, all the user types involved in the model are specified, the users' consumption, technology, involved energy prices, costs and the revenues related to the EC model. The analysis was performed by means of

different simulation scenarios where each was performed with an increasing level of some considered variables.

The new energy scenario that is shaping in the energy market suggests an EC model with aggregation of residential end-users as consumers, prosumers, prosumagers located within the same LV distribution network, in order to increase the energy self-sufficiency locally lowering the energy absorbed from the external grid (out of the community). Recently, global climate actions have led to the electrification of energy consumption; therefore, in order to evaluate the model feasibility of an energy community a possible configuration was simulated.

In order to perform the simulation, the end-user type considered within the analysis is a consumer with an average annual value of consumption of about 2,700 kWh/year. Taking into account the transition towards all-electric usage, an increase of electric consumption about reference users up to an annual consumption up to 5,000 kWh/year was considered. In the simulated scenario, the main renewable generation source for the community is represented by the solar systems according to the distributed approach as configuration b) in *Figure 3*. Generation technology is represented by several 3kWp PV plants with annual generation of 4.290 kWh/year and a cost of 1,000 €/kWp

It is assumed that end-users are equipped with an additional ‘enabling technology’ named nanogrid as illustrated in Menniti et al. (2016; 2018) that allows each end-user not only the integration of renewable generation plus small-scale storages, but also the possibility of executing control actions by mean of the individual ESS to exchange energy among end-users in order to obtain virtual self-consumption, increasing community self-consumption.

The nanogrids are equipped with an ESS with a battery capacity of 3 kWh and its cost is € 3,500. The price was determined considering the industrialization costs of nanogrid technology and ESS price per kWh in 2019. The useful life of the PV plant is assumed at 20 years while energy prices used, refer to the 2019 Italian energy market. The costs, for operations and maintenances, has been considered as 0.5% of the initial investment.

During the definition of the energy purchase (or sales) tariffs, optimal tariff definition problem as defined by Violi et al.(2018) and Beraldi et al. (2020), suggested defining the energy price in the EC with a binomial structure:

Table 5: EC tariff structure and constraints

Tariffs	Components	Tariffs constrains	Tariffs limits
PT - electricity purchase tariff within the aggregation.	$PT = PFC - PVC$ PFC: fixed component of the energy purchase tariff within aggregation. PVC: variable component of the energy purchase tariff within aggregation.	$0 < PVC \leq PFC * 0.025$	$PUN < PT \leq PUN * 1.35$ (for residential users)
ST - electricity sales tariff within the aggregation	$ST = SFC + SVC$ SFC: fixed component of the energy sales tariff within aggregation. SVC: variable component of the energy sales tariff within aggregation.	$0 < SVC \leq SFC * 0.025$	$PZ < ST \leq PZ * 1.35$ (for residential users)

In particular, the analysis considers some parameters related to involved end-users in the EC (such as self-consumption, excess energy reallocated within the EC, market prices, reduction in technological costs based on different percentage thresholds) with the aim of identifying a suitable size of the community. The greatest difficulty is the right trade-off parameters values that return a positive result for both, end-users and Aggregator.

There are no scientific studies or empirical evidences that can serve as a reference benchmark to identify a minimum size number or composition (number of participants by type) for an aggregation. In fact, there are currently no real cases with such similarity in other countries. The structure, based on a virtual model with explicit incentives, one type of RES only, residential users and a physically limited perimeter of action, make the proposed model significantly different from other examined cases, whose comparison could be misleading. Therefore, it is necessary to consider some simplifying assumptions:

- The community is composed by an equal number of end-users for each type (as in scenario s3). The types of end-users considered within the energy community are the following:

a) Consumers;

b) Prosumers with the whole technology owned by the aggregator;

c) Prosumers with PV generation plant to which the aggregator provides enabling technology;

d) Prosumers owners of all enabling technology.

- The profitability of the investment was investigated by using indicators such as Net Present Value (NPV) and Profitability Index (PI) calculated on a time horizon of 10 years is shown.
- The number of possible cases has been limited to three different scenarios.

The choice of including different types of users, depending on contractual conditions, allows different cases to be considered. It is possible to have only consumer users, users who already have generation plants available or other users that become prosumers or active users with facilities owned by the community acting as an ESCo (Iazzolino and Gabriele, 2016). The business model determines the structure of the EC. However, as reported in the research paper of Menniti et al. (2019) it is very important to evaluate the costs and revenues structure as depicted in *Figure 8*.

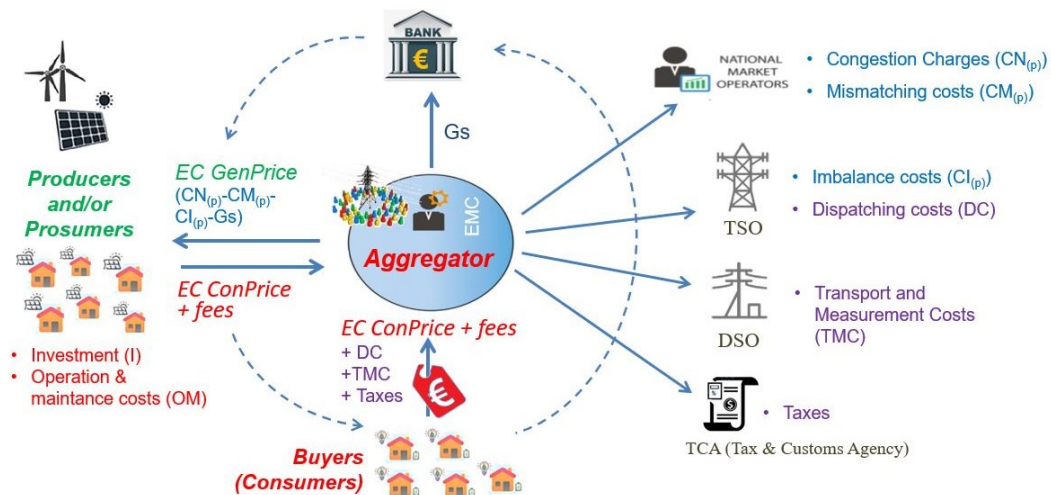


Figure 8: Contractual links within Energy Community and related costs/revenues

The main **costs** are reported in *Figure 8* and detailed in the following:

- Distributed (or centralized) cost of generation plants (I);
- Market costs and grid charges (CN , CI , DC , TMC);
- Energy purchases from the grid (CM);

- Purchase excess energy from prosumers (*EC GenPrice*);
- Operation and maintenance costs (*OM*);
- Aggregator and overheads (*EMC*);
- Financial guarantees to electricity system operators (*Gs*).

The main revenues are:

- Sale of energy to users *a*) and *b*) and energy absorbed by the grid from users *c*) and *d*) (*EC ConPrice*);
- Sale of enabling technology to users *c*) and *d*) (% of *I*);
- Energy trading, share and fee (*EC ConPrice*);

The simulation scenarios were analysed by making changes to the following parameters:

- Percentage of self-consumption of Prosumers (compared to total energy consumption);
- Percentage of energy produced by the Aggregator that is ‘re-allocated’ within the aggregation;
- Percentage increase of the purchased energy price on the market (*PUN*);
- Percentage increase in premium price calculated on the zonal price (*Pz*) due to the prosumers for the energy excess sold to the Aggregator;
- Technology cost reduction.

The following *Table 6* shows the parameters setting for each simulated scenario.

Table 6: Analysed scenarios

Variables considered in EC Simulations	SCENARIO_1 (Low)	SCENARIO_2 (Medium)	SCENARIO_3 (High)
% self-consumption (vs total energy consumption)	Up to 45%	Up to 60%	Up to 80%
% “reallocation” of energy within the community	Up to 60%	Up to 70%	Up to 80%
% increase in purchase energy price (PUN)	Up to 9%	Up to 20%	Up to 35%
Premium price (%) on selling energy price (Pz)	Up to 9%	Up to 20%	Up to 35%
% decrease of technology costs	Up to 19%	Up to 30%	Up to 35%

The simulation was performed considering the following basic assumptions:

- (i) The case refers to an EC located in Southern Italy composed of consumers and different types of Prosumagers. In this context, Italian rules about EC were applied.
- (ii) The values for energy prices refer to the national energy market price (PUN) and zonal price (Pz), which are the real 2019 average prices for the Italian energy market, as well as the grid charges that refer to the 2019 Italian prices .
- (iii) The surplus of energy from the Prosumers can be sold by the Prosumer-based Community:
- To the "wholesale market", using the Pz according to the rules provided by the current Italian regulatory framework.
 - Within the energy community (at a price higher than Pz and lower than PUN);
- (iv) The energy needed by Prosumers and Consumers, which the Aggregator cannot cover by re-allocating the energy surplus is purchased on the wholesale market at the PUN price.

Simulation results:

The results of the simulated scenarios have led to the considerations reported in the following in which the benefits of the aggregator increase with the increasing of:

- Percentage of energy exchanged within the energy community;
- Percentage of self-consumption by prosumers;
- Reduction of the cost of technology;
- Ability to clustering, in order to apply a different price policy according to the type of end-user.

From one point of view, it seems quite clear but simulation results return that the less is the energy lost by the energy community, the lower is the dependence on the external energy market that implies a degree of uncertainty and related risks.

On the other hand, as these parameters increase, the profitability of the investment for the aggregator increases as well. Analysis shows how the "minimum size" of the energy community is strongly determined by the ability to optimize the energy exchanged within the community, by the cost of the enabling technology and the consumption optimization of the individual members. For example, as

shown by the tables in the appendix section, 3,000 users can be considered an insufficient number of aggregated end-users to guarantee the sustainability of the EC, assuming they operate within the constraints of the second scenario in *Table 3*. From another point of view such results suggest that this dimension might be considered suitable if applied under the conditions proposed in the third scenario of *Table 3*.

In order to take into account a pessimistic situation, for the purpose of the aforementioned analysis some favourable conditions were not considered such as:

- The possibility that the aggregator is a producer of energy from renewable sources. This would allow the aggregator to supply itself part of the missing energy needs for the energy community (which turns into additional revenues) or even limit to zero the energy purchase from the external market.
- The energy purchase from the external market could take place through the aggregator configured as a purchasing group;
- Tax deductions for prosumers that own the enabling technologies have not been taken into consideration to separate the simulations from temporary solution that can improve the final results of the analysis. However, it is necessary to consider these conditions as additional benefits that allow the investments recovery to be reduced in favour of the EC development.

For each scenario, assumptions consider that the total number of users is similarly divided for each considered cluster of users. Furthermore, it is assumed that the payback times due to investments are: 2 years for consumers (end-user type a), 5-6 years for prosumers (end-user type c) and, about 7 years for Prosumers (end-user type d).

In the first scenario of *Table 6*, there are no results that can be considered positive for the entire EC, Aggregator and aggregated end-users.

The second scenario assumes that there is a 30% reduction in the technology cost and 70% of the energy exchanged intra-community. Considering the initial investment and considering the values of the obtained indicators (NPV and PI), there are obvious profitable results only for aggregations made

up of at least 5,000 users. In fact, 3,000 users make it possible to recover the amount invested, but the initiative is not profitable ($PI = 1$) thus it can be considered as the minimum size of EC that allow to balance costs with revenues.

Within the third scenario, we assume that the reduction in technology costs (35%) and the percentage of energy exchanged intra-community (80%) are greater than in the previous case. This suggests that the aggregator can offer better performance than the second scenario, which is repaid by an increase of the monthly fee paid by users. The same is true for prosumers, which have a self-consumption value of 70% (also achieved thanks to the nanogrids support and the aggregator services) higher than the 60% considered in the previous scenario. In conclusion, the increase in cash flows is also linked to the reduction in purchasing costs of the technology and it leads to an improvement of the indicators. In this case, in fact, 3,000 users are already sufficient to define the project profitability ($PI = 1.15$).

PI can be considered as an interesting parameter to evaluate the profitability of the investment. Taking into consideration the recent EU directives about REC that establishes energy communities aiming for benefits providing services to their members, instead of aiming for profits. As explained in the second scenario, the indicator can be considered to evaluate the minimum number of aggregated users beyond which, there are no profitable conditions. To do that, it is sufficient to identify the right trade-off among the many possible cases in which the PI indicator is equal to 1 ($PI=1$).

It is possible to imagine the last two scenarios in a temporal perspective. The transition over time from scenario 2 to scenario 3 could reflect the improvement of skills and performance of both the aggregator and the aggregate.

In the Appendix, the NPV and the PI calculated on a time horizon of 10 years are shown.

The originality of the results obtained by the simulated scenarios makes it possible to design/plan prosumer-based energy communities made up of different types of users and balance the economic interests of the actors. In fact, the profitability of the investment for the aggregator is represented by the economic savings of end-users involved. Economic savings can be calculated as the difference

between total energy bill of the end-user in normal condition and total energy bill of the end-user as a member of the EC.

As confirmed by recent regulation about EC, the communities' aim is not profit, so it is possible to customize the mix of the aggregation so that the profit is zero or it is enough to repay only the management costs of the aggregator.

The proposed model which is based on a mixed structure in terms of ownership of the generation-enabling technologies returns some advantages, such as (1) firstly, the investments in tangible fixed assets for the aggregator are reduced and, (2) secondly, Prosumers who purchase technology and join the community see their consumption optimized and by means of accumulated savings they return from the investment within a reasonable time period.

VI – CONCLUSION AND POLICY IMPLICATIONS

The evaluation of the "value for money" and the willingness to participate in ECs cannot be based under an economic point-of-view. It is quite clear how the involvement of consumers in the ECs is essential to achieve the goal of decarbonization of the energy system.

Several studies have analysed and discussed, also, the reasons that lead to joining an energy community and three different types of reasons have been identified: (i) financial reasons intended as economic savings, (ii) environmental reasons related to environmental protection, reduction of emissions and collective interests, (iii) community reasons as sense of belonging to the community and networking. From the study it arose how community motivations are in many cases linked to different indicators of involvement and how much the members are involved in the mechanism.

Similarly, other research on renewable energy investment decisions as investigated by Bauwens (2019) is not purely motivated by financial reasons, but can be influenced by various non-financial factors including demographic variables, knowledge, financial and technical attitudes, but also spatial dimensions and the business model.

As confirmed by the simulation performed, the number of end-users that determines the EC size, is quite important in sustainability. Considering that the aggregation boundary at the moment is represented by the MV-LV transformer substation, the obtained results suggest that it will be necessary to aggregate end-users under different MV-LV transformer substations to guarantee sustainability. In fact, following the recent directives about the energy community (European Commission, 2019) aggregation perimeter represented by the MV-LV transformer substation, under which community members are connected, does not have a sufficient numbers to implement sustainable EC model as the one represented. For this reason the aggregation perimeter should be represented by a HV-MV transformer substation or MV-MV substations that are an aggregation of several MV-LV transformer substations.

As reported in proposals for regulatory barriers (D.4-D.5) in section II, the adoption of a geographical criteria instead of electrical criteria based on the MV-LV transformer substation, it is preferred the management and operational simplicity than the electrical criteria of the substation therefore the concept of physical and virtual power exchanges would be overcome which is a key factors in the success of the models.

Adopting such approach there is a moving from a limited perimeters (for example, same street) towards larger areas (for example a municipality, postcode, province) mainly because the virtual self-consumption is increasingly different from a system with physical exchanges, becoming simply a compensation mechanism for commercial transactions. Even increasing the maximum power for the REC plants within the EC it could be facilitated the enlargement of the perimeter, allowing to make the most of the economy of scale.

Another recommendation is represented by a possible end-users ‘clusterization’, which could be an additional value since some end-users, owing to their energy consumption profile might be suitable more than others, so, as a consequence, obtaining a more profitable aggregation despite being a lower number of users.

The empirical analysis also shows that the determinants of the investment size is determined by the type of community. Energy communities developed in a specific place/space (LEC) tend to be small-sized and the environmental, social or other non-economic motivations dominate financial reasons. Conversely, for large energy communities, the incentives for prosumers participation must be extended to financial reasons ensuring the community wide access to asset creation.

Despite the general approach possibly tending to evaluate both financial and environmental reasons important for involvement in these types of collective schemes underestimating social reasons, the results show how the environmental and social reasons, but not financial, are mostly (positively and solely) linked to different indicators of users' involvement in LEC while the financial reasons are linked to the participation in larger energy communities. In this sense, alongside environmental reasons, community and social reasons can provide an interesting alternative path to encourage the involvement of people in energy community projects.

Initial investment according to the business model, may be a tough obstacle to overcome, so national incentives such as tax deduction to favour the development of generation facilities (for instance between 30%-50%) can foster the increases of ECs until renewable targets are reached according to the CEP. In addition, as with the energy so too the incomes and benefits deriving from variable incentives should be shared among community members in order to discourage individual opportunities. It seems to be the best way to allow the creation of new generation facilities, establishing a sustainable process to reach the European, national and community installation targets.

ACKNOWLEDGMENTS

This work was sponsored by the Italian Ministry of Economic Development (MISE) and the Ministry of Education, University and Research (MIUR), through the National Operational Program for Business and Competitiveness 2014-2020, PON F/050159/01-03/X32.

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Appendix:

In the following, the methodology for calculating the Net Present Value (NPV) and the Profitability Index (PI) is described.

Income statement

- Revenues
Energy sold to Consumers (end-user type a).
Energy self-consumed (on-site consumption) by Prosumers (end-user type b)

Energy sold to Prosumers (additional energy needs with respect to the on-site consumption)

Enabling technologies

Additional energy services

- Costs

Actual energy imbalances (due to TSO)

Platform fees for energy exchange [€/MWh]

Energy purchases for additional energy needs [MWh]

Energy excess cost paid to independent Prosumers d) [MWh]

Costs of SW management (ex EMS)

Overheads

= Contribution margin

- Amortisation (guarantees) and software platform costs (SW PC)

- SW Amortisation

- HW Depreciation

- Cost of Employees

- HW maintenance – SW incidence [€/year]

- General expenses

= EBIT

- Interest expenses

= EBT

- Income Taxes

= Net Income

Cash Flow Statement

Net Income

+ Amortisation (guarantees) and SW PC

+ SW Amortisation

= CF from current activities (a)

- Purchase of tangible and intangible fixed assets

- Financial fixed assets (guarantees) and SW

= CF from investing activities (b)

+ Equity

+ Bank loans

= CF from financing activities (c)

a + b + c = Cash Flow

The Net Present Value was calculated as follows:

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

t = time horizon

n = total years

I_0 = initial investment ($t = 0$)

CF_t = Cash Flow year t

i = discount rate (in %)

The Net Present Value was calculated considering a discount rate of 6.35%. This discount rate i is obtained as:

$$i = rf + spread$$

- rf = free risk rate = 1.35% (evaluated by considering risk free securities in Euro with the same time horizon as the simulation)
- $spread$ = 5% (hypothesized by considering the market premium of a set of securities belonging to the energy sector)

In addition, the PI was calculated as:

$$PI = 1 + \frac{NPV}{I_0}$$

The evaluation rule establishes that:

- If $PI > 1$ the investment is profitable
- If $PI < 1$ the investment is not convenient

Scenario_1: No results can be considered positive for aggregator and aggregated end-users, especially owing to the impact of the technology costs.

Scenario_2:

Table 7: Scenario_2 Results

	Aggregator	Consumer (user type a)	Prosumer (user type b)	Prosumer (user type c)	Prosumer (user type d)
Io = Initial investment [MLN €]	3.41 – 5.68 MLN €				
Technology cost reduction [%]	30%				
“Reallocation” of energy within the energy community [%] *	70%				
Fee EMS [€/month]		4 €/month	4 €/month	15 €/month	10 €/month

Premium price on Pz for energy injection in EC [- %]	-	-	10 %	20 %
Premium price on PUN for energy absorbed by EC [+ %]	10 %	10 %	20 %	20 %
% Self-consumption (vs total energy consumption)	-	60 %	60 %	60 %
Savings [%]	8,9 %	12 %	20 %	54 %
Payback time with cumulative savings (years)	2 years	-	5-6 years	7.5 years
Payback time with cumulative savings with tax deduction (years)	1 years	-	3.7 years	5.4 years
Total number of users	3,000	750	750	750
NPV (time horizon 10 years)	5,800 €			
PI	1.0			
Total number of users	4,000	1,000	1,000	1,000
NPV (time horizon 10 years)	144,900 €			
PI	1.03			
Total number of users	5,000	1,250	1,250	1,250
NPV (time horizon 10 years)	302,200 €			
PI	1.05			

* it is referred to the quantity (in %) of average annual energy surplus produced by the prosumers that the aggregator is able to reallocate, sell or store, within the energy community.

Scenario_3:

Table 8: Scenario_3 Results

	Aggregator	Consumer (user type a)	Prosumer (user type b)	Prosumer (user type c)	Prosumer (user type d)
Investment costs (MLN €)	3.41 – 5.68 MLN €				
Technology cost reduction [%]	35%				
“Reallocation” of energy within the energy community [%] *	80%				
Fee EMS [€/month]		4 €/month	4 €/month	16 €/month	13 €/month
Premium price on Pz for energy injection in EC [- %]		-	-	25 %	30 %
Premium price on PUN for energy absorbed by EC [+ %]		10 %	10 %	25 %	30 %
% Self-consumption (vs total energy consumption)		-	70 %	70 %	70 %
Savings [%]		8.9 %	11 %	23 %	56 %
Payback time with cumulative savings (years)		2 years	-	5-6 years	7.5 years
Payback time with cumulative savings with tax deduction (years)		1 years	-	3.7 years	5.4 years
Total number of users	3,000	750	750	750	750
NPV (time horizon 10 years)	520,200 €				
PI	1.15				
Total number of users	4,000	1,000	1,000	1,000	1,000
NPV (time horizon 10 years)	843,000 €				
PI	1.18				
Total number of users	5,000	1,250	1,250	1,250	1,250
NPV (time horizon 10 years)	1,174,000 €				
PI	1.21				