Techno-economic Analysis of Energy Communities and Self-Consumption Schemes in Portugal and Italy

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Abstract

The CoViD-19 pandemic brought significant changes to the economy, environment and public policies worldwide. The European Union distributed funds to help the Member States boost their economy and energy transition, a necessary action as a result of the increase on the global energy demand. This thesis aims to study the effect of the post-pandemic policies on photovoltaic (PV) technology in Italy and Portugal, mainly through the analysis of self-consumption schemes and Energy Communities in both countries. First, a techno-economic assessment was performed to find the optimal PV system for four families, considering each country's financial incentives. There are two self-consumption schemes in Italy (Superbonus 110 and Ecobonus), and in Portugal it is possible to access the Environmental Fund. It was found that, in Italy, it is possible to have profitable systems with storage equipment, contrarily to Portugal. More specifically, Superbonus 110 privileges smaller systems, Ecobonus bigger systems, and Portuguese policies are also intended to privilege smaller systems. Then, energy communities' simulations were performed using the same four families; in Italy, the optimal configuration for each family is the one in which the considered family is the producer, and that the optimal systems are the ones with bigger PV capacities and smaller batteries. In Portugal, energy communities' policies encourage small PV systems with no battery; the optimal configuration for each family is the one in which the family is the only consumer. However, if the Environmental Fund is considered, then the optimal configuration is the one in which all the families are producers in the same community.

Keywords: European funds, self-consumption, energy communities, photovoltaic technology.

1. Introduction

Since the industrial revolution, average global temperatures have been rising. The majority of the scientific community agrees that this temperature rise is wholly intertwined with the rise of the carbon dioxide (CO_2) levels in the atmosphere - a consequence of the growth in human activities and general better quality of living which led to a noticeable increase in the overall energy consumption [1].

The CO_2 is a greenhouse gas (GHG) and decreasing those emissions has been a challenge and a commitment since the first Conference of the Parties (COP) in Germany in 1995. At COP 21 - which occurred in Paris - the Paris Agreement was adopted by 196 Parties, whose goal was to establish a global warming limit of 1.5ºC [2] until the end of the century.

On top of this legislation and commitments, as a consequence of the CoViD-19 pandemic, the EU is directing all the available resources to help the member states respond to the economic and social damages consequent of the pandemic [3]. The NextGenerationEU is one of these instruments to help countries in the post-pandemic situation, and it mobilizes around €800 billion, from which €723.8 billion are intended to contribute to the digital and green transitions [4].

These incentives will contribute to the development of these countries and, eventually, they will also lead to an increase in energy efficiency, which probably means a decrease in consumption. However, in the following years, developing countries will want rightfully to increase their energy consumption to have better living conditions. If this is the case, i.e. in the future the production of energy will increase, renewable energy technologies might be our only opportunity of making this production increase in a sustainable way. Solar, in specific, is the technology that experienced the highest drop in the Levelized Cost of Electricity (LCOE). This metric is used to compare prices of different technologies taking into account the initial and during live costs.

The fact that, at the moment, solar technology is the cheapest way of producing electricity together with the high investment that countries are making in RES, makes the perfect combination for an environment of growth for this technology in the following years. Actually, the International Renewable Energy Agency (IRENA) expects solar PV to reach a capacity of 2840 GW by 2030 and 8519 GW by 2050, being almost eighteen times higher compared to the 2018 values. It is also expected that 60% of this installed capacity is referred to the utility of scale and 40% to distributed generation; however, this last one will probably grow faster due to supportive measures [5].

In this article, only the distributed generation - micro-generation - will be considered, by analysing self-consumption schemes and through the simulations of EC using solar PV technology.

As a consequence of the problem that is the expected increase in energy consumption in the coming years, and the fact that solar energy is the cheapest and cleanest way of producing energy at the moment, the main question to be answered in this article is: Considering self-consumption schemes and energy communities, which one of these options results in higher savings and is more economically viable?

The historical opportunity of having such a cheap technology allied with the fact that CoViD policies are relatively recent - and that mobilize billions of euros - makes this study a pioneering study on the effect of these policies on this technology both in Italy and Portugal.

In the following section - Section 2 -, an analysis of the Italian and Portuguese regulations will be performed, considering the European context. This will be followed by Section 3 in which the methodology for developing the programs used to perform the simulations will be described. The program used for self-consumption was developed in Excel and Matlab, and the program used for the EC was written in Python. In Section 4, the results of the self-consumption schemes and EC are shown, and a critical analysis is performed. Section 5 will be the last section; the overall conclusions of the thesis are presented as well as the future work that can be done using this knowledge and information.

2. Energy Regulations in the European Context

2.1. Italy

In September 2020, the Ministry of Economic Development, Ministero dello Sviluppo Economico (MISE), signed the decree-law that establishes the incentive tariffs related to the appreciation of self-consumed energy in self-consumption schemes and RECs [6]. For those who are part of a REC, the tariff has a value of 110 €/MWh [7].

Part of the *Next Generation EU*, Superbonus 110% (Scheme 1) enables consumers to install PV systems, with or without storage, and get 110% deductions over the first five years; however, those consumers cannot sell energy to the grid. It is also possible to access the Ecobonus (Scheme 2), a scheme on which consumers receive 50% deductions over ten years and remuneration for the energy sold to the grid. Both schemes are not cumulative and independent from each other except if it is an EC [8].

2.2. Portugal

In June of 2020, a law was published [9], in which individual and collective self-consumption schemes are dispensed of paying a part of the electricity tariff. More specifically, individual self-consumers don't pay 50% of the Costs of General Economic Interest, Custo de Interesse Económico Geral (CIEG) - which represents 29% of the electricity price in low voltage [10] - and REC don't pay 100% [11]. Similarly to Superbonus 110% in Italy, Portugal developed the Recovery and Resilience Plan, Plano de Recuperação e Resiliência (PRR), which is an investment plan also a consequence of the Next Generation EU program. "Climate Transition" is one of the three main sectors of PRR and it has a program focused on the *Energy Efficiency in Buildings* [12]. It aims to increase the efficiency of buildings and depending on the type of project, there is a different remuneration [13]. It is, then, possible to install PV systems with or without storage and have 85% of investment returned by the state until the limit of € 2500 per project (Environmental Fund).

3. Methodology

To do this analysis, it was necessary to use two different models: one for the self-consumption schemes and other for the EC. To simulate the EC, it was used a program developed by Valeria Casalicchio and explained in [14]. To simulate the self-consumption schemes in Italy and in Portugal, it was developed a program in Excel, but as a result of the different policies, some changes had to be made between the two cases.

3.1. Self-consumption Optimization Model

3.1.1 Italy

The SolarTech Laboratory from Politecnico di Milano provided information on the input power production of three mono-crystalline panels - 245Wp, 285Wp and 305Wp - from the end of January 2021 to the end of January 2022.

In a study performed by the European Commission [15], the average capacity in the residential solar PV sector in Italy is 3.73 kW. Accordingly, it was decided to analyze systems with 2 kW, 3 kW, 4 kW and 6 kW of installed capacity. These systems were inspired by the systems provided by Enel X, which is an Italian company with activities in the energy sector, innovation and sustainability. The four systems are composed of the same PV module but in different numbers. The PV module chosen was the one on the Enel X website, and the model is CS3L-380MS, from the Canadian Solar manufacturer; it has a peak power (Pp) of 380 W.

To simulate the systems using Milan's typical production profiles, the hourly power data of each PV panel - from the SolarTech Laboratory - was normalized and multiplied by each system's total power.

Regarding the consumption, four families were chosen from the automatically generated results of the Load Profile Generator (LPG):

- Couple working: representing two people that spend most of the time outside
- Couple retired: representing two people that spend most of the time inside
- Family with one child, one of the parents is working, and the other is at home: this case was chosen to see the differences when part of the family is at home
- Family with three children, both working at home: this case was selected to analyse the case when a big family is at home most of the time

Each case was chosen with a specific objective, and the four of them are meant to compose four different stages of life.

The buying prices for 2021 can be seen in this site [16] [1] and the electricity selling price is defined by the ARERA and is equal to Prezzo Unico Nazionale (PUN) [17] - this value changes every hour.

Similarly to the PV system, the batteries were also chosen from the Enel X website, and there are four different options: 2.4 kWh, 4.8 kWh, 7.2 kWh and 9.6 kWh. A sensitivity analysis was performed to find the optimal system for each family and scheme. To integrate the battery into the system, it was necessary to develop a MATLAB code and some rules had to be defined: the battery is not connected to the grid, when there is not enough electricity in the battery, only excess is purchased from the grid (not the entire necessity), and when there is an excess of production, injection in the grid only starts when the battery is full.

It was necessary to develop cost functions for the PV and the battery to know the total price of the system composed of any PV or battery. On the Enel X website, there is information regarding the price of PV alone for the four considered systems; however, for PV systems with storage, there was information only for three configurations: 3 kW + 4.8 kWh; 4 kW + 4.8 kWh and 5 kW + 7.2 kWh. Regarding the PV function cost, an interpolation was done using the four values of the site for the four PV systems (2 kW, 3 kW, 4 kW and 6 kW). To build the battery cost function, it was necessary to subtract the cost of the PV alone from the three configuration costs resulting in three prices of batteries. With those three values, an interpolation was done to obtain the battery cost function. After having those functions is possible to calculate the price of every battery and every PV, and the price of the system results from the sum of both prices.

It was decided to analyse the project during the lifetime of the PV system, 20 years, and the interest rate defined was 5% [18]. As the batteries and the inverters don't last 20 years, it is necessary to consider a battery replacement at t=10. The inverter is also replaced and it represents 30% of the PV cost; this value was founded by comparing the prices of the PV with the prices of each system's inverter.

The economic assessment needs to be split between Case 1 and Case 2, given that the return from the state is different between them. In Case 1, electricity is not sold to the grid; when the difference between production and consumption is negative, that is the amount necessary to purchase from the grid; when it is positive, that corresponds to excess; this excess is injected into the grid, but there is no remuneration for this scheme.

The Net Present Value (NPV) has four parcels, and they can be expressed in the following Equation 1. The first parcel corresponds to the first five years and the second one to the following 15 years. In the first period, there is an incentive correspondent to 22% of the investment cost (Inv), the energy savings (E_s) - which were calculated by the difference between electricity paid without the system and the electricity paid with the system, also considering a price for connecting the system to the grid that is 20.28 €/kW/year [19] - and the operation and maintenance cost ($O\&M$) which is 19 €/kW for the PV and 9 €/kWh for the battery [18]. The ka^x is intended to update the values, so this is calculated according to Equation 2:

$$ka^x = \frac{(1+r)^x - 1}{r(1+r)^x} \tag{2}$$

In which r is the interest rate - and so has a value of 5% - and x is the number of years in the period that is 5. In the second period, the revenues are only composed of the energy savings (E_s) and there is also the O&M costs; the ka^y is calculated in the same way as the ka^x, however considering a period of 15 years - y is equal to that time period. Lastly to fully update those values is necessary to divide that result by $(1+r)^x$, in which the r is also 5% and x is 5 years. The third parcel is related to the battery and inverter replacement (RC) expenditures and because that occurs at t=10, it is necessary to update them to the present; z is equal to 10. The fourth parcel is the initial investment.

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[1] It was necessary to do an average of the electricity grid price considering the 2019, 2020 and 2021 values, because during 2021, there were hours in which the PUN was higher than the electricity grid price.

$$NPV = (0.22 \times Inv + E_s - O\&M) \times ka^x + (E_s - O\&M) \times ka^y \times \frac{1}{(1+r)^x} - \frac{RC}{(1+r)^z} - Inv \qquad (1)$$

In Case 2, it is possible to sell electricity to the grid; when the difference between production and consumption is negative, that is the amount necessary to purchase from the grid; when it is positive, that corresponds to an excess that is injected into the grid, and the remuneration is equal to the PUN. The NPV, in this case, has also four parcels, as can be expressed in the Equation 3. The first parcel corresponds to the first ten years, the second one to the following ten years and third one to the same OM expenditures of case 1 . In the first period, there is a 5% return of the investment cost (Inv), the energy savings (E_s) and the O&M costs. As in the first scheme, the revenues of the second period are composed of the energy savings (E_s). Because it is possible to see electricity in this scheme, energy savings have that profit included. The process of updating is the same as in scheme 1, however because the time periods are different, in this case, z is equal to 10.

The second economical parameter that is also going to be used to make decisions is IRR, which is the interest rate when the NPV is zero [20].

In these cases it is assumed that the outcome corresponds to the investment which is done at t=0, t=10 and the O&M costs; the income corresponds to the revenues in each year, that were described for the scheme 1 and scheme 2.

3.1.2 Portugal

After calculating Italy's production data, those values were compared with the PVGIS data and it was found that the errors between the two methods were below 10%. This satisfactory results and due to the impossibility of having Portugal real data, PVGIS simulator was chosen to generate the production data to do these simulations.

In order to have the most similarities between the two countries, the PV module chosen was a monocrystalline of 400 W_p. The slope and the azimuth angles were defined as optimal - being 32º and 2º, respectively - and the radiation database chosen was PVGIS-SARAH2. Because it was necessary to choose a specific location, the center of Lisbon was the defined point, with a latitude equal to 38.7º and longitude equal to -9.1º.

Regarding the consumption profile, the four families used in Italy's simulations were used to perform Portugal simulations.

In Portugal there are three different types of electricity tariffs: simple, bi-hourly and tri-hourly. The simple tariff assumes a fixed electricity price independently of the time of the day or day of the week - 0.1815€/kWh. The bi-hourly and tri-hourly tariff can be split into weekly or daily cycle and has different electricity price depending on the time of the day, day of the week and depending if it is summer or winter [21]. The time of the day in which the electricity price is lower is called off-peak hours - 0.1669 €/kWh - and the hours in which the electricity is more expensive is called peak hours - 0.1865 €/kWh. The timetable for this tariffs can be seen in [21]. As individual self-consumption are exempt of paying 50% of the CIEG [9], the electricity price on simple tariff is 0.1551 €/kWh and on bi-hourly tariff the electricity price is 0.1427 €/kWh and 0.1595 €/kWh on off-peak and peak hours, respectively.

According to decree-law 15/2022 [22], the remuneration for the electricity supplied to electricity grid by the producer can be given by Equation 4:

$$R_m = E_m \times (MP_m - C_m) \qquad (4)$$

In which, R means remuneration in month m, E is the amount of electricity in month m, MP is the simple arithmetic average of the daily market closing prices in month m and C is the charges defined by the energy services regulatory entity (ERSE) in month m. This parameter C reflects expenses related to the transport and distribution of electricity [23]. It is also directly connected to the type of tariff and to the type of projects (for example, the projects that are exempt of 50% or 100% of CIEG have different values for this parameter). In [24] it is possible to see the values of these charges in projects that benefit from 50% and 100% of exemption of CIEG.

After computing the average monthly values for 2021 of the market price, it was possible to conclude that charge prices in the simple tariff are always higher than the market price except on November and December. In the bi-hourly tariff, the charges are lower than market prices (except for April) in off-peak hours. This is highly dependent on the year considered; however, it was assumed that 2021 is a representative year and it was used to apply the 2022 legislation. Regarding this, simulations were performed using a simple tariff - in which the extra electricity produced is injected in the grid but without remuneration and so the consumers don't have a smart meter -, bi-hourly weekly tariff and bi-hourly daily tariff.

The chosen PV company was Solar Impact, as it has similar PV systems to Enel X and all the

$$NPV = (0.05 \times Inv + E_s - O\&M) \times ka^z + (E_s - O\&M) \times ka^z \times \frac{1}{(1+r)^z} - \frac{RC}{(1+r)^z} - Inv \quad (3)$$

prices are available [25] [2]. The chosen PV systems were 2050 W (RMM12I), 3060 W(RPM14I), 4080 W (RPM17I) and 5440 W (RPM19I). The chosen batteries were the Solax Triple Power 4.5 kWh, 5.8 kWh and 6.3 kWh.

Considering these equipment, the first system is the only one in which the incentive is not 2500€ because 85% of that system' investment is less than 2500€. For the rest of the systems, the incentive will be 2500€. Simulations for every family were done using all possible combinations between them.

Due to the fact that Portugal does not have government incentives spread in multiple years like Italy has - the incentive is given at t=0 - the revenues of the NPV throughout the 20 years (the lifetime of the system) are only the energy savings in each year. As seen before, energy savings result from the difference between the electricity bill before (considering the price without the exempt of 50% of CIEG) the PV system and after the PV system (considering the electricity price with the exempt of 50% of CIEG) plus the energy sold. Then, NPV can be computed using the Equation 5.

In which, O&M values are equal to the ones used for Italy - because those are assumed to be for European systems - *ka* can be calculated using the Equation 2 and R represent the replacement of the battery and inverter at t=10 (z is equal to 10). Inv is the initial investment and GI is the government incentive. An interest rate of 5% was also used.

3.2. Energy Communities Model

3.2.1 Italy

To simulate an EC in Italy, the four houses described before were used to form a community and the four production profiles were used to know which is the optimal system for each house.

According to Italian legislation, EC have a remuneration from ARERA that corresponds to 8 €/MWh and from MISE equal to 110 €/MWh.

Because it is not possible to specify the capacities of the systems, due to the fact, that it is not known which system is present in each house, the cost functions for the PV and battery were introduced in the program. The PV O&M was defined as 19 €/kW and the battery OPEX as 9 €/kWh [18]. The interest rate and the number of years are the same as the ones defined in the self-consumption schemes.

The buying and selling price were defined as the prices assumed for the self-consumption; however, the incentives will make the shared electricity cheaper for who is buying and more expensive for who is selling.

After running an optimisation, different simulations were performed with different configurations - to know which is the best scenario for each family - shown in Table 1. The families that are prosumers, in all the cases, will have the same installed capacities of the optimization.

Table 1: Description of the simulations' scenarios

Scenario	Description
Baseline	Configuration with the discrete values of the optimization
1a	Couple working is the producer
1b	Family with 1 child is the producer
1c	Family with 3 children is the producer
1d	Retired couple is the producer
2a	Couple working and family with 1 child are the producers
2b	Family with 1 child and family with 3 children are the producers
2c	Family with 3 children and retired couple are the producers
2d	Retired couple and couple working are the producers
3a	Couple working, family with 1 child and family with 3 children are the producers
3b	Family with 1 child, family with 3 children and retired couple are the producers
3c	Family with 3 children, retired couple and couple working are the producers
3d	Retired couple, couple working and family with 1 child are the producers

Then, an economical analysis will be done considering the Ecobonus policy on the energy communities. It was decided not to simulate the Superbonus in the community because, in that scheme, there is no remuneration for the excess of the electricity or for the shared electricity, only above 20 kW per system.

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[2] These prices are less than 1€/W and this is also true for the following brand [26]

$$NPV = (E_s - O\&M) \times ka - \frac{R}{(1+r)^z} - Inv + GI \tag{5}$$

3.2.2 Portugal

In Portugal, the main incentive is the price of purchasing electricity from the community and the price of buying electricity from the grid. Those who are part of an EC don't have to pay 100% of the CIEG costs, corresponding to 29% of the total electricity price [9]. On top of this, the price for purchasing and selling electricity inside the community is defined by the community itself [27]. The price of purchasing has to be lower than the grid price to encourage the sharing of electricity inside the community and so, a hypothesis was made assuming that it has the same reduction (29%) as the electricity of purchasing from the grid compared to the original price. The price of selling electricity inside the community was assumed to be equal to the price of selling to the grid to have a difference that enables to pay general costs of the community, such as monitoring equipment or registering costs in DGEG. [3] The charge prices, for the projects that benefit from 100% exemption of CIEG are different of those used in the self-consumption [24].

Regarding the consumption profiles, the same four families were used and regarding the production, the PV Portugal profiles (adimensional) were introduced in the program - given the fact that one of the outputs of the program is the nominal capacity for each family.

Similarly to Italian EC, it is not possible to specify the investment and the O&M - because they depend on the install capacity, so, the data introduced in the program will be the cost functions for the PV and battery. The PV O&M costs were also defined as 19 €/kW and the battery O&M as 9 €/kWh [18]. The interest rate and the number of years are the same as the ones defined in the self-consumption schemes.

Similarly to Italy, the scenarios presented in Table 1 will be performed to know which configuration is better for each family. All of these scenarios will consider the same capacity of the optimal result.

Finally, an economic analysis will be done, considering the Environmental Fund.

4. Results

The objective of the simulations presented in this chapter is to analyse which option results in higher savings between choosing a scheme to bet on self-consumption or joining an energy community where everyone's energy is shared.

4.1. Self-consumption Model

4.1.1 Italy

In Scheme 1, the consumers are not allowed to sell to the grid but the state gives 22% of the investment in each of the first 5 years of the project. The optimal system for the four families, without batteries, is the smallest one - 2 kW. Considering batteries, the optimal configuration is the smallest PV system with the smallest battery - 2 kW and 2.4 kWh. The economic parameters in each case are shown in Table 2.

Without Storage		
Family	NPV	IRR
I	1285.87	0.18
II	2920.48	0.28
III	3983.52	0.34
IV	1786.66	0.21
With Storage		
Family	NPV	IRR
I	2250.52	0.21
II	3701.87	0.28
III	4748.72	0.32
IV	2800.24	0.24

Table 2: Optimal systems in scheme 1
I - Couple Working; II - Family with child; III - Family with 3 children; IV - Retired Couple

The optimal system in every family - according to the IRR - is the smallest one, as it is the one with lower investment and lower price when connecting to the grid. Because in this scenario the only gains that come from the system - in the most part of the system's lifetime - is through the energy savings, the more energy self-consumed, the less is necessary to be purchased from the grid at a higher price. The optimal system with storage for all the families is 2 kW and 2.4 kWh. The system with the highest self-consumption percentage is the 2 kW and 4.8 kWh; however, that system is much more expensive. As the battery is replaced after ten years, it is necessary to consider two batteries over its life time and so, the bigger the battery, the more significant the investment. The optimal system has the second-highest self-consumption rate and that proves that self-consumption is a critical factor when analysing residential PV systems. As there is no remuneration for the excess that is injected in the grid, scheme 1 privileges smaller systems.

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[3] If the price for buying inside the community is 7 cent/kWh and the price of selling for both the community and the grid is 2 cent/kWh, the 5 cent/kWh of difference is intended to contribute to those general costs.

In Scheme 2, the consumers are allowed to sell to the grid but the state only gives 5% of the investment in each of the first 10 years of the project. The optimal system for the couple working and retired couple, without batteries, is the biggest one - 6 kW, and for the two families is the 4 kW. Considering batteries, the optimal configuration is the biggest PV system with the smallest battery - 6 kW and 2.4 kWh. The economic parameters in each case are shown in Table 3.

Without Storage		
Family	NPV	IRR
I	7882.97	0.25
II	7175.73	0.29
III	8477.75	0.33
IV	8388.43	0.27
With Storage		
Family	NPV	IRR
I	7798.41	0.23
II	9206.26	0.26
III	10697.53	0.28
IV	8283.21	0.24

Table 3: Optimal systems in scheme 2

This scheme privileges the bigger systems in which is possible to produce more electricity in excess. On the other hand, the bigger the system, the higher is the cost to connect to the grid and the higher the O&M expenditure and so, there are two factors that work against each other - the remuneration of the excess and the expenses - thus, the optimal system is not always the biggest one. Although the percentage of self-consumption is lower, and therefore, the purchasing is higher, the amount sold to the grid is $3 - 5$ times higher than the amount purchased. And even though the buying price is higher than the selling price, it's about only three times higher. So, the bigger systems are optimal for a scheme that enables selling.

Regarding the situation with batteries, the optimal system is the 6 kW and 2.4 kWh because is the system with the higher amount of electricity injected to the grid but at the same time has the lowest investment regarding the battery - that has to be replaced in the midlife of the PV system.

4.1.2 Portugal

In the simple tariff, the consumers don't receive anything by injecting the excess of electricity in the grid, and the price of electricity is always 0.1551 €/kWh. The results are shown in Table 4.

Without Storage		
Family	NPV	IRR
I	1290.81	0.45
II	2833.93	0.83
III	3678.33	1.03
IV	1665.55	0.55

Table 4: Optimal systems in Simple Tariff

The results of the scenarios with storage are not shown because the IRR is always negative or positive but lower than the interest rate. The only scenario in which the IRR is 7% is relative to the family with 3 children and the smallest PV with the smallest battery: 2 kW and 4.5 kWh.

The bi-hourly tariff has similar but slightly lower results due to the increase in the initial investment as a result of the smart-meter.

4.2. Energy Communities Model

4.2.1 Italy

The optimal configuration for the community, is the one in which the family with 3 children is the only producer; however, for each family, the optimal scenario is the one in which the considered family is the producer. This is because, when there is only one producer in the community, the shared electricity is higher and the majority of the incentives goes to the producer - around 80% is these four cases. Also, the producer is always going to have self-consumption savings and sales from the surplus produced. The economic metrics are shown in Table 5

Without Ecobonus			
Family	NPV	IRR	Scenario
I	11295	0.27	1a
II	12372	0.29	1b
III	13304	0.31	1c
IV	11860	0.28	1d
With Ecobonus			
Family	NPV	IRR	Scenario
I	13193	0.32	1a
II	14269	0.34	1b
III	15202	0.36	1c
IV	13757	0.33	1d

Table 5: Optimal systems in an EC

It can be concluded that, the best option in Italy, for each family, is to integrate an EC with the Ecobonus benefits and being the only producer in the community.

4.2.2 Portugal

The optimal configuration for the community - in both tariffs -, is the same as in Italy, the one in which the family with 3 children is the only producer. Contrarily to Italian EC, the optimal configuration for each family is the one in which that family is the only consumer. Not only the initial investment is zero, but this is the case in which there is more excess from the producers and so, that family as a consumer, can pay less for more electricity in excess inside the community. Considering the Environmental Fund, the scenario that has the maximum IRR for all the families is the baseline scenario in which all of the families are prosumers. The results are shown in Table 6

Without EF [1]

Family	NPV	IRR	Scenario
I	2202	0.7	3a
II	1991	0.13	3b
III	3186	0.16	3c
IV	3864	0.07	3d

With EF

Family	NPV	IRR	Scenario
I	2156	0.65	B[2]
II	3939	1.05	B
III	4925	1.27	B
IV	2481	0.72	B

Table 6: Optimal systems in an EC

[1] Environmental Fund

[2] Baseline Scenario

Note that this values are from the simple tariff simulations, but the results are very similar for the bi-hourly tariff.

5. Conclusions

This article aimed to study different self-consumption schemes and energy communities to compare these two options, both in Italy and Portugal. The goal was to analyse which one is more economically viable considering the different policies of both countries.

In Italy, there are two self-consumption schemes in action, the first one - Superbonus 110 - in which the state finances 100% of the investment but consumers are not allowed to sell to the grid, and the second one - Ecobonus - in which the state finances 50% of the investment but selling to the grid is allowed.

The results from the self-consumption analysis in Italy were: 1) In scheme 1, the optimal system for all the families was the smallest one (2 kW); 2) In scheme 1 with batteries, the optimal system for all the families is the smallest one together with the smallest battery (2kW and 2.4 kWh); 3) In scheme 2, the optimal system for the couple working and for the retired couple was the biggest one (6 kW) and for the other two families was the 4 kW system, and 4) In scheme 2 with batteries, the optimal system for all the families was the biggest one with the smallest battery (6 kW and 2.4 kWh).

In scheme 1 without batteries, the optimal system is explained since the smaller system is the cheapest, and the only savings in this situation are from the self-consumed energy - this is the configuration with the highest share of self-consumption. In the same scheme with batteries, the optimal system is the one with the smallest battery because it is the cheapest configuration. Contrarily, in scheme 2, because selling to the grid is allowed - the bigger systems are encouraged; without batteries, the bigger system is optimal, and with batteries, the bigger PV system is optimal with the smallest battery. Batteries are still expensive, and because they have a lifetime much shorter than the PV, it is necessary to replace them, so smaller batteries are the best way to assure an economically viable project.

In Portugal, the simulations were performed regarding the two tariffs used - simple and bi-hourly. The results from the self-consumption analysis were: 1) Both tariffs had very similar results but the bi-hourly tariff had slightly lower values of NPV and IRR; 2) In the bi-hourly tariff the investment increased by 150€, which is the price of the smart meter - necessary to sell ele,ctricity to the grid - and this was not totally compensated by the number of revenues from selling to the grid; 3) The optimal system for all the families, without storage, was the smallest one (2 kW); and 4) Considering storage, all the scenarios resulted in non-profitable projects, except the smallest system with the smallest battery for the family with 3 children.

Then, simulations on energy communities were performed both for Italy and Portugal; this was done in an optimization program made by Valeria Cassalichio [14]. This program was designed considering Italian policies for Energy Communities; this is, the shared energy has a remuneration from ARERA and MISE, with a total amount of 118 €/MWh - enabling producers to receive more than by selling to the grid, and consumers to pay less than purchasing from the grid. It was found that: 1) The configuration with higher total IRR is the one in which the family with 3 children is the only producer of the community; this way the initial investment is the lowest - only one PV system and battery - and in this case, the electricity shared will be maximum as there is only one member that is producing inside the community; 2) Looking at each member individually, the optimal configuration for each one will be the one in which that family is the only producer and this is because that family is receiving through the self-consumption savings and also through the energy shared for the other 3 members; and 3) Considering the Ecobonus inside the EC, it is more profitable for all the families to be in this situation than being on an individual self-consumption scheme.

Portuguese policies, contrarily to Italian, do not establish the price of electricity inside the community. The Portuguese incentive is through the electricity price from the grid by exempting members from paying CIEG costs, which corresponds to 29% of the total electricity price. The optimal results were in the simple tariff, the community was composed only of one producer – a family with 3 children – with a PV system of 2 kW and no battery; in the bi-hourly tariff, the community was composed of two producers – family with 1 child and family with 3 children – both with a PV system of 2 kW and no battery. This capacity was used for simulating all possible configurations of communities. It was found that: 1) The configuration with maximum NPV and IRR for both tariffs was the one in which the family with 3 children is the only producer; 2) The IRR and NPV of both tariffs were very similar but, in general, the simple tariff is slightly higher, and this might be because it is not worth for these families to have the bi-hourly tariff - in which the off-peak price is lower but the peak price is higher; 3) The optimal configuration for each family - in both tariffs - contrarily to Italy, is the one in which that family is the only consumer. There is no initial investment for that family, the electricity grid price is lower than being outside the community, and it is also the configuration in which that family can benefit from the highest amount of excess electricity from the producers; and 4) Considering the Environmental Fund, the best configuration for each family and for the community is when all the families are producers. As producers, the families receive the Environmental Fund, and take advantage of the lower electricity price and of the shared electricity inside the community.

The main conclusion that answers the research question is that for both counties, and for these four families, it is more economically viable to be part of an energy community - with the Ecobonus and the Environmental Fund - than being on an individual self-consumption scheme. This shows that the energy communities' policies are aligned with the goal of expanding the residential PV capacity in both countries.

In the future, some aspects could be considered in a similar study, like the degradation rate of the PV system and the inflation rate in the updating of the costs. Also, a sensitivity analysis could be performed to analyse which Portuguese incentive could be appropriate for storage equipment to make them a good investment.

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