Sustainable energy communities.

Feasibility for today or long term? Case Analysis

Ramon Balaguer Vich

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Supervisor: Prof. Manuel Guilherme Caras Altas Duarte Pinheiro

Examination Committee

Chairperson: Prof. Jorge De Saldanha Gonçalves Matos
Supervisor: Prof. Manuel Guilherme Caras Altas Duarte Pinheiro
Member of the Committee: Prof. Carlos Augusto Santos Silva

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Resumo

Nos últimos anos, o conceito de Comunidade de Energias Renováveis e da Comunidade de Energia foram incluídos no quadro jurídico da União Europeia, enquadrado na procura de uma Comunidade de Energia Sustentável (SEC). Estas abordagens poderão desempenhar um papel importante dentro dos objetivos estabelecidos para as próximas décadas para combater as mudanças climáticas e tornar a Europa o primeiro continente com emissões neutras.

Esta tese aplica o conceito de SEC, a diversidade existente e quais são os principais fatores que podem garantir seu sucesso. São estudadas a situação de quatro países europeus, algumas das suas comunidades de energia já implementadas, e quais são as possíveis causas que tornaram esse conceito mais difundido.

Para aferir a sua aplicação local, analisou-se a implementação de um caso real na Espanha. Nele, a curva de procura elétrica para duzentas casas foi definida e uma proposta de solução renovável foi identificada para a comunidade produzir a eletricidade local. Em seguida, diferentes cenários de mudança foram propostos nos quais o projeto poderia ser localizado e o sistema mais ideal no caso da viabilidade atual e futura de cada um deles foram estudados.

Palavras-chave: Comunidade de energia sustentável; Micro-redes; Energia renovável; Projeto cidadão

Abstract

In recent years, the terms of the Renewable Energy Community and Citizen Energy Community have been included within the legal framework from the European Union. These can be included within the general term known as the Sustainable Energy Community (SEC), which is going to be called to play an important role within the objectives that have been set for the coming decades to combat climate change and make Europe the first continent with neutral emissions.

This thesis explains the concept of SEC, the existing diversity and what are the key factors that can guarantee its success. The situation of four European countries, some of their already implemented energy communities, and what are the possible causes that have made this concept more widespread are studied.

Once this was done, the implementation of a real case in Spain was analysed. In it, the electrical demand curve for two hundred homes has been defined and a renewable solution has been proposed for the community to generate its electricity. Then, different changing scenarios have been proposed in which the project could be located and the most optimal system in the current and future viability of each of them have been studied.

Keywords: Sustainable energy community; Microgrids; Renewable energy; Citizen project

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Nomenclature

CER	Renewable Energy Communities
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
EU	European Union
FIT	Feed-In Tariff
GDP	Gross Domestic Product
LPG	Liquid Petroleum Gas
NECP	National Energy and Climate Plan
NPV	Net Present Value
nZEB	Nearly Zero Energy Building
PV	Photovoltaic
PVGIS	Photovoltaic Geographical Information System
RES	Renewable Energy System
SEC	Sustainable Energy Community
SME	Small and Medium-sized Enterprises
WT	Wind Turbine

1. Introduction

1.1. Why and Scope

For a few years now, the fight against climate change has been one of the main objectives of the United Nations and the European Union. It is an urgent challenge and an opportunity to build a better future. For this, all sectors of society and the economy play an important role, especially the energy sector.

Within the European Union, the so-called European Green Pact was launched, an ambitious package of measures that aims to create a framework of policies and research and cooperation between member countries, to reduce the effects of climate change in the coming years.

In this way, in 2016 the European Commission rewrote the EU's energy policy framework to promote a clean and fair energy transition. Through the package called Clean Energy for all Europeans, completed in 2019 and consisting of eight legislative acts, a modern and stable legal environment is promoted. By establishing a clear and common sense of direction for member countries, the EU can stimulate the necessary public and private investment and bring added value by tackling the challenges of climate change together [1].

The Clean Energy for All Europeans package strikes the right balance between decision-making at EU, national and local levels. Member States continue to define their energy mix but must meet new commitments to improve energy efficiency and adoption of renewable energy by 2030.

Although these objectives are established mainly at the European level, it is established that each country must prepare a National Energy and Climate Plan for 2021-2030. These draft plans, which affect both the public and private sectors, will be evaluated by the European Commission to ensure that the EU can collectively meet the commitments of the Paris Agreement [2].

The EU has been the first major economy to present a vision for the future of a modern, climate-neutral economy by 2050. To achieve this goal, different short, medium and long-term goals have been set [3]. Below are presented:

- 2020 targets:

  By establishing a package of measures, three fundamental objectives were set:

  - 20% reduction in greenhouse gas emissions (relative to 1990 levels)
  - 20% renewable energy in the EU
  - 20% improvement in energy efficiency.

  These objectives vary according to each country, according to their initial situations in the production of renewable energy and their capacity to increase it.

  The EU is currently on track to meet its 2020 greenhouse gas emission reduction target.

- 2030 targets:

  A framework for action on climate and energy was presented with a series of political goals and objectives during the period 2021-2030. These objectives, revised upwards in 2018 and which are currently in force, are:

  - at least 40% reduction in greenhouse gas emissions (compared to 1990)
  - at least 32% share of renewable energy
  - at least 32,5% improvement in energy efficiency.

- 2050 targets:

  Although no clear and measurable objectives have been defined, the European Union aspires to be climate neutral by 2050 (as settle in the Paris Agreement). In other words, a model of greenhouse gas emissions lower than what the Earth can absorb and that does not contribute to the increase of its concentration in the atmosphere.

This channel will open a door to the so-called local energy communities. This is one of the different figures that the European Union has defined in the framework of policies against climate change and that is expected to have an important role in the implementation of technologies for the production and consumption of energy from renewable sources. The citizen will have a more participatory role, as well as become aware of the problem and assume what possibilities are in their hands and in those of their closest community to reverse it.

A challenge is how to assure the implementations to reduce and achieve carbon neutral using the sustainable energy communities' approaches. A link questions is if this communities is feasibility for today or long term and what will be the implications to specific case. This is the focus of the thesis.

1.2. Objectives and methodology

The objective of this thesis is to study the feasibility of implementing a sustainable energy community in the current and future context, varying the possible scenarios that may arise and analysing the most influential factors for this type of project.

Firstly, the thesis starts with a presentation and comparison of real success stories and analysis of the key aspects that have led to the success of the initiatives. Different publications dealing with the subject of energy communities are studied and the situation of different European countries is compared to study which models have been most successful.

Secondly, the current legal framework and possible subsidies that affect the development of a community sustainable energy project are studied. Currently, some of the technologies that can be installed are not mature enough or do not adapt profitably to the characteristics of the place. That is why, from the different governments, a subsidy plan has been established for the citizen to start investing in a sustainable energy project. The objectives and scope of the project are defined.

It is important to know the characteristics of the place, its potential for energy production, the activities that are intended to be carried out in the energy community and to study the possible options for operation and organization of the community. It is also necessary, if the community works connected to the network, see how it will interact with it. The preliminary study will mark the success of the installation and that is why the problems and changes that may arise during the useful life of the project must be considered.

Next, the final optimal architecture of the system must be determined, how it will adapt to space and what will be the environmental impact it will generate. Some of the most used technologies currently are solar panels or wind turbines, which require a large surface for their installation, and which can cause discomfort to citizens, wildlife and the landscape.

Once the installation and integration proposal are well defined, a financing plan and the economic risk analysis must be drawn up for the different situations that may arise. The possible participation of the local public administration in the investment and a possible reduction of taxes will be analysed, in addition to advising on the selection of suppliers and facilities management tools.

Finally, and although it is outside the present thesis, to guarantee the long-term success of the initiative, the project must be equipped with various mechanisms. The first of these is to establish tools for community management, that is, to manage its activity during the operational period and to control and monitor the results for continuous improvement. On the other hand, it is intended to promote the communication and dissemination of the results to encourage the creation of new communities.

1.3. Thesis structure

This approach is present in the following thesis structure:

Chapter 1

The topic to study and the importance that it has in today's world are presented. The challenges facing the European Union regarding actions against climate change in the coming decades are described. In addition, the objectives and way of working of this thesis are explained.

Chapter 2

This chapter describes the theoretical concept of sustainable energy communities and their functioning. The legal framework in which this type of energy association is presented, the key factors for its operation and the different variations in which it can be found are studied.

A review of the publications and case analysis. Then, the situation of four countries with respect to their positions and level of maturity of the implantation of sustainable energy communities is studied. The measures adopted to promote it are explained and an example of success for the communities is given for each country. Finally, the observed differences are compared.

Chapter 3

In the third chapter a case analysis for the implementation of a sustainable energy community project in the Son Espanyol neighbourhood on the island of Mallorca is studied and discussed. The current situation of the island's energy mix and the characteristics that make the neighbourhood an interesting place for this proposal are explained. Based on a sample of data collected in the neighbourhood and from different historical studies carried out, the hourly load curves for the 200 houses that will make up the energy community are defined.

Then, the different energy resources that could be successfully exploited in the area are studied. The implantation of photovoltaic panels and wind turbines to produce electricity is analysed, as well as battery systems for energy storage. The implementation of a converter system is also studied to enable the correct operation of both the different components of the installation and the consumption produced by the houses. Each of the resources and technologies is studied from a technological and economic point of view.

Chapter 4

In this chapter, eight different scenarios are presented in which the energy community could work. Through the Homer energy software, a software that has as to optimize the design of microgrids, the viability of the project will be analysed in each of the workshops. Homer allows simulating a viable hybrid system for the possible combinations of equipment that you want to consider and simulates its operation for a whole year in time steps of one minute to one hour. Finally, Homer examines the possible combinations of system types sorts them according to a chosen optimization variable [4].

Once the optimal combination of equipment for the architecture of the sustainable energy community of Son Espanyol has been obtained, the technical, environmental and economic results obtained for a life of the project of 25 years are presented.

Chapter 5

The results obtained in each of the eight simulations, their feasibility and the key factors that can change the viability and profitability of an energy community are compared and discussed. Aspects such as the impact generated by the project at an environmental level and how it affects citizens are analysed. Also, it is discussed how each of the eight scenarios presented and their design can achieve the climatic objectives set by the EU.

Chapter 6

The thesis is concluded by commenting on the conclusions obtained about the present and future viability on Sustainable Energy Communities and on how a correct preliminary design to adapt to the objectives and characteristics of the place can make the difference between success and failure.

References

Annexes

Additional information corresponding to the case analysis is presented in the annexes. Firstly, a more detailed plan of the two hundred homes that would form the energy community is presented, and the data on electric bills provided by some residents are also shown.

In the third of the annexes, various figures are located showing the interaction between the grid and the energy community for each hour of the day.

2. Energy communities review. Approaches and practice

2.1. Concept and main important aspects

If the academic definition of "community" is reviewed, it defines it as the people who live in an area or a group of people who are considered as a unit because of their shared interests. It is a somewhat abstract definition that does not give a clear and specific vision of the concept. When we refer to a Sustainable Energy Community, the concept is only limited by "energy sustainable" and still has some abstract. It refers to a wide range of collective energy actions that involve citizen participation in the energy system, with varying degrees of community participation in decision-making and the distribution of benefits [5].

Formally, the legislative framework of the Clean Energy for All Europeans package defines two terms related to the SEC concept and which are of special attention to endow the concept with a legal framework.

First, and according to Directive (EU) 2018/2001 – Article 2.16, *'Renewable energy community' means a legal entity: (a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity; (b) the shareholders or members of which are natural persons, medium-sized enterprises or local authorities, including municipalities; (c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits* [6].

Second and according to Directive (EU) 2019/944 – Article 2.11, *'Citizen energy community' means a legal entity that: (a) is based on voluntary and open participation and is effectively controlled by members or shareholders that are natural persons, local authorities, including municipalities, or small enterprises; (b) has for its primary purpose to provide environmental, economic or social community benefits to its members or shareholders or to the local areas where it operates rather than to generate financial profits; and (c) may engage in generation, including from renewable sources, distribution, supply, consumption, aggregation, energy storage, energy efficiency services or charging services for electric vehicles or provide other energy services to its members or shareholders* [7].

The concept of community must be explained from a social point of view. Within a SEC, the people who make it up have a high degree of importance in the functioning and success of it. They are people with a common interest in the improvement of the space in which they live and especially in the improvement of the climatic and energetic conditions. That is why it must be formed of people with qualities such as organization, participation, innovation and collective interest.

Although the term SEC refers to the production, distribution or consumption of electricity and heat, the reality is that the term reaches broader concepts. A model of sustainable consumption, the reduction of emissions in transport or even the demographic control of the community, can be considered directly or indirectly linked to the concept of sustainable energy community.

Figure 1 and Figure 2, present the space in which the concept of the community would be framed, on the one hand, and that of energetically sustainable on the other. With the combination of these two and the fulfilment of the requirements, it can be affirmed that we are in front of a Sustainable Energy Community

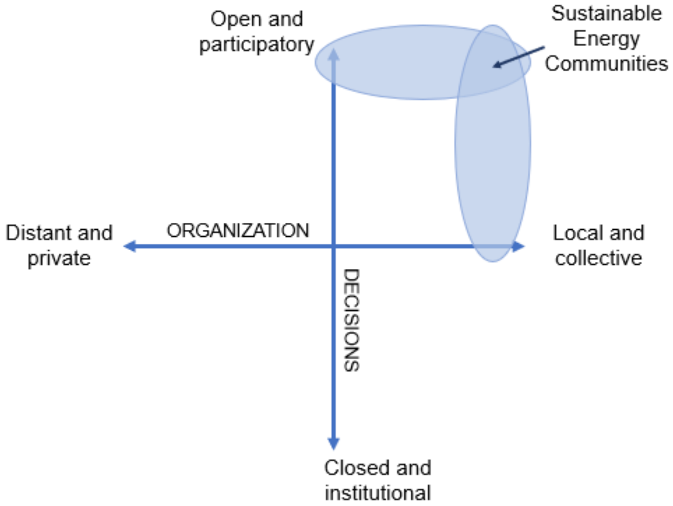


Figure 1: Community renewable energy in relation to project decisions and organization dimensions. Source: [8]

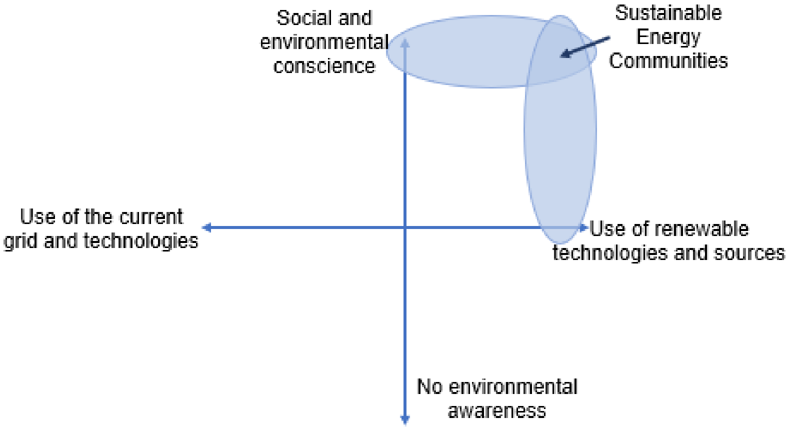


Figure 2: Social conscience and technical dimensions of a SEC. Source: [9]

According to various studies, it can be affirmed that the process that marks the transformation towards a SEC is marked by the following aspects [9]:

- Awareness of the community regarding sustainable energy aspects.
- Participation of people and institutions. The more people and organizations involved, the easier it will be to invest and carry out the projects.
- Acceptance of the use of RES and what this implies, such as the possible energy rationing at certain times or the obligation to change some habits of daily life. All this, with the mentality of not putting the sustainable energy future at risk.
- Adaptation of energy consumption to what production allows. That can lead to reducing consumption or shifting the load.

- As with all projects, the financial part is a very important aspect. The fact that people agree to make an investment and be able to receive subsidies at the state or European level, will enable the development of the SEC at a financial and motivational level.

The main advantages found for the SEC nowadays are the reduction of energy acquisition costs (something that must be studied and confirmed in each case, as it is highly variable); improvement of supply efficiency and reliability; and the use of resources and a local economy.

It is for all this mentioned and for what will be commented in the next chapter, that the definition that can be given to the Sustainable Energy Community concept is that of a group of people based on their voluntary participation and that has the common goal of providing environmental, economic or social benefits related to the production, distribution or consumption of renewable energy. The SEC's cover all those projects that have these objectives, regardless of the degree of technological development that it may have to become a "smart community", its activity or the way it works as a legal entity.

2.2. Options and approaches

As has been said, the SEC is not unique and therefore can exist in different scenarios. In this section, the types of energy communities are categorized according to different perspectives and parameters.

The first of these is the one that defines the activities of the community. The community can have different objectives, from the most common such as the generation and consumption of electricity or district heating to some of those that have emerged in recent years such as promoting sustainable mobility through sharing of electric vehicles.

Second, the community bases its operation on one or more types of technologies that enable energy production and consumption. This is one of the points that mark the viability of the projects since not all of them are suitable for installation in each community. An example is an impossibility of obtaining good yields of photovoltaic or wind production in certain places or the limits that mark not yet mature technologies such as batteries and that directly affect e-mobility.

Other perspectives that affect the architecture of the community are the characteristics of the place, the size and access to the electric grid. All the options are possible to be a SEC objective, but for example, a facility developed for an entire city in a developed country with connection to the grid is very different from another one proposed for a small village in an undeveloped country that lacks connection. It is important to know the place, the magnitude of the objectives to be covered and what are the points that will limit the project.

Finally, it is also necessary to define the economic and organizational aspects. Who leads the project and who provides the financing is one of the aspects that has marked the direction of the community project since its inception. It can be initiatives that emerge from the citizen, public organizations, private companies or from a combination of them. Each one seeks different objectives and performance than the rest and has a degree of knowledge and professionalism that makes him work concretely. This perspective also defines the structural organization of the community. The community can exist in the form of a cooperative, one of the most widespread options today; it can be run entirely from a private company, or it can work like any other legal organization that is contemplated in the current legislation.

Table 1: SEC's categorization from different perspectives. Source: [5] and [10]

Perspective	**Categorization**
Activities	Generation Supply Consumption and energy sharing Collective purchasing Distribution (electricity and heating networks) Energy services Electro-mobility Financial services
Energy technologies	Wind Solar Small hydro Bioenergy Heat pumps District heating networks Electric vehicles
Scale	Large: city, region Medium: neighbourhood Small: household/buildings
Grid connection	Grid connected Off-grid
Initiatives	Led by citizens Led by private enterprises Led by government
Location	Developed countries – urban and rural Developing countries – urban and rural
Organisational structure	Cooperative Association Partnership Development trust Private company

According to the categorization in the previous Table 1, many characterization combinations define the functioning of the final energy community. Each community has its geography, occupational status, typology of users and loads of individual energy vectors, technological development, availability of energy resources, territorial economy and sociocultural development. For these reasons, it is impossible to define the SEC uniquely. Furthermore, it is unlikely that a monodisciplinary approach can link all the issues considered in the initial objectives. The same objectives could be achieved by defining action on three main action themes [11]: sharing, the multi-energy and environmental approach. Furthermore, for each chosen approach it is possible to define different subtopics to identify a correct strategic procedure to define the construction parameters of an SEC, as exemplified in the Figure 3.

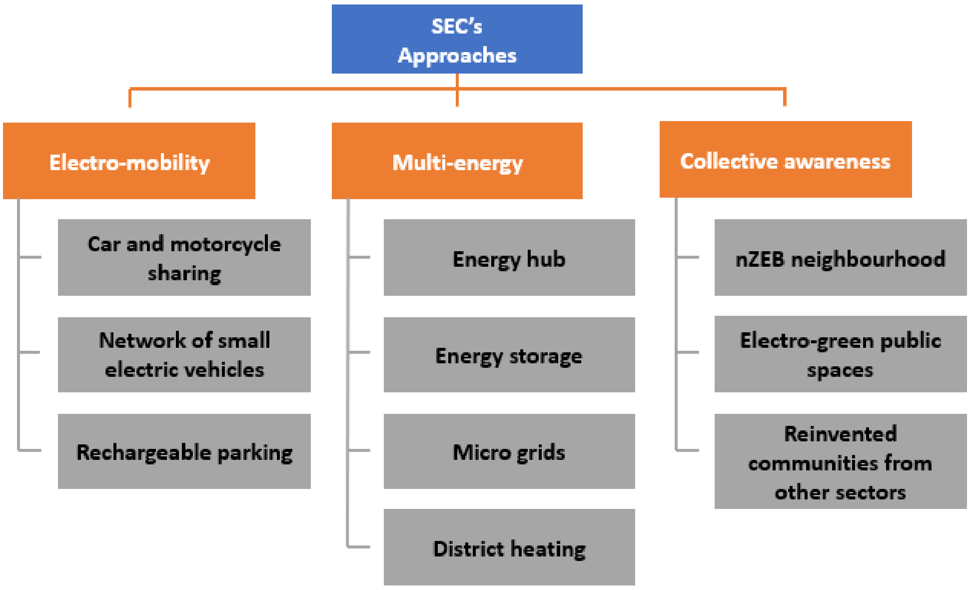


Figure 3: SEC approaches. Source: [11]

2.3. Review of publications and cases

2.3.1. Germany

In 2017, about 46% of the whole renewable energy capacity in Germany was owned by private individuals and farmers [12]. This is due to the commitment and the policies carried out by the German government in recent decades. These encourage the development of local communities and implement tax incentives for low-power renewable facilities.

The main reasons that have led to the growth of the number of SEC's in Germany are two [13].

- First, a modification of the German cooperative law carried out in 2006. This modification mainly contained measures to extend the payment of fees corresponding to members up to 10 years. On the other hand, only three people were needed to create a cooperative and the information obligations were reduced for cooperatives with annual incomes of less than one million euros.
- Secondly, this growth is due to the German System of Energy FITs (Feed-In Tariff). In it, the government establishes different rates for the electrical energy injected by the power plants depending on the size, location and type of energy. To benefit the investment in renewable energies and to favour the fulfilment of the European objectives against climate change, the

main beneficiaries were the small producers of renewable energies. They obtained sales prices higher than their real value, although this value was decreasing depending on the year in which the installation was built.

After 2013, the number of new cooperatives plummeted due to a new amendment to the Renewable Energy Act. The FIT's were replaced by auctions in the purchase price of electricity and, therefore, the benefits of the facilities were reduced.

A German case study is Jühnde [14], a small village with a population of about 750 inhabitants. In 2005, a bioenergy plant was opened, and the town was established as the first bioenergetic town in Germany. The plant works with wood chips and biogas to supply heat and energy to the community. Also, it is owned by residents through a cooperative, approximately 75% of Jühnde residents are members of the cooperative.

The system contains a 700 kW CHP generator that runs on biogas to produce electricity and a 550 kW wood chip boiler to supply heating to the district's local grid. It currently produces 70% of the village's heating demand and doubles the demand for electricity.

The impulses that the inhabitants received to decide to carry out the project were very important to achieve it. From the energy policies that contemplate guaranteed access to the network and stable FITs for the next 20 years; even the role of the local council in the project and the University of Göttingen. The mayor's work was very important to encourage the national government and the banks so that they will provide the necessary funds, in addition to motivating residents to participate in the project. For its part, the University of Göttingen provided a scientific point of view and not driven by profit-making.

The main objective of the cooperative is to obtain heating at a low price and not a high profit. That is why the revenue that cooperative members obtain is not particularly high. The current perspectives are to invest money in the improvement and flexibility of the plant with the prospect of adapting to the finish of the FIT and to use excess electricity production to charge electric vehicles, a sector on the rise in the future.

2.3.2. Portugal

Portugal is among the top eight countries in the European Union with the highest share of renewable energy in gross final energy consumption. This is an unusual position when compared to the neighbouring countries of southern Europe since the rest occupy more lagging positions and the first positions are occupied by the Nordic countries.

Some of the renewable energy policies carried out in the country and which have served to increase the share of renewables in recent years, are to establish fixed feed-in tariffs guaranteed for 15 years depending on some aspects; and that of encouraging up to 40% investment in projects [15].

With the entry into force of Decree-Law No. 162/2019 of October 20th, the figure of Sustainable Energy Community has been included in the legal regime applicable to self-consumption of renewable energy. Specifically, it is established that the so-called «Renewable Energy Communities (CER)» as "*a legal* *entity established under the terms of this decree-law, with or without profit, based on an open and voluntary adherence of its members, partners or shareholders, who may be natural or legal persons, of a public or private nature, including, namely, small and medium-sized companies or local authorities, who are independent of their members or partners, but effectively controlled by them, provided that they are cumulative* " [16].

The stable law decree that the energy communities are an important and complementary system to the national electrical system, which will allow the fulfilment of the goals and objectives of Portugal in terms of energy and climate, which include by 2030 reaching participation of 47% of renewable energy in final energy consumption and have at least 80% of the production of electricity from renewable sources.

Besides, in the national energy and climate plan established for the period 2021-2030, a line of action of its own has been established to promote the diffusion of distributed production and self-consumption of energy and energy communities [17]. The plan includes measures to promote the creation and development of communities through technical support, help with procedures and a subsidy program for the coming years.

To understand the situation of the energy communities in the country, it is important to do an historical review. In Portugal, most of the existing energy cooperatives were created in the 30s of the last century. They were created to provide access to electricity in remote areas in the north of the country and were based on medium to low voltage electrical transformation points that were later distributed to homes. Over the years, most of them disappeared in a process of commercial concentration and currently, there are only about six. Therefore, these cooperatives should not be considered as an example of modern SEC, but as a sample of how to provide access and democracy power to remote communities.

The case study of Portugal is the only sustainable community created this century in the form of a cooperative that produces renewable energy, namely Coopernico. It was founded in 2013 in Lisbon by a group of people to promote a decentralized and sustainable energy model. Even though its contribution is practically marginal in the electricity market, it currently has 1.700 partners and 1.030 supply contracts [18].

The operation of the cooperative is mainly based on two business models. Firstly, that of electricity supply to homes that have a contract with the cooperative. Although the cooperative has been generating and marketing electricity for several years, it was not until 2020 that it managed to establish itself as an independent marketer. Until now, this function was developed jointly with the private company YLCE by ENFORCESCO S.A.

In second place and as the engine of the cooperative so far, is the development and investment in renewable energy generating facilities. Since Coopernico's inception, citizens have had the opportunity to invest money in various photovoltaic projects, which they later partially recovered. With this model, today there are already 20 active photovoltaic parks, totalling approximately 1.332 kW of installed power, with a 1,7 GWh electricity production in 2019 [18].

2.3.3. Spain

It is one of the countries of the European Union that has experienced a greater increase in the use of renewable energy in the last decade due to the enormous potential it has, especially in the production of photovoltaic energy. Despite this, it is one of the countries with the lowest number of SEC's in Europe.

The reasons are several, but it is necessary to pay special attention to the functioning of the Spanish electricity market, the government's policies in this field and the knowledge and acceptance of people regarding the implantation of Sustainable Communities.

In Spain, the number of sustainable energy communities operating as a cooperative is small. Although several projects have emerged in the last years, there is a great distance from other. As in the case of Portugal, it should be considered that half of them were created in the twentieth century to give access to electricity in different areas of the territory of Valencia. In addition to these, there were many other renewable energy cooperatives spread throughout the rest of the Spanish territory and based on electrical transformation points and hydroelectric generation. But after the Civil War, most of them disappeared.

Unlike countries like Germany, in Spain, 60% of the installed power of wind, solar photovoltaic and solar thermoelectric is owned by only 5 large companies. With this data alone, it can already be seen how the growth of renewables has not been promoted and invested largely by citizens.

To understand what happens in Spain, one must go back to the period between 2000 and 2014, the Spanish electricity system operated with financial losses. Since the liberalization of the market, a policy of freezing the electricity tariff began to be applied outside of the declared energy costs, which became a state debt with the electricity producing companies, which reached the 30.000 M€ in 2013 [19]. From that moment, the government decided to start implementing a series of measures to contain this deficit and reduce it in the following years.

One of these measures was to eliminate the FIT's and FIT's Premium system in 2013, a system similar to that of Germany, in which fixed and profitable tariffs were set for those who decided to start producing energy from renewable sources. Even so, also in 2013, through Law 24/2013, it was clearly established that cooperatives and individual producers could commercialize their energy produced in the electricity market.

The other important measure was that the consumer should pay the corresponding taxes for the energy produced in his self-consumption installation. This fact, together with the bureaucratic complexity that led to the implementation of energy self-consumption projects, led to a substantial decrease in the future renewable energy facilities that would have been carried out.

At the end of 2018, the royal decree was repealed by the new Spanish government and therefore, producers were exempt from paying those fees. Due to the short time that has passed, the impact of this new measure cannot be evaluated, however, it is estimated that the power of photovoltaic solar energy will double in the period 2019-2020, while wind power will increase by around 20% [20].

Unlike Portugal, Spain has not yet defined a legal framework that includes the Energy Communities as a legal entity. Even so, in the recently approved Integrated National Energy and Climate Plan for the period 2021-2030, a specific measure is included for what they call Local Energy Communities. In it, it is envisaged to incorporate this term into the Spanish legal system, defining it as follows: *"A local energy community is one controlled by partners or members who are near the projects and its objective must be to provide environmental, economic and social partners or members or local areas where it operates. Also, in the case of renewable energy communities, partners must be individuals, SMEs or local authorities (including municipalities) "* [21].

Besides, an action framework is foreseen that eliminates the existing barriers to its creation, which includes facilitating administrative processes, promoting community demonstration projects, education and training programs so that the necessary human and technical resources are available, and finally designing specific lines of guarantees and financing.

A case of success that is important to analyse is the Som Energia cooperative, founded in 2010 in the city of Girona and considered the first in Spain to implement the modern SEC concept. It started as a small cooperative that emerged from a university initiative to produce and market 100% renewable energy. Its growth in the last 10 years has been such that it currently has more than 66.600 partners and some 116.000 contracts, producing in the last year 17 GWh [22]. Despite these numbers, this production only represents between 3-4% of the energy it sells, and the rest is purchased in the electricity market, data that reminds us of that of a conventional marketer.

With this small percentage of self-production and the high number of partners across the country, maybe the SEC's definition as a neighbourhood that produces the energy it will consume would no longer apply to Som Energia. Still, despite the distance, people continue to have a strong bond of unity as they belong to this cooperative project and continually invest to carry out new projects for renewable energy facilities.

2.3.4. Denmark

To understand what has happened in the Danish energy landscape, one must go back to 1979 with the oil crisis. That year, Denmark's energy dependence on the outside world was evident, and from then on, the history of renewable energy, and especially in the wind energy sector, changed dramatically in the country.

This situation led the Danish government to promote measures that would change the energy map at that time. Also, at that time there was a strong mobilization in the country against the Nuclear sector and that had led to the creation of groups of people promoting the elimination of this technology. Once the objective of these groups of people was achieved with the restriction of the construction of nuclear power plants, the new objectives of these communities was to approach climate change [23].

Thus, in the early 1980s, the first local wind turbine cooperatives in Europe began to develop. These initiatives were carried out by communities of individuals and families thanks to government-sponsored tax incentives for those who generate electricity for their local community. In 1996, it was estimated that there were approximately 2,100 wind turbine cooperatives across the country, and in 2001 their stake in wind turbines installed in Denmark was 86% [24]. These are numbers that no other European country has achieved at such early dates.

To obtain a high degree of growth in the wind sector, the Danish government was one of the first to implement a feed-in tariffs system for this type of technology, which lasted between 10 and 20 years. Also, an income tax exemption for income from wind energy projects was implemented [15].

But all this changed in 1999, at which time an electrical reform was launched to liberalize the market and reduce aid to renewables. This produced an increase in the costs of consumers' electricity bills. Furthermore, the feed-in tariff system was also significantly reduced. As a result of these measures, between 2004 and 2008, practically no new wind turbines were installed in the country [24].

Again, in 2008, the system of aid to renewables was reformed, including other technologies such as photovoltaics. This fact has once again led Denmark to new growth in the installation of new renewable energy projects, once again being one of the reference countries.

A Danish case study is that of the Hvide Sande Wind Farm [14]. In 2012, three 3 MW wind turbines were installed on the beach where they generate energy as efficiently as offshore wind farms. The electricity generated is sold to the national grid in Denmark and the profits obtained after the repayment of the bank loans are invested in projects to improve the local area.

The project is led by the Hvide Sande Community Foundation, a charitable organization that was created in 2010 for this project. The foundation owns 80% of the project, and the other 20% is owned by 400 local cooperative investors, as required by Danish law regarding wind farm projects. With this shareholding structure, private individuals are prevented from buying and collecting many shares to obtain individual benefits, which later do not affect the well-being of the community.

The local action groups and the strong social pressure that they carry out on local governments have been of great importance in the development of this project and the following ones that have been carried out with a similar model in Denmark. Fear of political parties not to be re-elected in the elections, they have no choice but to support cooperative projects to the detriment of forcing to accept those proposed by large private companies.

2.3.5. Comparison between countries

Once the different situations and the measures adopted by the different countries regarding the promotion of renewable energy projects, and especially of the sustainable energy communities in the legal form of energy cooperatives, are known, different data from Portugal, Spain, Germany and Denmark are compared to obtain an explanation of the differences that exist in the success of projects promoted by citizens in each of them.

First, a comparative Table 2 is shown in the cases studied. The cooperative models developed in Portugal and Spain are quite different from the models that are proposed in the northern countries. In Germany and Denmark, the cases analysed consist of projects developed by small neighbourhood communities that are both partners and consumers. In Portugal and Spain, on the other hand, the cooperative model is that of a kind of larger company, which tries to expand throughout the country by creating other small cooperative centres, but under its name. In addition, in southern cooperatives, their members differentiate between members who invest money and consumers who maintain a contract to obtain electricity.

Table 2: Comparison of the analysed cases. Data source: [14], [18] and [22]

Country	Germany	Portugal	Spain	Denmark
Case analysed	Jühnde	Coopernico	Som Energia	Hvide Sande
Technology	Bioenergy	Photovoltaic	Photovoltaic Biogas Hydropower	Wind turbines
Scale	Village	Country	Country	Village
Organisational structure	Cooperative	Cooperative	Cooperative	Cooperative
Installed power	1,25 MW	1,33 MW	8,88 MW	9 MW
Members	560	1.700 partners 1.030 contracts	66.600 partners 116.000 contracts	400

Bellow, the evolution that the contribution of renewable energy sources has had in final energy consumption and electricity generation in each of the four countries are presented in Figure 4 and Figure 5. In all cases, it is observed that the proportion of renewable energy has been increasing practically every year. Although the installed powers of renewable technologies in Spain and Germany are indeed vastly higher than those of Portugal and Denmark; these last two countries, with the smallest population, are the ones that have a higher percentage of final energy and electrical energy from sustainable sources. Furthermore, the role played by wind energy in the Danish mix is of importance. In 2018, it generated 93,6% of the renewable electricity produced in the country, while in the rest, other types of sources such as solar and hydro, also contributed significantly to generation [25].

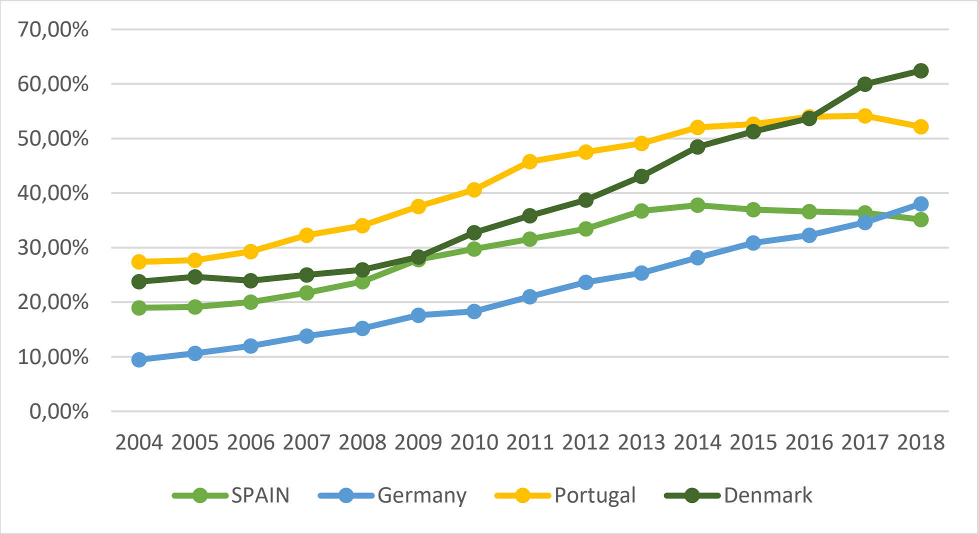


Figure 4: Share of renewable energy in electricity generation. Data source: [26]

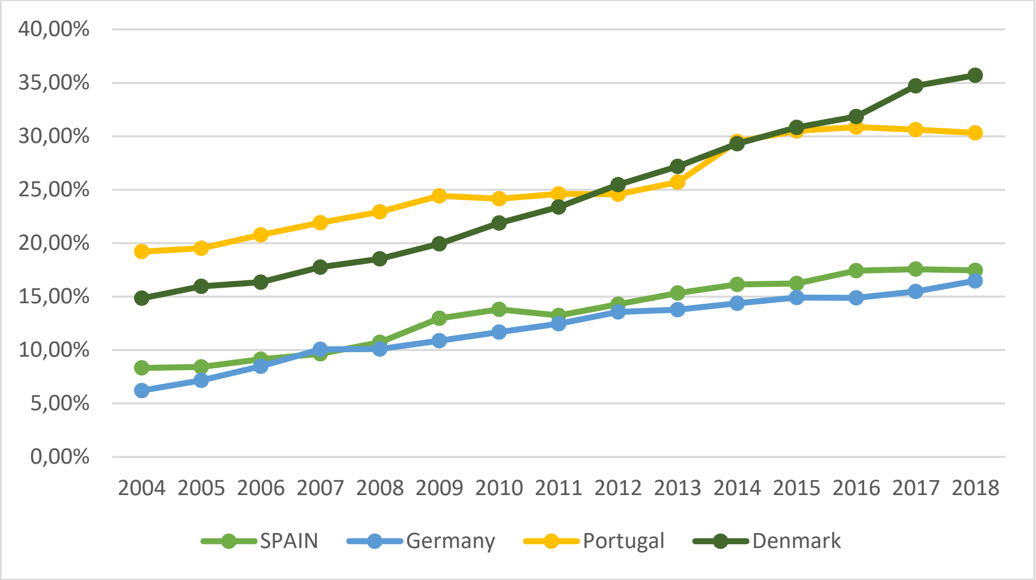


Figure 5: Share of renewable energy in gross final energy consumption. Data source: [26]

According to the objectives proposed by the Clean Energy for All Europeans package, by the year 2020, the member countries of the European Union must reduce their greenhouse gas emissions by 20% compared to those existing in the year 1990. Also, by 2030, that limit reaches 40%. As can be seen in the following Figure 6, both Germany and Denmark have already achieved the first objectives set, having reached emission reductions of approximately 30% in 2018. For their part, Spain and Portugal have also made a remarkable effort to lower their numbers in recent years; although despite this, coming from very high relative emission values, they are still far from the set targets.

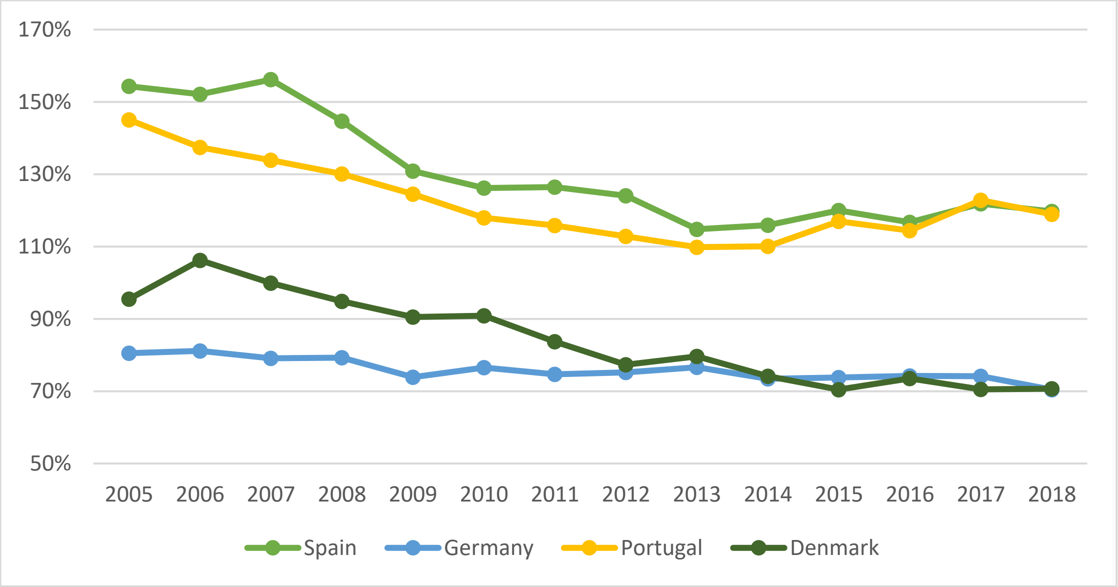


Figure 6: Greenhouse gas emissions compared to 1990 levels. Data source: [27]

Regarding the evolution of the number of sustainable energy communities in the legal form of cooperatives that exist in the countries, the values are very different between each of them. The Figure

7 shows the evolution of the approximate number that exist in each country. For Denmark, there is only those included wind power, since those referring to other types of technologies have not been found.

In the first place, there is Germany, who in recent years is the only one of the four countries that have significantly increased the number of cooperatives, reaching a figure higher than 1000 in 2018. Denmark has had a different behaviour, who is 1999 had a peak of around a thousand, is the country that was more above the rest. From that moment on, things changed, the combination of various factors such as the disappearance of Feed-in Tariff, the liberalization of the electricity market and the appearance of large investments in off-shore wind farms made the number decrease year after year. Many of them reached the end of the life of the wind turbines and others were sold as utilities [28].

And finally, in a position far below are Spain and Portugal. The first has doubled the number of cooperatives since 2004, going to approximately 29 in 2018. Portugal, on the other hand, continues to find no start to this energy model and only has one energy cooperative. The two countries, along with others in the south such as Italy, have a deficit in promoting electric cooperatives [29].

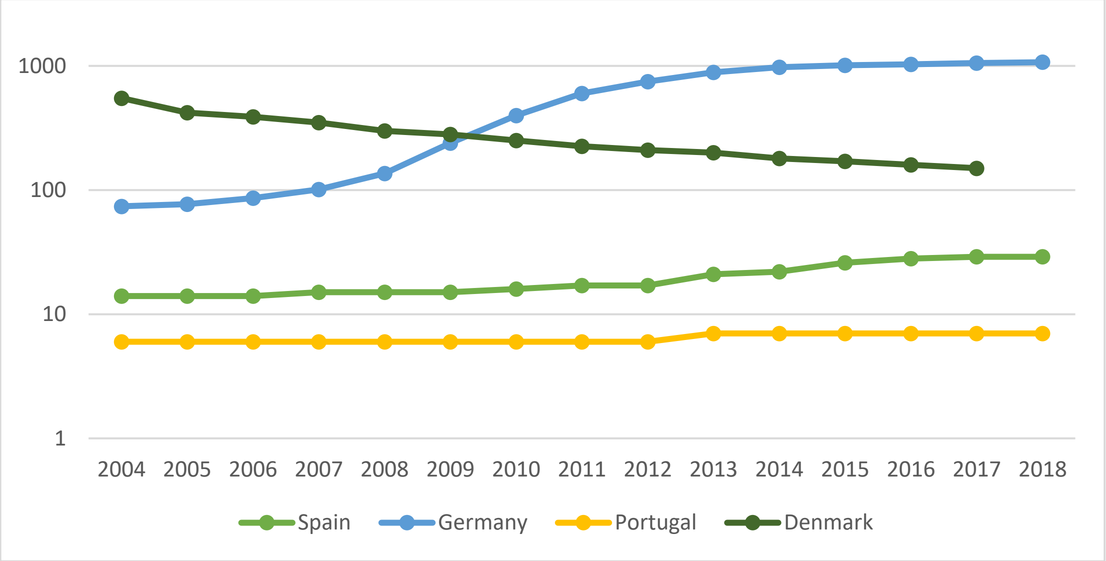


Figure 7: Approximate number of energy cooperatives. Data Source: [13], [29], [30], [28] and own work

To better understand why these differences arise, it is important to analyse the social and economic factors that each country presents. On the one hand, regarding the role that local governments have regarding the active promotion of responsible behaviour and offering opportunities for citizen participation in environmental aspects, Germany and Denmark rank above the rest of European countries. For its part, Spain is situated at values like the average and Portugal is considered a country with little promotion of citizen participation in these issues [31]. In general terms, the Nordic and German countries are benchmarks in content dissemination through electronic tools, transparency and responsibility of their governments, which make people more likely to participate in their communities.

For its part, the economic factor is also one of the keys to the success of promoting sustainable energy communities in the form of cooperatives or other types of organization. Both Denmark and Germany have a GDP per capita higher than Portugal and Spain, as can be seen in the evolution shown in the

Figure 8. The German country in particulates is the only one of the four that managed to slightly exceed in 2018 the values of before the economic crisis [32]. It is also the only one that has managed to maintain a contribution of the industrial sector to GDP above 25%. Therefore, it is possible to observe the clear influence that the industrialization of the country and the wealth of its citizens have when investing and promoting community projects.

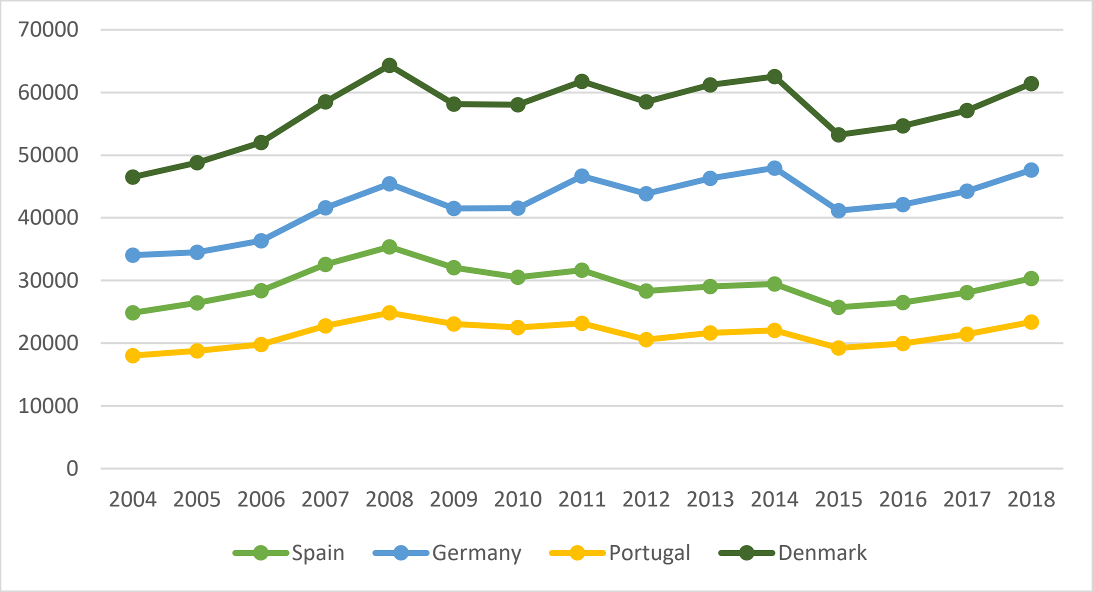


Figure 8: GDP per capita, values in $. Data Source: [32]

2.4. Challenges for Energy Communities

It is important to mention what are the main problems facing the implementation of the SEC. Trying to understand their level of importance and how it affects each community differently, it can be understood because even the SEC is not a reality in all countries. The key issues could be classified as follows [10], [33].

- Technological issues:

Evolution and innovation in technology is extremely important for the development and growth of SEC's. The two main problems facing energy technology today are two. On the one hand, the high investment required to carry out the projects. The democratization of prices and search for new tools of lower cost, can encourage the formation of new sustainable communities. On the other hand, innovative technologies are needed to solve the current obstacles that each community has at the level of operation of the electricity grid. Briefly, the technological issues could be mentioned as follows:

- Socio-economic issues:

Another of the key issues for the development of the SEC's are the socio-economic factors. That is, what directly or indirectly affects the willingness of people to invest money and feel motivated with the development of the sustainable community. This is especially important in those communities with a high dispersion of the population and with a lower GDP per capita. It is usual to see how those areas with lower levels of wages, do not feel so aware of the impacts that their actions have on the environment, much less if it implies spending their money.

- Environmental issues

It is probably the engine that promotes and motivates the development of SEC's, although it is not the decisive factor in many cases. Awareness of the effects of climate change and the willingness to leave a better planet for the next generations, enable the community to join a common front. On the other hand, it also includes aspects of the environmental impact that a project of these characteristics would generate in the local area and how they should be managed.

- Institutional issues

Finally, institutional aspects, ranging from financial aid and tax incentives to changes in legislation to facilitate this new concept of electric microgeneration to the detriment of the current centralized generation. All these institutional issues will change the legal and economic aspects of the project.

All these mentioned issues are categorized in the Table 3.

Table 3: Issues facing energy communities

Categorization	**Issues**
Technological	Matching demand with supply Energy efficiency Storage Local flexibility and grid’s impact
Socio-economic	Energy autonomy and security of supply Initial costs and financing Economic incentives Community engagement Willingness of people to pay
Environmental	Environmental awareness and climate change Emission levels Waste generation and management Space available for installation
Institutional	Motivation and continuity on the project Energy democracy Installation's ownership Long-term goals Institutional design Roles and responsibilities of people in the community

3. Case analysis

3.1. General aspects

The case study selected to analyse the implementation and viability of an energy community is that of Son Espanyol, a small neighbourhood located on the outskirts of Palma de Mallorca, in Spain. Its location is indicated in Figure 9.

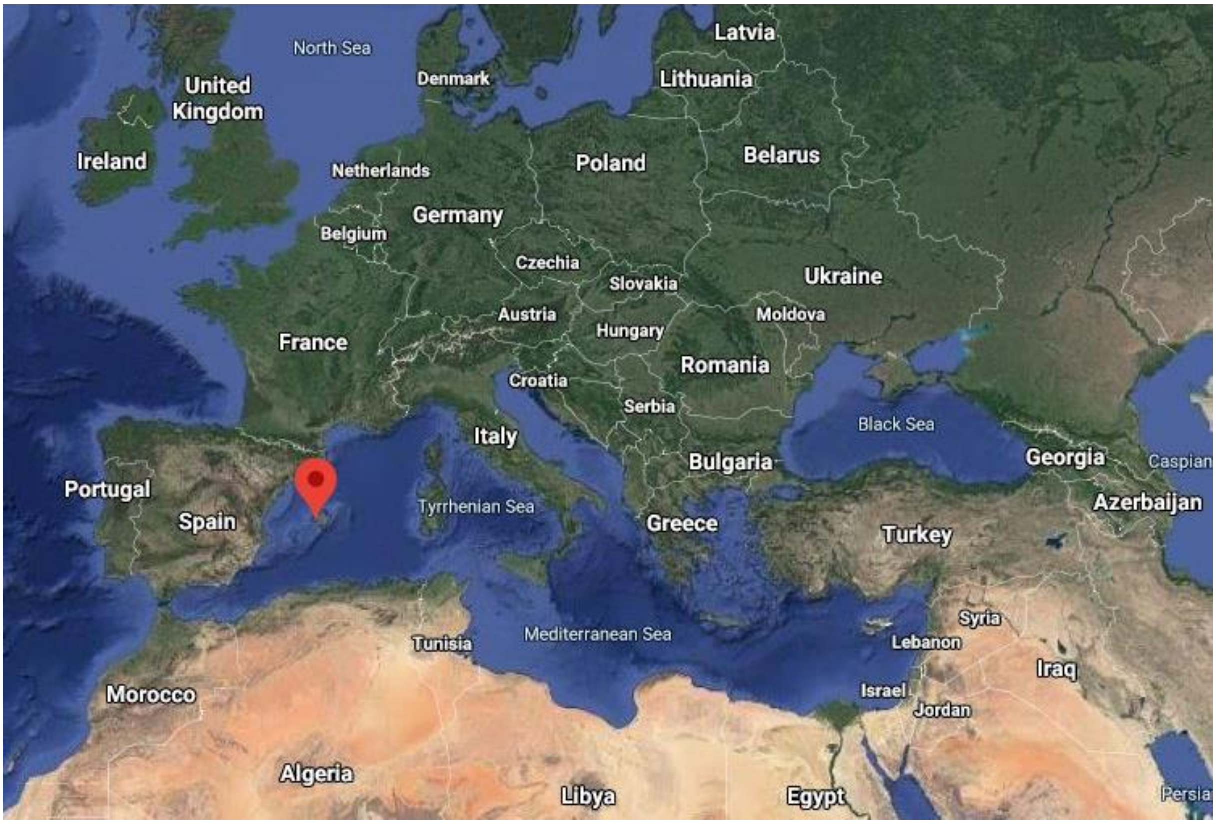


Figure 9: Location of Palma de Mallorca. Source: [34]

To understand the reason for this choice, it is important to know what the current energy mix of the Balearic Islands is. As can be seen in Figure 10, the archipelago depends to a large extent on the electrical contribution that is made from the Iberian Peninsula through the cables that connect Mallorca with Valencia. This link, which came into operation in 2012, is 244 km long and helps improve the reliability and quality of the Balearic electric system [35]. In addition, it guarantees coverage of demand on the islands, as well as being a complementary option to the construction of new power plants in the Balearic Islands.

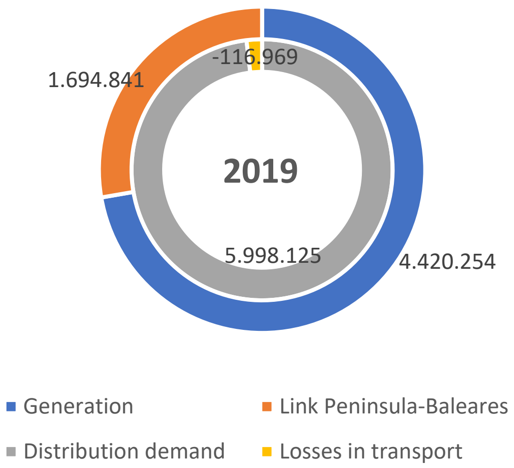
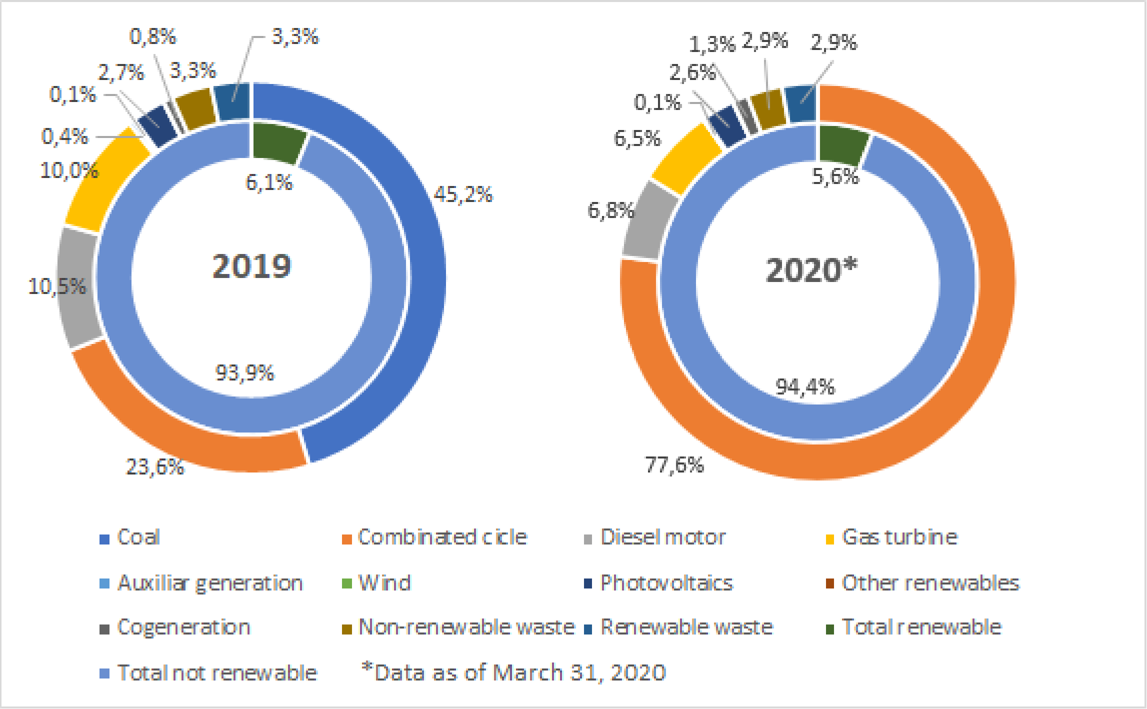


Figure 10: Balearic electricity system balance during the year 2019, in MWh. Data source: [36]

Despite the benefits that this link has brought to the Balearic electricity system, it is surprising to see that during 2019, almost 28% of the electricity consumed was provided by continental Spain. This data already indicates the low energy independence of the islands. Despite the enormous efficiency of the installed cable, it remains a link of a very long length and with its consequent losses. In addition, a cable break like the one that occurred in the link between the islands of Mallorca and Menorca in 2017 [37], is a huge problem for the electrical system and leads to the fossil fuel power plants starting up.

If you study the remaining 72% of electricity, which is generated in the islands, it cannot be said that it is a sustainable generation either. Approximately only 6% of the energy generated comes from renewable sources, most of it produced by photovoltaic parks and renewable waste, as shown in the Figure 11.

The rest of renewable technologies have a small role in the energy mix, for example, in terms of wind energy, there is only one wind farm consisting of four wind turbines on the island of Menorca. Despite the existence of different proposals to set up new wind farms, none of them has been carried out for a variety of reasons such as social rejection due to the landscape impact, and negative evaluation by the Environment Commission [38].



*Data as of March 31, 2020

Figure 11: Mix of the Balearic electrical system. Data source: [36] and [39]

Table 4 shows the emission factors of the Balearic electrical system corresponding to the year 2018. Although they may have varied slightly with the closure of the coal plant, they are the most recent values that have been achieved.

Table 4: Emission factors of the Balearic electrical system in 2018. Data source: [40]

kg CO_2/kWh	0,7754
g SO_2/kWh	1,0627
g NO_x/kWh	1,7305
g Particles/kWh	0,0380

As can be seen in the previous Figure 11, this year electricity production has ceased through coal power plants. The last one on the island of Mallorca was closed at the end of 2019 and its production has been supplanted by combined cycle power plants [41]. This is an important step in reducing CO_2 and emitted pollutant particles, even so, it is only an intermediate step on the road to climate neutrality. To achieve European environmental objectives, it will be necessary to promote the implementation of new renewable energy projects and sustainable communities.

3.2. Son Espanyol neighbourhood

Son Espanyol is a peripheral and scattered neighbourhood that still retains a certain rural character. Its formation dates to the 19th century, when the local lands began to be divided up and the first houses were built, many of which still exist.

With the growth of tourism and the agricultural crisis of the 1960s, a slow process of fragmentation began, although it did not lead to the creation of any urban nucleus. Between the 80s and 90s, two important constructions were made for the Majorcan population, the University of the Balearic Islands and Parc Bit, a technology park.

Of the total of 89 existing neighbourhoods in Palma, Son Espanyol is one of those with the fewest population, although it has experienced growth in recent years reaching 665 people in 2019, as can be seen in the Figure 12. Its population density is low, about 1,5 people per hectare in 2012. Also, demographic data indicated in Figure 13 states that it is one of the oldest neighbourhoods in the city, with more than 20% of people older than 65 years [42].

According to data from 2010, the neighbourhood has some 232 homes, of which 95% are main homes, that is, they are inhabited most of the year. In addition, it is estimated that the average number of people residing in each house is 2,8 [43].

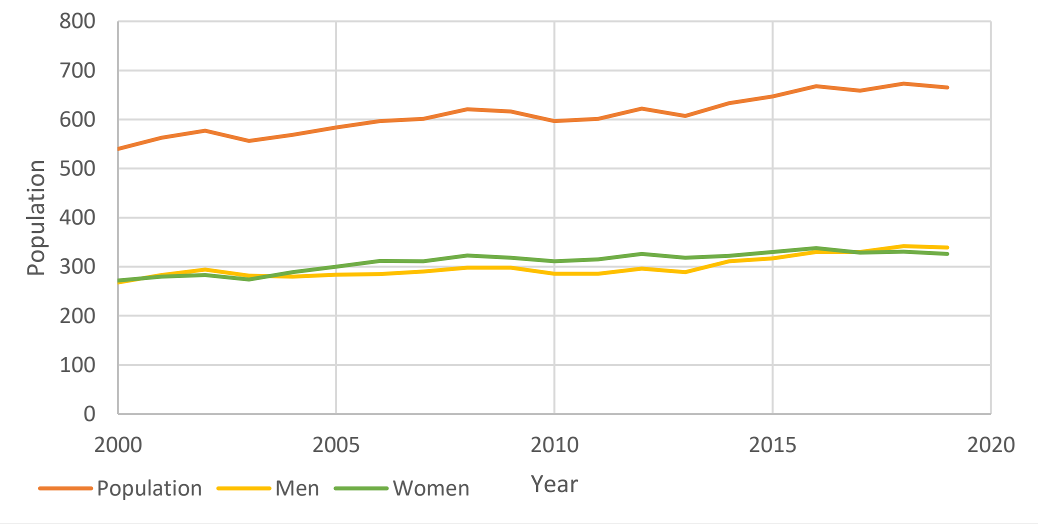


Figure 12: Evolution of the population of the Son Espanyol neighbourhood. Data source: [44]

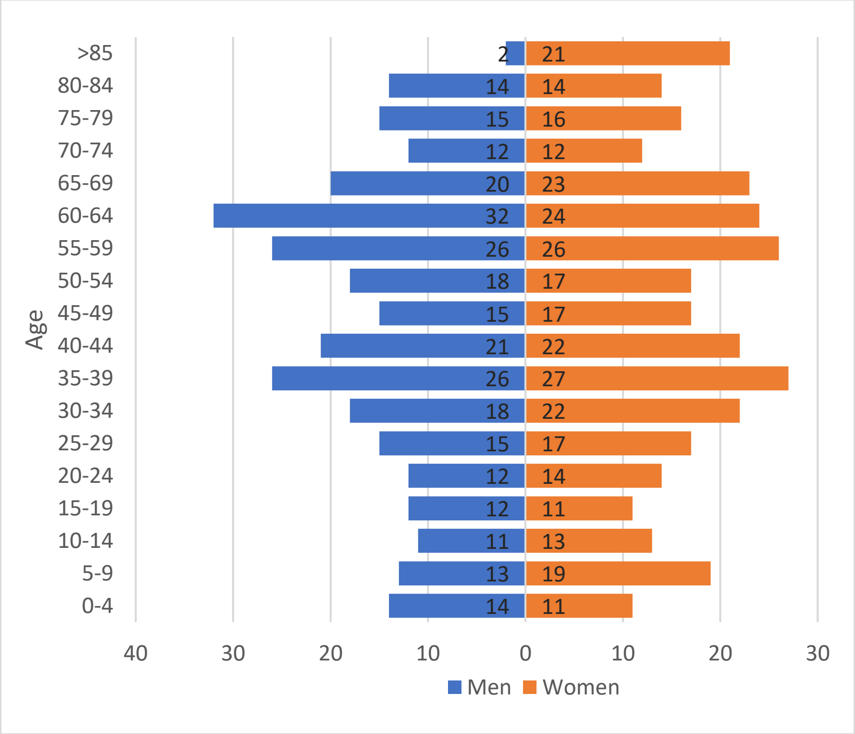


Figure 13: Population of the Son Espanyol neighbourhood according to age and gender. Data Source: [42]

In this study, the homes belonging to the Son Espanyol water community will be analysed. It is a group formed in 1984 and that groups 200 homes. Its history goes back to the years when people in the area demanded more and more water, but there was still no municipal supply network that reached that place. It was then when the neighbours decided to form the community and obtain the water that is currently extracted from a well and distributed through different pipes to those 200 houses [45]. Considering the average of 2,8 people per habitat mentioned above, it can be estimated that the number of inhabitants that make up this community of 200 houses is approximately 560 people.

As stated in the guide for the development of instruments to promote local energy communities [46], a good starting point for the formation of new energy communities is the irrigation communities, or in this case, water. These are groups of people with an organization and cohesion already established and, therefore, greatly facilitates the process of a project like this. It could be said that people are more willing to accept new proposals that have an impact on the improvement of the existing community.

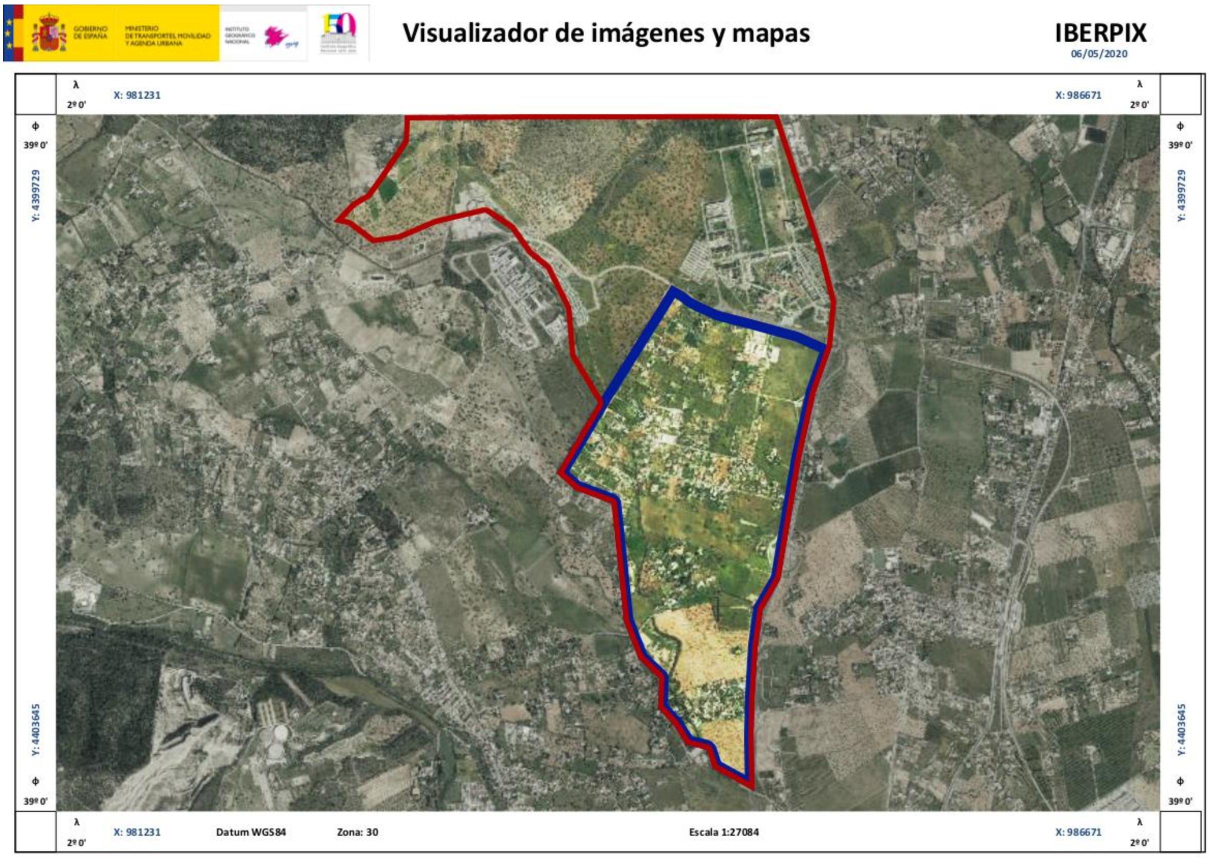


Figure 14:Satellite image of the Son Espanyol neighbourhood. Data source: [47]

The total area of the neighbourhood, marked in red in the Figure 14 and which includes the area occupied by the university and the technology park, is approximately 4,6 km^2. If the mentioned facilities, which are not going to be studied, are not considered, the approximate area occupied by the residential area is about 1,95 km^2. This area is the one marked in blue and, in addition, it also includes some of the houses that do not participate in the water community and that is not going to be studied either.

3.3. Study of current energy demand

To carry out the current energy study of the 200 houses that make up the water community, mainly four data sources have been used. These four resources have been the Atlas of Spanish electricity demand [48], a study on the analysis of energy consumption in the residential sector in Spain [49], the collection of electricity bills in recent months for 11 houses located in the neighbourhood and finally, obtaining consumption hour by hour of three of the houses through the smart electric meters that they have [50]. This last resource will only be used as a source of comparison with the previous ones due to the low statistical representativeness of a sample of 3 houses compared to the total of 200.

3.3.1. Energy consumption

The average consumption of a single-family house located in the Mediterranean climate zone is 1,255 toe per year (14.596 kWh). Below is the Table 5 with the average annual energy consumed per service and the proportion it represents to the total. These data will serve to understand how consumption works in homes like those that exist in the studied neighbourhood and what the lines of action may be.

Table 5: Average energy consumption per service in a Mediterranean single-family house. Data source: [49]

Service	toe/house	Percentage
Space heating	0,795	63,3%
Water heating	0,138	11,0%
Cooking	0,070	5,6%
Space cooling	0,015	1,2%
Lighting	0,040	3,2%
Home appliances	0,177	14,1%
Standby	0,019	1,5%
TOTAL	1,255	100%

As can be seen, most of the energy consumed is for space heating, amounting to 63,3% of total consumption. However, to fulfil this function, wood burning is widely used. And to a lesser extent, diesel and small LPG boilers are also used [49]. It can be said that biomass plays an important role within the energy demands of housing, even so, and although it is considered a renewable source, there is debate as to whether it is clean energy with neutral emissions.

On the other hand, regarding cooking and water heating services, many houses in the area have boilers and kitchens that work with LPG. Currently, the natural gas network has not yet reached this area of the municipality. Also, there is a regulation that requires that the solar contribution for water heating for homes in the area must be between 50 and 70% depending on consumption and whether the energy source is an oil product, gas or electricity [51]. This regulation is only applicable to new construction homes or those that are going to be rehabilitated, therefore, due to the age of the houses in the area and that most have not undergone a rehabilitation process in recent years, the contribution solar thermal power is still small.

3.3.2. Electric consumption

In this section, it will be defined the electric charge curve that best defines the homes of the neighbourhood. This process is going to be carried out by two different routes. First, through the historical studies found, a theoretical curve will be presented. Secondly, it will be graphed the existing average curve of the 11 houses that have provided their electricity bills in recent months. Finally, these two curves will be compared and the load that best fits the total situation of the 200 houses and that will be used in the case analysis curve build.

Electricity consumption by service in single-family homes in the Mediterranean, shown in Table 6, is significantly lower than energy consumption if all resources are considered. The annual average per home is 3.611 kWh electric, for the approximately 14.596 kWh energy mentioned in the previous section. As stated, the reason is due to the use of biomass for space heating and LPG for water heating and cooking.

Table 6: Average electric consumption per service in a Mediterranean single-family house. Data source: [49]

Service	**kWh/house**	**Percentage**
Space heating	230	6,4%
Water heating	321	8,9%
Cooking	276	7,6%
Space cooling	94	2,6%
Lighting	460	12,7%
Home appliances	2006	55,5%
Standby	224	6,2%
TOTAL	3611	100%

With the annual theoretical consumption data per house and the evolution of monthly demand, the electrical consumption curve per house for each month is drawn in Figure 15. On the other hand, is also plotted the average of the collected electric bills, this recollection of data can be found in Annex II.

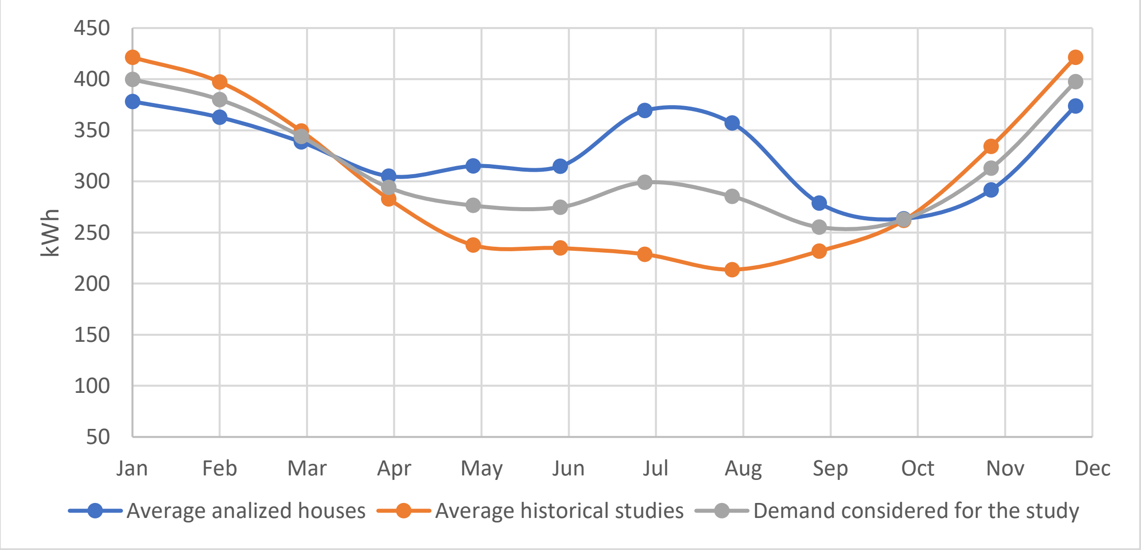


Figure 15: Monthly electricity consumption per house. Theoretical, bills average and case analysis curve. Data source: [48], [49] and own work.

During the cold months, the theoretical curve and that of the sample of houses follow a similar trend and values. On the other hand, during the months in which the temperatures are highest, the average of the collected values exceeds the theoretical consumption. In Annex II it can be seen how most houses have consumption peaks in summer, which are accentuated in those with more irregular values throughout the year.

To minimize possible variations and since neither of the two curves can be considered correct, one is based on a sample of only 11 houses and the other on a study of all single-family homes in the same climate zone, it has been decided that the monthly curve to be used in the study is the average of the two.

To study the variation in consumption during each day of the week and since the variation is minimal, the values that appear in the Atlas of Spanish electricity will be used. For this, January, February and December have been considered as winter months; like summer months have been June, July and August; and on average the rest of the months. As can be seen in Figure 16, the greatest consumption peaks occur on the weekends of winter, spring and autumn, when people spend more time in their homes.

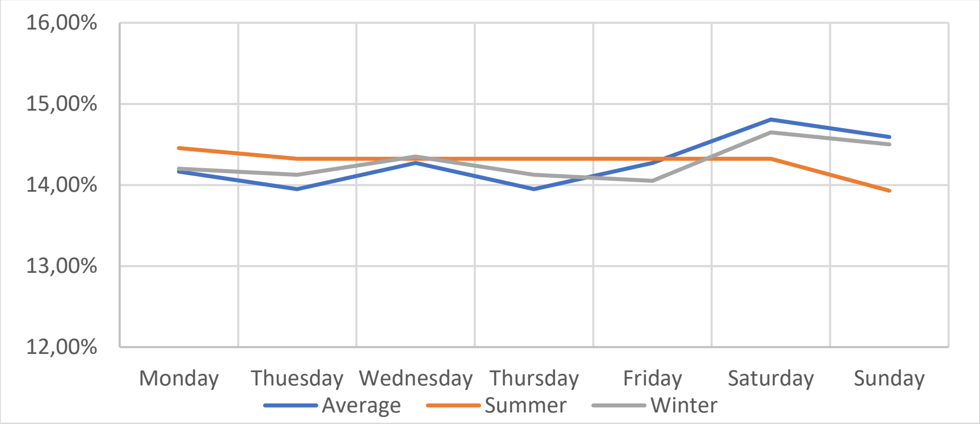


Figure 16: Daily profile of electrical consumption according to historical data. Data source: [48]

To finish defining the electrical curve of the houses in the neighbourhood, it has been plotted the average of the proportions of hourly consumption of electricity consumed from a sample of three houses. The curve provided in the Atlas of Spanish electricity is also shown.

Due to the small number of houses in the sample, the hourly data to be considered in the case analysis will be that provided by the Atlas. However, it is interesting to see Figure 17 where even a sample of these dimensions is quite close to the theoretical curve, showing the greatest difference in the peak generated during the winter months and that it should be studied if that difference exists or is due to the specific behaviour of these three houses.

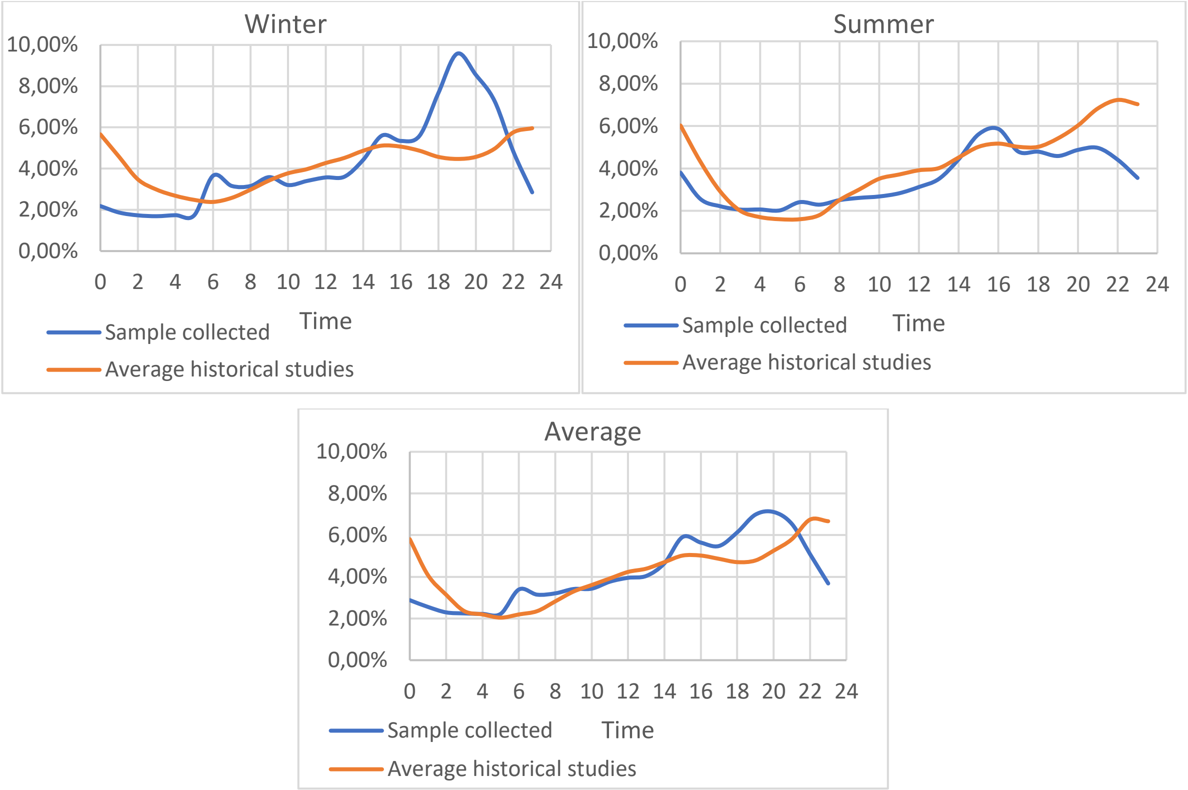


Figure 17: Hourly profile of electricity consumption for historical data and for a sample of 3 houses. Data source: [48] and [50]

Once the behaviour that the load curve will have during each hour and day of the year has been defined and knowing the number of houses that belong to the water community, which are 200, this value has been multiplied by the consumption that a house would have alone and the consumption profile of the community as a whole has been obtained. Using the Homer Energy software, the annual profile of the 200 houses has been plotted as shown in the Figure 18.

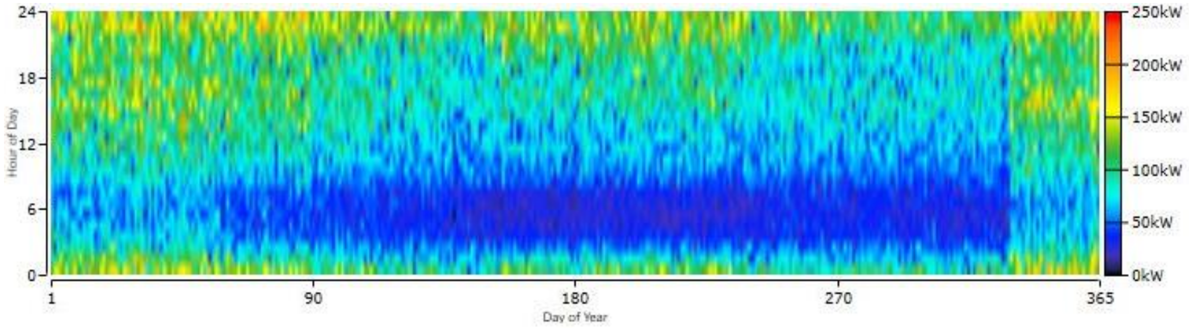


Figure 18: Electricity consumption of the 200 houses for each hour and day of the year. Source: [52]

3.4. Study and modelling of the solar resource

With an average of more than 300 sunny days a year and global irradiation greater than 2000 kWh / m^2 [53], without a doubt, one of the most projected energy resources in this location is that of solar energy. For its exploitation, there are two viable alternatives for the characteristics of the neighbourhood.

On the one hand, the installation of photovoltaic panels for the generation of electricity; its installation could be carried out on the roofs of the houses or on the multiple lands that are not used right now. On the other hand, there is the possibility of installing thermal solar panels to generate hot water or for the space heating; In this way, it would be possible to reduce the energy consumption of two of the most important services within the home.

Despite the great reduction in energy consumption that a solar thermal energy installation could offer, in this case analysis, only the generation of electricity with photovoltaic panels will be studied. The reasons are that a centralized thermal production facility that brings neighbours together in the community would be highly difficult and expensive due to the infrastructure it would entail. In addition, according to current regulations, the installation of thermal solar panels is mandatory in new homes or in those undergoing rehabilitation [51], which is why sooner or later, all houses must face this fact individually and would make a centralized installation will no longer make sense.

To carry out the study and modelling of the photovoltaic installation, it must first be known what the irradiation of the place is. Through the PVGIS platform [53], the hourly global irradiation data has been downloaded during each day of the year. Since a motorized solar panel system for tracking the sun depending on the variation of its angle of inclination is very expensive, in this project will be analysed the installation of fixed solar panels. Even so, and to counteract the angle of solar incidence and obtain higher performance, it will be considered that all the panels would be oriented towards the south direction and inclined at an angle of 35º, the optimal value for the Son Espanyol area. In Figure 19, the average global irradiation can be observed during one day of each month for this optimal angle.

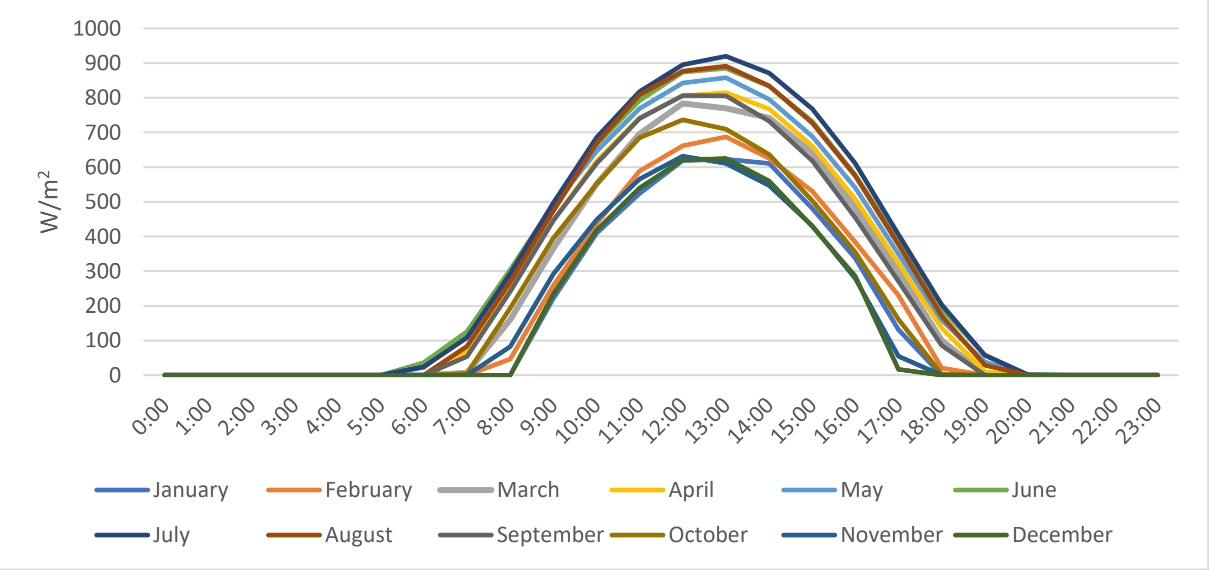


Figure 19: Average global irradiation during a day of each month, for an angle of 35º. Data Source: [53]

The performance of the solar cell decreases with increasing temperature. Both the electrical efficiency and the output power of a photovoltaic (PV) module depend linearly on the operating temperature. The electrical performance is mainly influenced by the photovoltaic material used. A typical commercial grade silicon photovoltaic module converts 6-20% of the incident solar radiation into electricity, the rest of the incident solar radiation is converted to heat, which significantly increases the temperature of the photovoltaic module and reduces the efficiency of the module [54]. Therefore, it is essential to analyse the air temperature at each time of the year to know what the operating temperature of the photovoltaic cells will be. Again, the data of air temperature at 2 m height for each day and time of the year have been obtained using the PVGIS platform and the hourly average is presented in Figure 20.

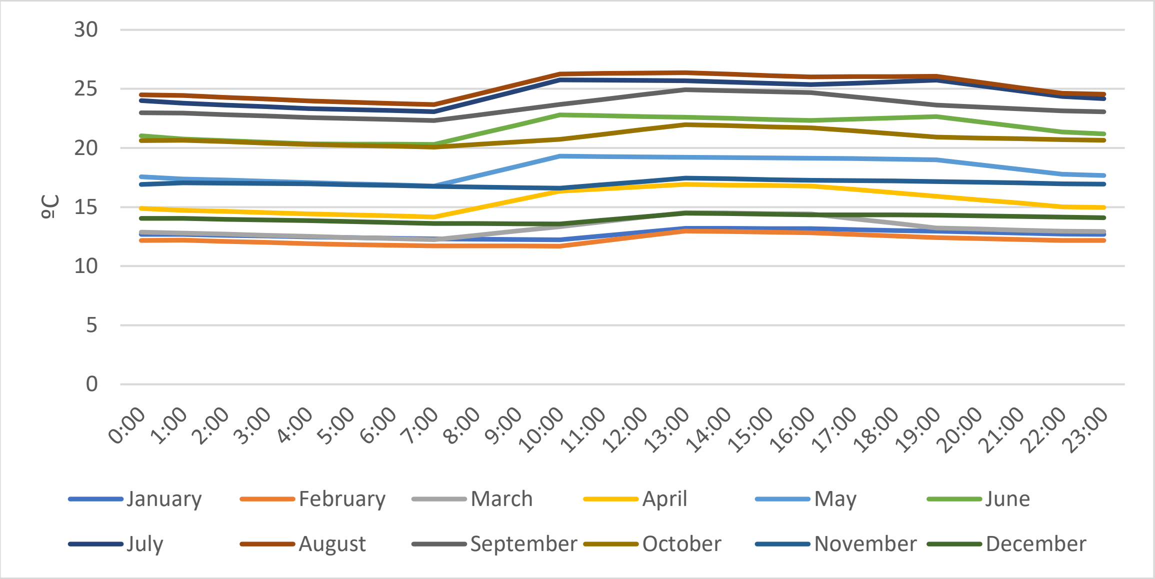
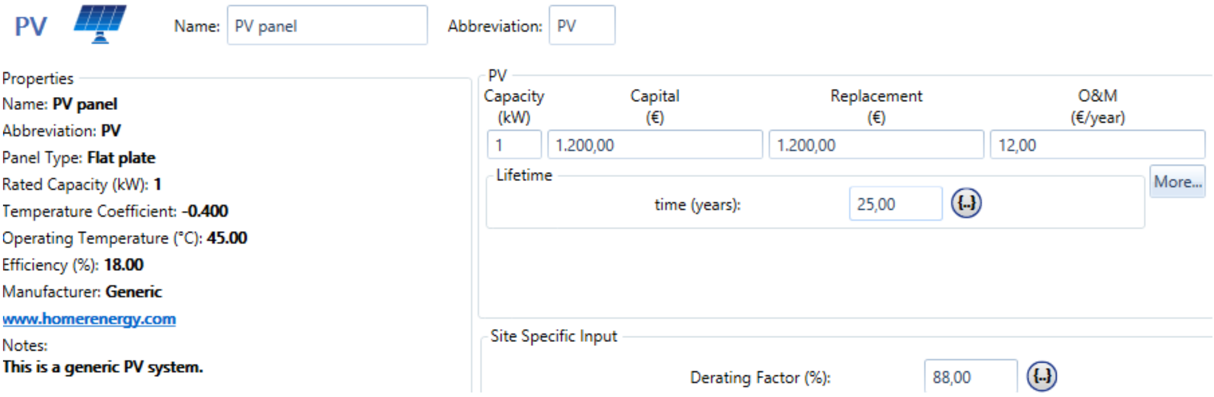


Figure 20: Average air temperature at 2 m altitude during one day of each month. Data Source: [53]

To do the optimization of the system with the Homer software, the data corresponding to the global horizontal irradiance per surface and the air temperature downloaded from the PVGIS were first entered. Also, an investment cost of 1,2 € / W has been estimated, this cost includes the panels and their installation [55]. For the technical characteristics, efficiency of the panels of 18% and a coefficient of losses because of temperature of -0,4% / ºC have been chosen. These are standard values of the current market and although more efficient panels can be placed, their price rises too much. Then, it has been estimated that the maintenance costs would be 1% per year concerning the initial investment and that the lifetime of the plates is 25 years. Finally, it has been established an inclination of the panels of 35º with respect to the ground and an Azimuth angle of 0º, that is, an orientation to the south. The data introduced in the software are those that appear in the Figure 21.



Name: PV panel

Abbreviation: PV

Properties

Name: **PV panel**

Abbreviation: **PV**

Panel Type: **Flat plate**

Rated Capacity (kW): **1**

Temperature Coefficient: **-0.400**

Operating Temperature (°C): **45.00**

Efficiency (%): **18.00**

Manufacturer: **Generic**

www.homerenergy.com

Notes:

This is a generic PV system.

PV

Capacity (kW)	Capital (€)	Replacement (€)	O&M (€/year)
1	1.200,00	1.200,00	12,00

Lifetime

time (years): 25,00

Site Specific Input

Derating Factor (%): 88,00

Figure 21: Solar panels characteristics

3.5. Study and modelling of the wind resource

Due to the decrease in radiation received during the winter months and the increase in electricity consumption in those months, it is important to study another energy resource that can balance production and demand during that period. For this, the implementation of wind turbines will be studied.

As can be seen in Figure 22, the Son Espanyol neighbourhood is not located in an area with a large wind resource, in fact, it is in one of the areas with the worst power density on the four islands. Even so, and due to the increase in wind speed in cold months, the feasibility of wind turbines will be studied

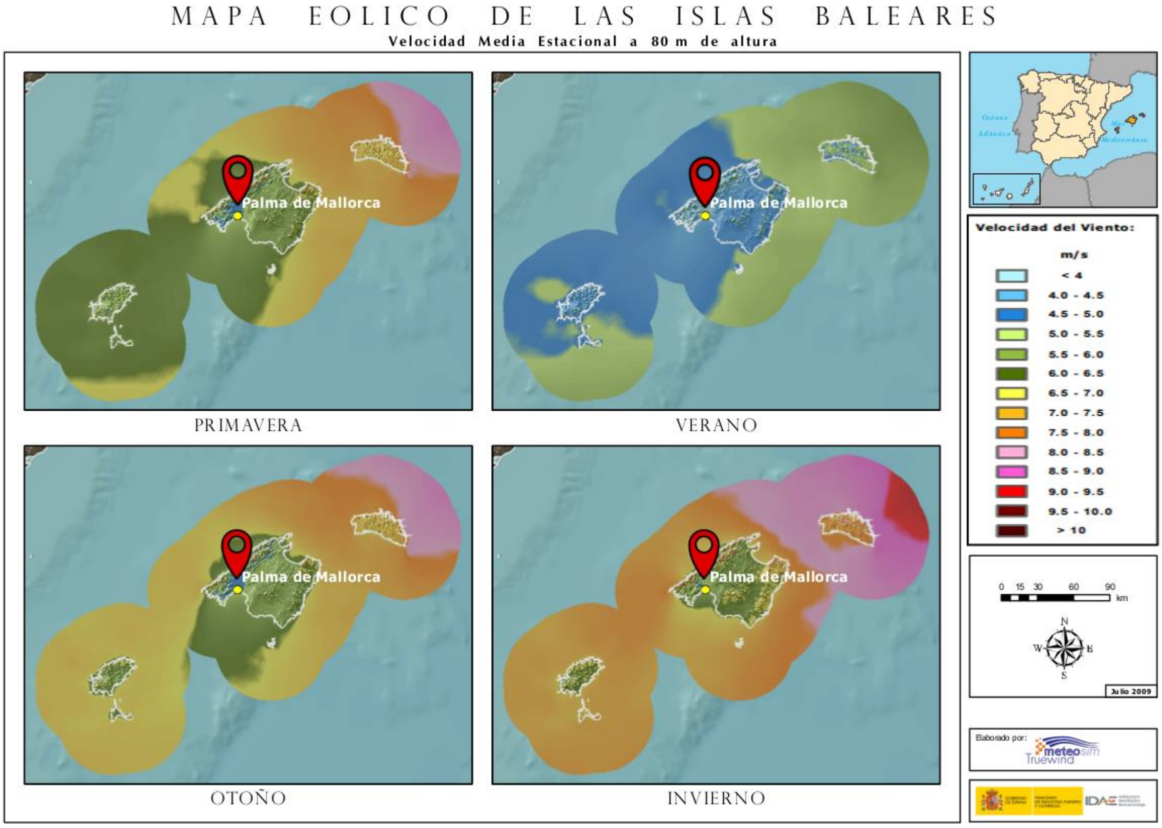


Figure 22: Seasonal wind map of the Balearic Islands at 80m altitude. Source: [56]

After consulting the current regulatory standards and due to the characteristics of the place and environmental regulations, it has been considered that the installation of permits for large wind turbines is practically unfeasible. Approximately 74,45% of the Balearic territory is not exploitable because it is located within urban centres or environmentally protected areas [57]. Therefore, it will be studied the installation of small wind turbines that would serve as support for photovoltaic technology and that should not have any restrictions regarding legal or environmental aspects.

To start with the modelling of wind turbines, firstly, the speeds that occur throughout the year have been studied. In this case, and to treat the data in a more precise way, the Weibull curve has not been constructed for the entire year, but instead, the speed data for each hour and day of the year was downloaded from the PVGIS platform at 10m from a height. On the other hand, from the Global Wind Atlas platform, the roughness coefficient for the area has been determined, which is 0,3 m due to the trees and the set of houses present [58]. With the set of speeds of 8760 that occur throughout the year and with the roughness coefficient; it has been determined, using the following wind profile equation, the speeds throughout the year at a height of 25 m, a typical height value for the type of wind turbines that are planned to be installed; obtaining the values presented in the Figure 23.

$$v = v_0 \times \frac{ln\left(\frac{h}{\beta}\right)}{ln\left(\frac{h_0}{\beta}\right)} \qquad (1)$$

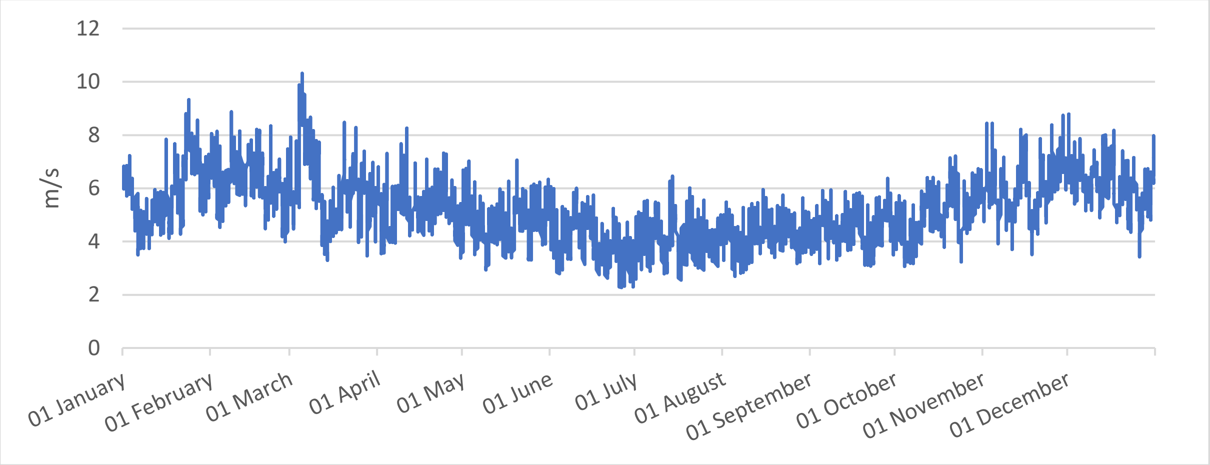


Figure 23: Wind speed for every hour of the year at an altitude of 25 m. Data Source: [53]

Once the wind speed at the typical height of the mini wind turbines was obtained, several models have been studied to decide which one best suit the environment. It is especially important to carry out this market study, as there are currently many wind turbines and each one of them has different behaviour and is the rest. For this, the power curves of each of them have been obtained, and together with the speed, it has been calculated what their annual production would be. In the Figure 24, the different wind turbines are shown comparing a year's production in kWh with the price they have in the market.

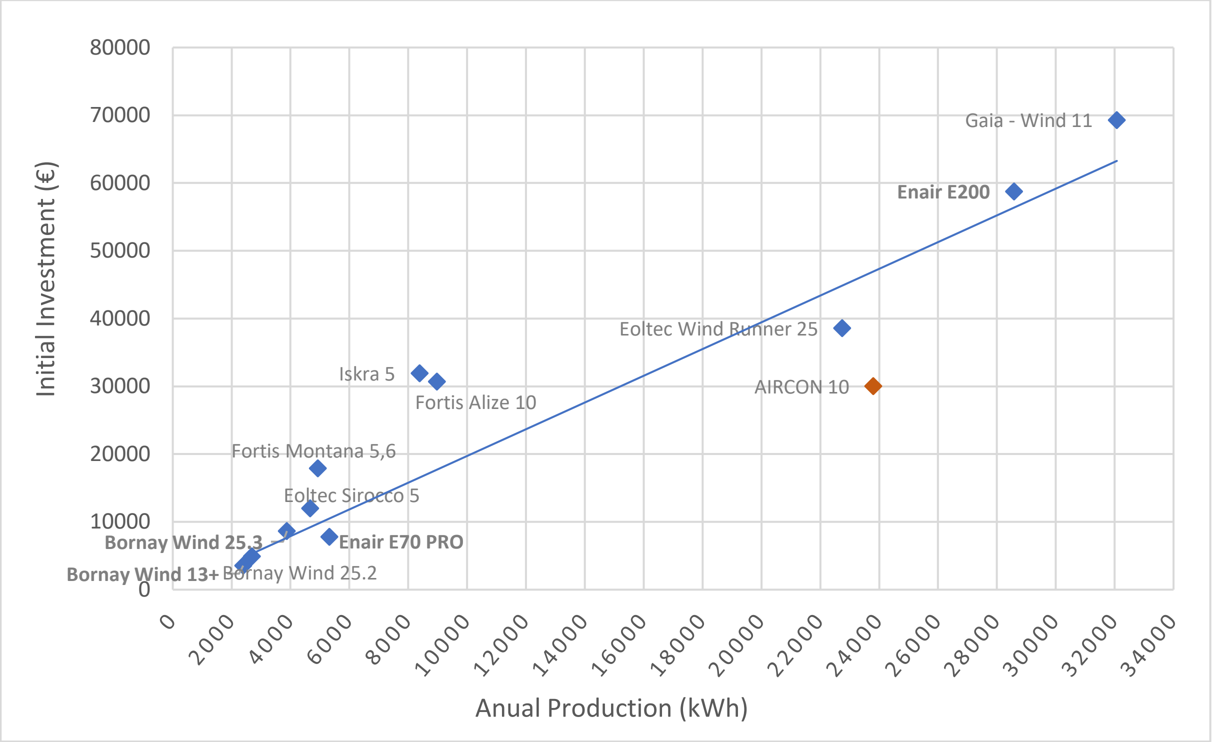
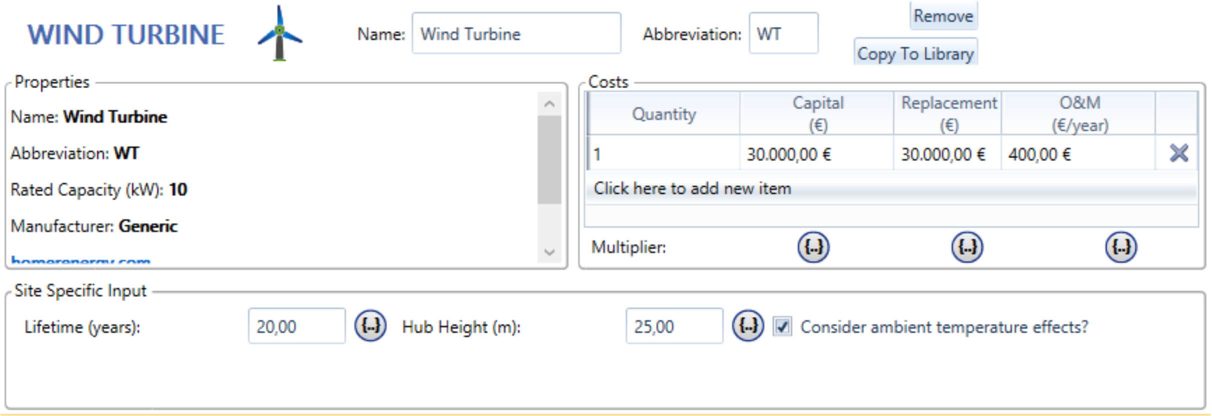


Figure 24: Comparison of the annual production of different wind turbines at an altitude of 25 m in Son Espanyol. Data source: [59], [60], [61] and own work

Two parameters have been used to choose the most suitable wind turbine for Son Espanyol. The first has been to discard those models that have small total production. Even though perhaps they could work in the generation of one or two houses, the case study of a community of 200 houses and the impact it would generate, makes it impossible to install many wind turbines. Once those models were discarded, the wind turbine with the best investment/production ratio was finally chosen. Thus, the model chosen for the feasibility study has been the Lely Aircon 10.

Subsequently, the technical characteristics and costs corresponding to the wind turbine have been introduced into the Homer software as in Figure 25 and Figure 26 for the subsequent optimization of the electrical architecture of the energy community.



Name: Wind Turbine
Abbreviation: WT

Name: **Wind Turbine**
Abbreviation: **WT**
Rated Capacity (kW): **10**
Manufacturer: **Generic**

Quantity	Capital (€)	Replacement (€)	O&M (€/year)
1	30.000,00 €	30.000,00 €	400,00 €

Click here to add new item

Lifetime (years): 20,00
Hub Height (m): 25,00
☑ Consider ambient temperature effects?

Figure 25: Lely Aircon 10 characteristics. Data Source: [62]

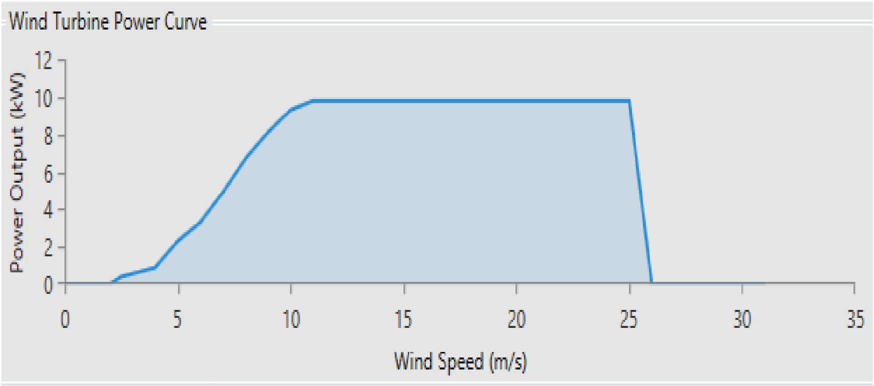


Figure 26: Lely Aircon 10 power curve. Data Source: [63]

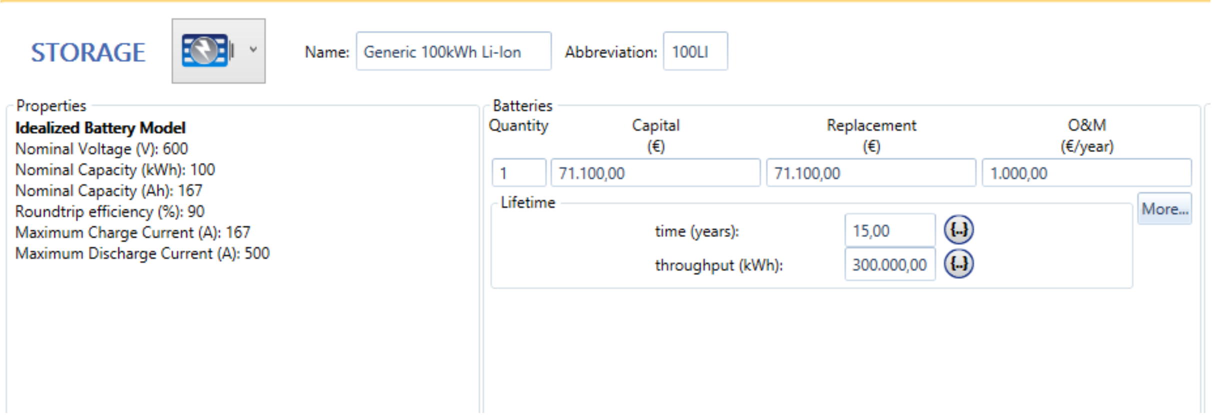
3.6. Modelling of the batteries

The possible installation of batteries has been modelled. Its function would be to store the excess energy production that photovoltaic panels would produce during the central hours of the day so that they could be consumed at night. Also, the battery system would provide stability to the community's electrical system, avoiding power cuts that would involve requesting electricity from the grid at times when the wind stops blowing or the sky suddenly clouds, at which time energy production would decrease dramatically.

This is possibly the most critical point in a renewable energy production installation. On the one hand, batteries enable us to produce more energy than is necessary at certain times of the day and their subsequent consumption, a fact that greatly reduces emissions to the atmosphere as consumption from the conventional network is reduced. But on the other hand, there is the economic factor, despite the current innovations that are taking place in this field, the batteries continue to have a high price in the market and their lifetime is less than that of the rest of the installation, such as solar panels or wind turbines. For this reason, it must be assessed whether the cost of storing each electric kWh is profitable or if it compensates with the reduction in emissions that would be occurring.

Of the current mature technologies for residential energy storage, it has been decided to analyze the installation of lithium-ion batteries. It is the predominant option for residential use and utility applications, given its low maintenance costs, which has no memory effect, it's high energy density compared to other types of batteries, and given its good efficiency, which is greater than 90% [64]. Also, and as will be seen later, they are the only type of batteries that are currently eligible for government subsidies [65].

The characteristics corresponding to a lithium ion battery bank that have been introduced in the Homer software, as appears in Figure 27, correspond to a price of 711 € / kWh, an average market value, and a lifetime of 15 years and 3.000 full discharge cycles [66].



Name: Generic 100kWh Li-Ion
Abbreviation: 100LI

Properties
Idealized Battery Model
Nominal Voltage (V): 600
Nominal Capacity (kWh): 100
Nominal Capacity (Ah): 167
Roundtrip efficiency (%): 90
Maximum Charge Current (A): 167
Maximum Discharge Current (A): 500

Batteries

Quantity	Capital (€)	Replacement (€)	O&M (€/year)
1	71.100,00	71.100,00	1.000,00

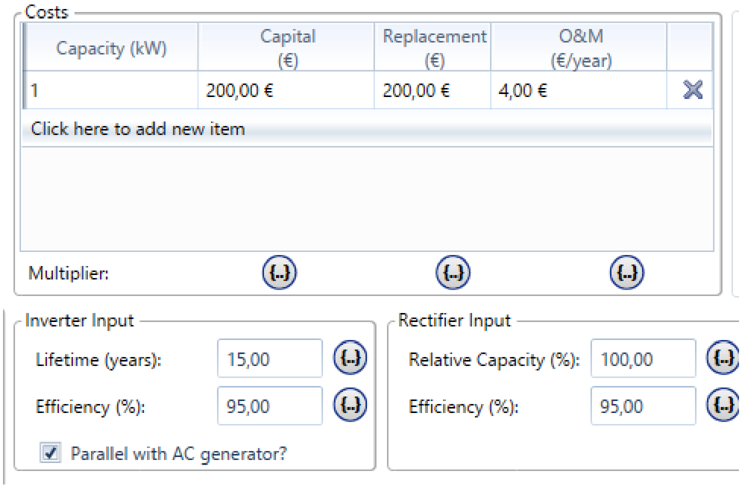
Lifetime
time (years): 15,00
throughput (kWh): 300.000,00

Figure 27: Characteristics of the lithium-ion batteries

3.7. Modelling of converter

With the installation of photovoltaic plates or energy storage systems of the battery type, it is necessary to install a converter from direct to alternating current. On the one hand, there would be the system of solar panels and the bank of batteries that work in direct current. On the other hand, the houses in the neighbourhood demand a classic single-phase and alternating current. And finally, there are the wind turbines that also have an alternating current output.

To square this architecture and that the type of current demanded by the houses can arrive, as well as so that it can be stored correctly in the batteries; The installation of converters has been modelled. It is a mature technology and, therefore, it does not have great difficulty for its study and implementation. For this, an investment cost of 200 € / kW of capacity and maintenance costs of 2% have been assumed concerning the initial investment. The data introduced in the software are those that appear in the Figure 28.


Costs

Capacity (kW)	Capital (€)	Replacement (€)	O&M (€/year)
1	200,00 €	200,00 €	4,00 €

Inverter Input
Lifetime (years): 15,00
Efficiency (%): 95,00
☑ Parallel with AC generator?

Rectifier Input
Relative Capacity (%): 100,00
Efficiency (%): 95,00

Figure 28: Characteristics of the converter system

3.8. Current grants to avail

To calculate the subsidies that could be received if the project will be developed, the current decree that regulates the public call for subsidies for the promotion of photovoltaic and micro-wind solar energy installations aimed at individuals, non-profit entities, small and medium-sized companies has been analysed [65]. These grants are made through funds belonging to the European Regional Development Fund.

Below is the information corresponding to what type of groups can avail of the subsidies, what characteristics the facility must have and what would be the amounts of money received; all this related to a project like the one proposed for the Son Espanyol neighbourhood:

In the first place, all those small and medium-sized companies, business associations, communities of owners and non-profit entities are eligible for these grants. Aid can be aimed at:

- Investments in new installations (including extensions of existing installations) of photovoltaic solar energy for self-consumption, with a peak power to install of up to 50 kWp. In the case of installing a power greater than 50 kWp, only the first 50 kWp will be subsidized.
- Investments in new small wind farms installations with peak power to install up to 10 kW. In the case of installing a power greater than 10 kW, only the first 10 kW will be subsidized. The mills must be integrated into the landscape and the installation of metal lattice supports is prohibited.
- Investments in lithium-ion accumulation systems, with an accumulation capacity between 2 kWh and 12 kWh, that have a minimum operating warranty certified by the manufacturer for five years.

Secondly, and regarding the amounts of money that would be received, the information is as follows:

- For applications submitted by non-profit entities and communities of owners, a 50% subsidy is established on the value of the admissible investment of photovoltaic installations. The maximum allowable investment value is 1,50 € / Wp for installations up to 10 kWp, 1,20 € / Wp for installations between 10 kWp and 25 kWp, and 1 € / Wp for the rest.
- For applications submitted by business associations or non-profit entities and communities of owners, a 50% subsidy is established on the value of the admissible investment of the micro-wind installations. The maximum admissible investment value is 5 € / W.
- In the case of photovoltaic or small wind farms installations that incorporate lithium-ion accumulation systems, a subsidy amount of 50% is established on the value of the admissible investment in accumulation. The maximum admissible investment value is 600 € / kWh accumulation.

4. Assessment of application and feasibility

This section will show the simulations and optimizations that have been carried out for the project of a sustainable energy community in the Son Espanyol neighbourhood. For this, different possible scenarios have been contemplated in which they could be found throughout the project. All of them, are presented in the Table 7.

Firstly, due to the installed power that the installation will have (> 100kW), and according to current regulations, surplus electricity must be sold on the open market and cannot be eligible for a feed-in tariff [67]. For this reason, optimizations will be carried out scenarios with two different prices for the kWh sold. First, it will be studied with a low price corresponding to 0,04 € / kWh and then with a price of 0,08 €/ kWh, values between which the sale of surplus electricity production could fluctuate. Also, a range of prices has been defined for the purchase of electricity, which ranges from 0,10 € / kWh to 0,20 € / kWh. As can be seen in Annex II. Data collected from electricity bills, in the invoices obtained for the study, the kilowatt-hour is currently being paid at 0,123 € or 0,148 € if the taxes are included.

Secondly and due to the possible modifications that the previously explained subsidies could undergo. It must be remembered that these subsidies are for the present year 2020 and that for future years they could change or be directly eliminated since it is a very variable aid fund depending on who governs at the time. Therefore, the project will be simulated on one stage with these aids and another without.

Table 7: Characteristics of the simulated scenarios

Scenario	Sale price	Purchase price	Grants	Additional characteristics
1	0,04 € / kWh	0,10 € / kWh	No	-
2	0,08 € / kWh	0,10 € / kWh	No	-
3	0,04 € / kWh	0,20 € / kWh	No	-
4	0,08 € / kWh	0,20 € / kWh	No	-
5	0,08 € / kWh	0,10 € / kWh	No	Limitation of installed power
6	0,08 € / kWh	0,20 € / kWh	No	Limitation of installed power
7	0,04 € / kWh	0,10 € / kWh	Yes	-
8	0,04 € / kWh	0,20 € / kWh	Yes	-

4.1. Scenario 1

In this simulation an optimization of a future sustainable energy community in the 200 homes that make up the water community in the Son Espanyol neighbourhood, a scenario has been contemplated in which the price at which excess electricity generated in the community would be sold is 0,04 €. On the other hand, the purchase price from the network has been established at 0,10 € / kWh, a low market price. Also, it is contemplated that the project could not access to public subsidies.

The first thing that is observed in the results is that because the Homer Energy software performs optimization for the search for the best solution in economic terms; in the current scenario, the options contemplated for the installation of lithium batteries and wind turbines are ruled out. The cost of storing the batteries is 0,25 € / kWh and the cost of the wind production is approximately 0,126 € / kWh throughout their useful lives, results above what is currently paid for the purchase of electricity from the network, which is approximately 0,10 € / kWh depending on the contracted marketer.

Thus, the optimal architecture offered by the results of the simulation carried out with the Homer Energy software is that of the installation of photovoltaic panels and the respective converter system, as indicated in the Table 8 and Table 9. It is established that the optimal power to install is 145 kW, which would entail a production cost of 0,0585 € / kWh. It is a cost that is above the value that would be received if energy were sold to the market but below the price at which it would be purchased from the marketer. That is, it is a price that guides the architecture of the installation to the objective of covering the demands of the houses during the hours of production of the panels and that in the long term offers economic savings to the population since they are decreasing their consumption in the conventional electrical network.

Table 8: Optimized solar panels system. Source: [52]

Quantity	Value	Quantity	Value
Rated Capacity	145 kW	**Minimum Output**	0 kW
Mean Output	27,5 kW	**Maximum Output**	121 kW
Mean Output	661 kWh/d	**PV Penetration**	32,5 %
Capacity Factor	19 %	**Hours of Operation**	4.162 hrs/yr
Total Production	241.315 kWh/yr	**Levelized Cost**	0,0585 €/kWh

Table 9: Optimized converter system. Source: [52]

Quantity	Inverter	Rectifier	Quantity	Inverter	Rectifier
Capacity	92,9 kW	92,9 kW	**Hours of Operation**	4.162 hrs/yr	0 hrs/yr
Mean Output	25,8 kW	0 kW	**Energy Out**	226.353 kWh/yr	0 kWh/yr
Minimum Output	0 kW	0 kW	**Energy In**	238.266 kWh/yr	0 kWh/yr
Maximum Output	92,9 kW	0 kW	**Losses**	11.913 kWh/yr	0 kWh/yr
Capacity Factor	27,8 %	0 %			

As can be seen in **¡Error! No se encuentra el origen de la referencia.**, the PV Penetration, consisting o f the average output power of the PV array divided by the average primary load, is 32,5 %. If sales and purchases from the electricity grid are considered, it is observed that finally that the fraction of the energy delivered to the load that produces the self-consumption is 27,2 %.

From the total energy produced by the solar system, and once the losses of the converter system are discounted, there is a volume of self-consumed energy of 201.855 kWh and the remaining 24.498 kWh are sold to the grid each year. In this way, the community would be purchasing 540.063 kWh annually to reach the total load that reaches approximately 741.918 kWh, as shown in the Figure 29. The hour-by-hour interaction with the grid can be seen in the Annex III figures. On the other hand, in Figure 30, it can be seen what the costs associated with each component of the installation would be, including the purchase of electricity from the grid.

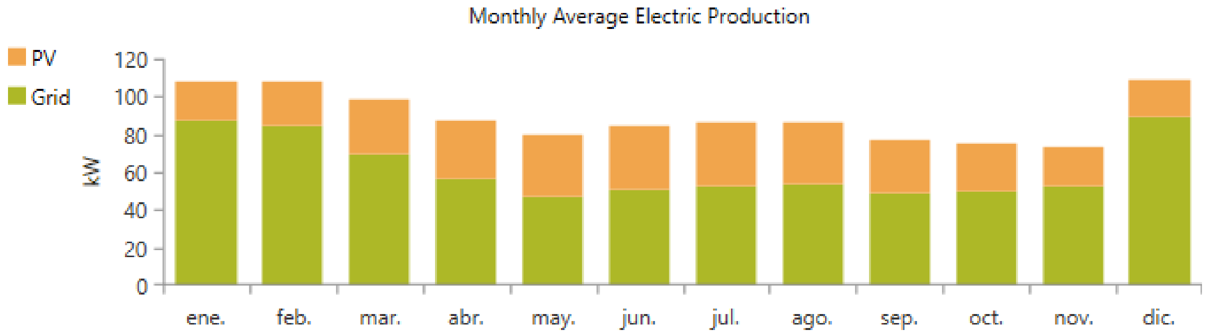


Figure 29: Monthly average of electricity production by source. Source: [52]

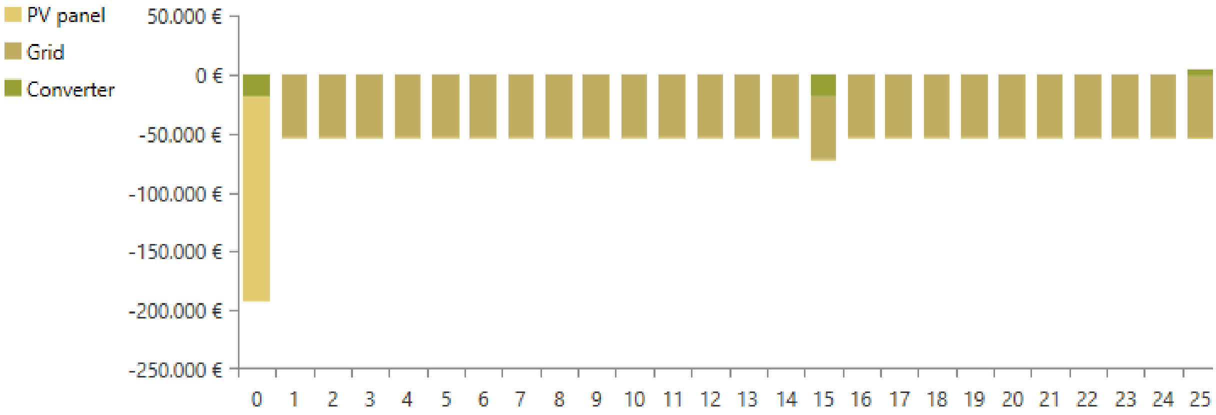


Figure 30: Nominal cash flow costs. Source: [52]

Regarding the atmosphere emissions, shown in Table 10, the system has calculated that 418.764 kg of CO2 will be emitted per year in the new sustainable energy community that is proposed. This value has been calculated from the energy that would be purchased from the grid and the emission factors presented in Table 10. Comparing with the base scenario, in which all electricity is purchased from the grid and the quantity of emissions emitted is 575.283 kg of CO2 per year; the reduction obtained is around 27,2%.

Table 10: Simulated system emissions. Source: [52]

Quantity	Value
Carbon Dioxide	418764 kg/yr
Carbon Monoxide	0 kg/yr
Unburned Hydrocarbons	0 kg/yr
Particulate Matter	20,5 kg/yr
Sulfur Dioxide	574 kg/yr
Nitrogen Oxides	934 kg/yr

Finally, in the Table 11, is studied the economic viability of the energy community proposed in this scenario. For 25 years, a discounted return period of approximately 15,47 years is obtained; for this, the investments made throughout the life of the project have been assumed as monetary outflows and the annual savings that would be produced with the reduction of electricity purchases from the grid as inputs. Also, it is obtained that at the end of those 25 years, the net present value is 68.441 €; a value that would correspond to the total accumulated savings over those years.

Table 11: Economic comparison between the proposed system and the current one. Source: [52]

Metric	Value
Present worth	68.441 €
Annual worth	4.856 €
Return on investment	5,6 %
Internal rate of return	8,3 %
Simple payback	10,13 yr
Discounted payback	15,47 yr

4.2. Scenario 2

In this second simulation, a scenario is proposed in which no subsidy is received again, the purchase price from the network remains at 0,10 € / kWh, but in which the sale price of the electrical surplus produced is somewhat higher, at 0,08 € / kWh. Again, the options to install the selected lithium batteries and wind turbines are ruled out. The cost of storing batteries is still 0,25 € / kWh and the cost of wind production is around 0,126 € / kWh, above what is currently paid for the purchase of electricity from the grid.

The optimal architecture in this new scenario proposes the installation of the maximum possible photovoltaic power. Solar production costs are estimated at 0,0585 € / kWh and, as has been said, the price at which the surpluses would be sold is 0,08 € / kWh. In this way, all the energy that the system is generating provides a positive net benefit to the community and is interested in producing the highest possible levels.

The proposed architecture is 1.657 kW of installed power in solar panels and a 1.035 kW converter system, as indicated in the Table 12 and Table 13, being more similar values to those of the large solar parks owned by the large electricity producers.

Table 12: Optimized solar panels system. Source: [52]

Quantity	Value	Quantity	Value
Rated Capacity	1.657 kW	**Minimum Output**	0 kW
Mean Output	314 kW	**Maximum Output**	1.381 kW
Mean Output	7.540 kWh/d	**PV Penetration**	371 %
Capacity Factor	19 %	**Hours of Operation**	4.162 hrs/yr
Total Production	2.751.993 kWh/yr	**Levelized Cost**	0,0585 €/kWh

Table 13: Optimized converter system. Source: [52]

Quantity	Inverter	Rectifier	Quantity	Inverter	Rectifier
Capacity	1.035 kW	1.035 kW	**Hours of Operation**	4.162 hrs/yr	0 hrs/yr
Mean Output	293 kW	0 kW	**Energy Out**	2.569.572 kWh/yr	0 kWh/yr
Minimum Output	0 kW	0 kW	**Energy In**	2.704.812 kWh/yr	0 kWh/yr
Maximum Output	1.035 kW	0 kW	**Losses**	135.241 kWh/yr	0 kWh/yr
Capacity Factor	28,3 %	0 %			

The penetration of the photovoltaic system is 371%, that is, almost three times more electricity is generated than the community consumes at the end of the year. Considering the interactions with the conventional electrical network, the final fraction of the energy delivered to the load that originates from renewable energy sources without taking into account the losses of the converter system is 41,7%.

Of the approximately 741.918 kWh of electricity that the sustainable energy community of Son Espanyol would consume per year, a total of 432.901 kWh would be purchased from the grid and 309.017 kWh would come from the community's production. Also, the excess energy produced by the photovoltaic system would be 2.260.554 kWh per year, a value well above the previous ones, as shown in the Figure 31. In Figure 32, it can be seen what the costs associated to each component.

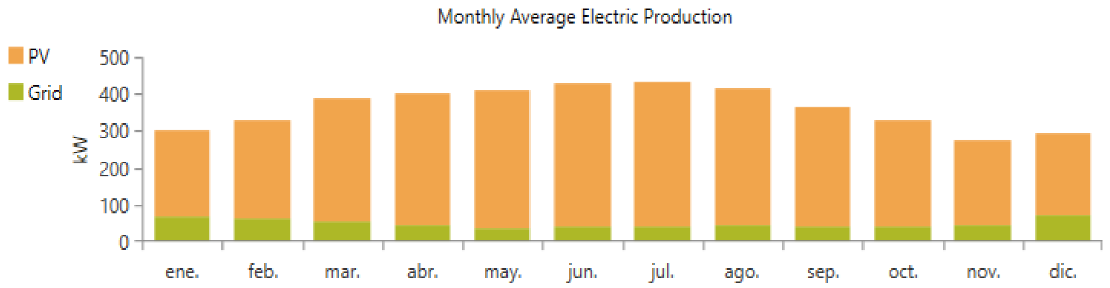


Figure 31: Monthly average of electricity production by source. Source: [52]

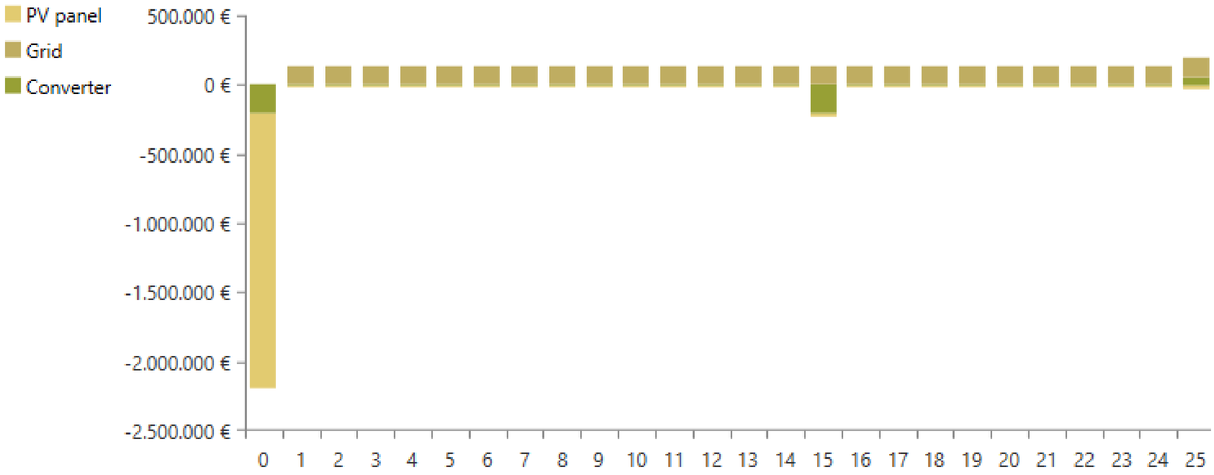


Figure 32: Nominal cash flow costs. Source: [52]

In the present scenario, it has been calculated that for the proposed installation, there would be a total of 335.671 kg of CO_2 emitted per year into the atmosphere due to the consumption of electricity from the conventional electrical grid. This value, presented in Table 14, represents a reduction of 41,7% compared to the 575.283 kg currently emitted per year.

Table 14: Simulated system emissions. Source: [52]

Quantity	Value
Carbon Dioxide	335.671 kg/yr
Carbon Monoxide	0 kg/yr
Unburned Hydrocarbons	0 kg/yr
Particulate Matter	16,5 kg/yr
Sulfur Dioxide	460 kg/yr
Nitrogen Oxides	749 kg/yr

Regarding the economic viability, of the energy community proposed in this scenario, for 25 years and shown in the Table 15, a discounted amortization of 19,37 years is obtained. This is a somewhat high value, due to the high initial investment that must be made to install the photovoltaic panels. Also, a net present value of 371.004 € is obtained at the end of those 25 years. Unlike the previous scenario, this value is now real benefits that the community would obtain from the sale of electricity to the grid.

Table 15: Economic comparison between the proposed system and the current one. Source: [52]

Metric	Value
Present worth	371.004 €
Annual worth	26.324 €
Return on investment	4,3 %
Internal rate of return	6,6 %
Simple payback	11,7 yr
Discounted payback	19,37 yr

4.3. Scenario 3

In this scenario, the sale price of surplus electricity is re-established at 0,04 € / kWh, but the price that the consumer would pay for purchases from the grid is increased to 0,2 € / kWh. In this way, the variation in the viability of the energy community would be studied if the price of the electric bill increases over the years.

The optimal architecture presented by the system in terms of the photovoltaic system is 121 kW installed, slightly lower than that of the first scenario and which would serve to cover the electrical demand in the hours of solar production. Besides, the installation of the wind turbines is now profitable, since its production cost is 0,126 € / kWh and would generate savings compared to the 20 cents paid to the grid. The result is that the installation of 16 wind turbines is optimal, with a total installed power of 160 kW. For its part, the recommended converter system would be 75,9 kW. Next, the optimal results for each of the systems are presented in Table 16, Table 17 and Table 18.

Table 16: Optimized solar panels system. Source: [52]

Quantity	Value	Quantity	Value
Rated Capacity	121 kW	**Minimum Output**	0 kW
Mean Output	22,9 kW	**Maximum Output**	101 kW
Mean Output	550 kWh/d	**PV Penetration**	27,1 %
Capacity Factor	19 %	**Hours of Operation**	4.162 hrs/yr
Total Production	200.792 kWh/yr	**Levelized Cost**	0,0585 €/kWh

Table 17: Optimized wind turbines system. Source: [52]

Quantity	Value	Quantity	Value
Total Rated Capacity	160 kW	**Minimum Output**	3,34 kW
Mean Output	41,3 kW	**Maximum Output**	151 kW
Capacity Factor	25,8 %	**Wind Penetration**	48,7 %
Total Production	361.666 kWh/yr	**Hours of Operation**	8.760 hrs/yr
		Levelized Cost	0,126 €/kWh

Table 18: Optimized converter system. Source: [52]

Quantity	Inverter	Rectifier	Quantity	Inverter	Rectifier
Capacity	75,9 kW	75,9 kW	**Hours of Operation**	4.162 hrs/yr	0 hrs/yr
Mean Output	21,4 kW	0 kW	**Energy Out**	187.705 kWh/yr	0 kWh/yr
Minimum Output	0 kW	0 kW	**Energy In**	197.585 kWh/yr	0 kWh/yr
Maximum Output	75,9 kW	0 kW	**Losses**	9.879 kWh/yr	0 kWh/yr
Capacity Factor	28,2 %	0 %			

The annual generation that this system represents concerning the total load of the 200 homes is 75,8%. However, an important part of the production is sold to the grid and finally, 59,5% is covered with self-consumed energy. Therefore, and considering the losses, of the 741.918 kWh consumed annually by the energy community, a total of 300.480 kWh would be purchased from the grid and 441.438 kWh would come from the community's production. Grid sales would represent 107.933 kWh per year. In Figure 33 and Figure 34, the monthly averages of production according to source and cash flows according to the component are shown respectively.

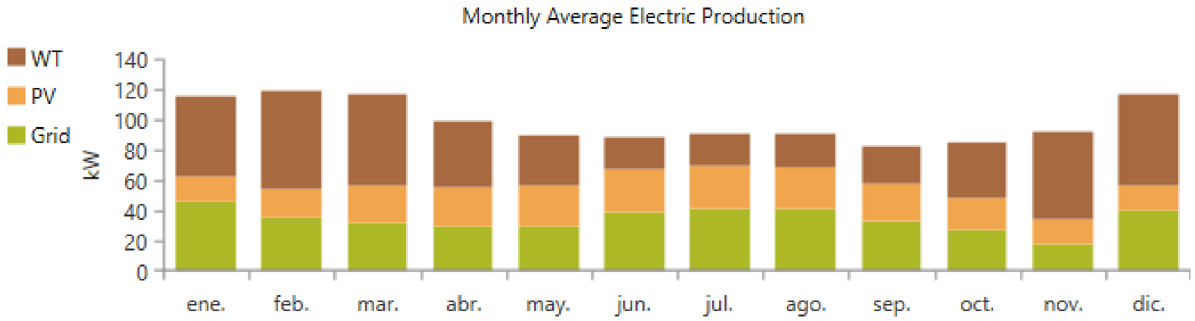


Figure 33: Monthly average of electricity production by source. Source: [52]

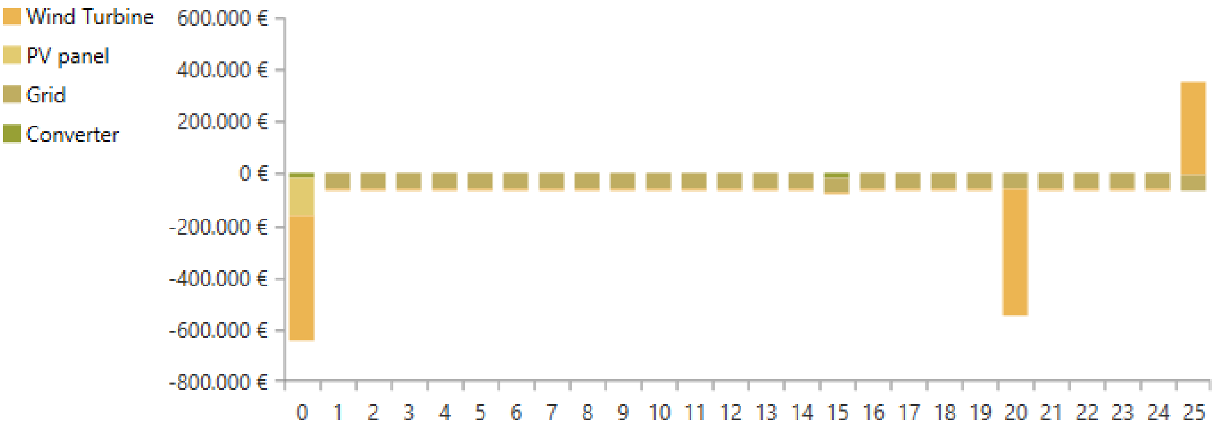


Figure 34: Nominal cash flow costs. Source: [52]

The total of emissions produced per year due to the to the consumption of electricity from the conventional electrical grid 232.992 kg of CO_2. This value, presented in Table 19, represents a reduction of 59,5 % compared to the 575.283 kg currently emitted per year.

Table 19: Simulated system emissions. Source: [52]

Quantity	Value
Carbon Dioxide	232.992 kg/yr
Carbon Monoxide	0 kg/yr
Unburned Hydrocarbons	0 kg/yr
Particulate Matter	11,4 kg/yr
Sulfur Dioxide	319 kg/yr
Nitrogen Oxides	520 kg/yr

Finally, and regarding the economic viability of the energy community shown in Table 20, it is obtained a discounted payback of 9,77. It is a very interesting payback period and could be lower if it were not for the installation of the wind turbines. Also, a net present value of 469.555 € is obtained at the end of those 25 years. This value corresponds to the savings that would be generated in the electric bills by reducing the electrical consumption of the network that is paid to 0,2 € / kWh.

Table 20: Economic comparison between the proposed system and the current one. Source: [52]

Metric	Value
Present worth	469.555 €
Annual worth	33.316 €
Return on investment	8,4 %
Internal rate of return	11,8 %
Simple payback	7,58 yr
Discounted payback	9,77 yr

:

4.4. Scenario 4

In the fourth scenario, high values are proposed for both the sale price of surpluses, located at 0,08 € / kWh, and the purchase price on the grid, at 0,2 € / kWh. This situation could occur if the price of electricity rises over the years and the electricity companies are willing to pay more money to produce the energy communities and individual producers.

As can be seen, the optimal architecture of this scenario is a mixture of that offered in the simulations of scenario 2 and 3. On the one hand, since the cost of solar production is lower than the purchase of surplus, it is recommended to install the maximum possible photovoltaic panels to generate direct benefits; obtaining results of 1.659 kW of solar power. On the other hand, the costs of wind production are lower than the purchase price on the grid and the installation of wind turbines is profitable, which results in savings in bills. The optimal wind system is 17 wind turbines, with a total power of 170 kW. Optimal results for each of the systems are presented in Table 21, Table 22 and Table 23.

Table 21: Optimized solar panels system. Source: [52]

Quantity	Value	Quantity	Value
Rated Capacity	1.659 kW	**Minimum Output**	0 kW
Mean Output	314 kW	**Maximum Output**	1.383 kW
Mean Output	7.548 kWh/d	**PV Penetration**	371 %
Capacity Factor	19 %	**Hours of Operation**	4.162 hrs/yr
Total Production	2.754.920 kWh/yr	**Levelized Cost**	0,0585 €/kWh

Table 22: Optimized wind turbines system. Source: [52]

Quantity	Value	Quantity	Value
Total Rated Capacity	170 kW	**Minimum Output**	3,55 kW
Mean Output	43,9 kW	**Maximum Output**	160 kW
Capacity Factor	25,8 %	**Wind Penetration**	51,8 %
Total Production	384.271 kWh/yr	**Hours of Operation**	8.760 hrs/yr
		Levelized Cost	0,126 €/kWh

Table 23: Optimized converter system. Source: [52]

Quantity	Inverter	Rectifier	Quantity	Inverter	Rectifier
Capacity	1.035 kW	1.035 kW	**Hours of Operation**	4.162 hrs/yr	0 hrs/yr
Mean Output	294 kW	0 kW	**Energy Out**	2.571.707 kWh/yr	0 kWh/yr
Minimum Output	0 kW	0 kW	**Energy In**	2.707.060 kWh/yr	0 kWh/yr
Maximum Output	1.035 kW	0 kW	**Losses**	135.353 kWh/yr	0 kWh/yr
Capacity Factor	28,4 %	0 %			

As in the second simulated scenario and as appears in Figure 35, a large overproduction occurs in the photovoltaic system that is sold to the grid. In total, the community produces 3.139.191 kW a year, which represents 423,1% of what the houses as a whole demand. Of this value, and subtracting the losses produced in the converter system, a total of 493.447 kWh is destined for self-consumption and 2.462.530 kW are sold. In this way, the final self-consumption represents 66,5%.

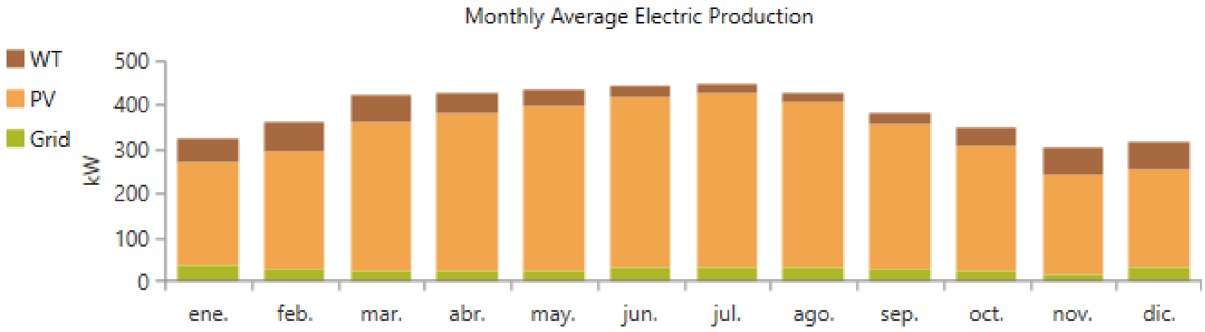


Figure 35: Monthly average of electricity production by source. Source: [52]

In Figure 36, its presented the costs associated with each component of the installation, including the purchase of electricity from the grid.

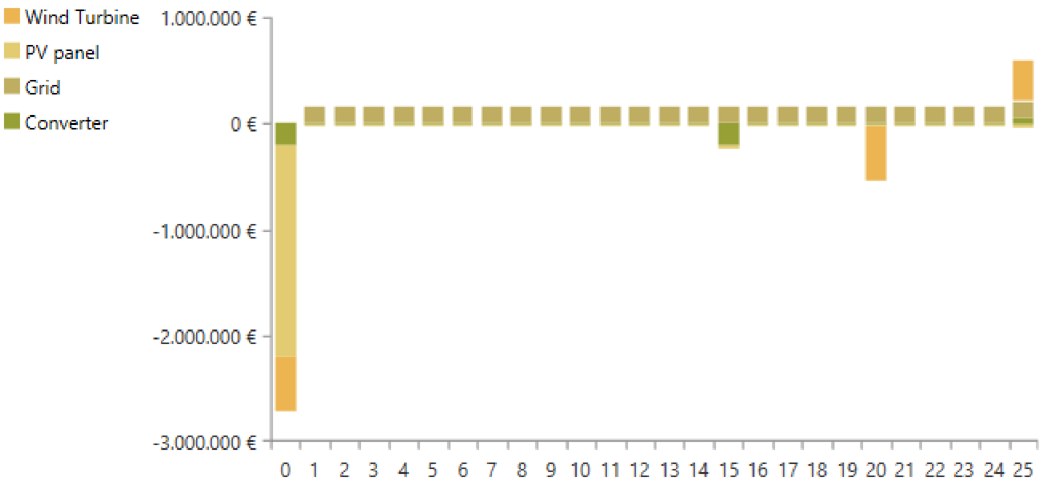


Figure 36: Nominal cash flow costs. Source: [52]

The 66,5% of self-consumed energy also affects a reduction in annual emissions in the same proportion. With the new system, the community emits 192.664 kg of CO_2 per year and represents a notable reduction compared to the 575.283 kg currently emitted. These and the other emissions are shown in Table 24.

Table 24: Simulated system emissions. Source: [52]

Quantity	Value
Carbon Dioxide	192.664 kg/yr
Carbon Monoxide	0 kg/yr
Unburned Hydrocarbons	0 kg/yr
Particulate Matter	9,44 kg/yr
Sulfur Dioxide	264 kg/yr
Nitrogen Oxides	430 kg/yr

In terms of economics, a discounted payback of 15,48 years is estimated, due to the large installed solar power. The net present value, as shown in Table 25, estimated at the end of the 25-year life of the project is 866.618 €, a value that includes both the benefits obtained from the sale of electricity and the savings from the self-consumption of energy from both the panels and wind turbines.

Table 25: Economic comparison between the proposed system and the current one. Source: [52]

Metric	Value
Present worth	866.618 €
Annual worth	61.489 €
Return on investment	5,4 %
Internal rate of return	8 %
Simple payback	10,22 yr
Discounted payback	15,48 yr

4.5. Scenario 5

This new scenario has the same characteristics contemplated in the second scenario, with a purchase price of 10 cents per kilowatt and 8 cents for sale. The difference is that the power of the solar system to be installed has now been limited. It is understood that a power greater than megawatt, is more representative of an electric company that seeks to generate economic benefits than of a sustainable energy community.

Therefore, the power has been limited according to the total energy that the 200 houses would need in a year. Although the installation of a storage system within the community is currently not economically viable, the grid can be used as a macro-battery in which energy is shared between the different communities and large renewable production systems. Although to truly have neutral global emissions, other sustainable energy communities must be formed on the island and the energy mix has to increase its share of renewables.

To set the power limits, it has been established that the outgoing energy of the converter system is close to the 741.918 kWh that is needed per year. Therefore, the losses produced in the converter system and the losses produced by temperature variations in the photovoltaic system and wind turbines will be considered. The optimal result is that 473 kW installed in a photovoltaic system is necessary and the installation of wind turbines is ruled out because it has an energy production cost higher than the purchase price for the grid. The optimal results of the photovoltaic system and the converter system are presented in the Table 26 and Table 27.

Table 26: Optimized solar panels system. Source: [52]

Quantity	Value	Quantity	Value
Rated Capacity	473 kW	**Minimum Output**	0 kW
Mean Output	89,7 kW	**Maximum Output**	395 kW
Mean Output	2.153 kWh/d	**PV Penetration**	106 %
Capacity Factor	19 %	**Hours of Operation**	4.162 hrs/yr
Total Production	786.019 kWh/yr	**Levelized Cost**	0,0585 €/kWh

Table 27: Optimized converter system. Source: [52]

Quantity	Inverter	Rectifier	Quantity	Inverter	Rectifier
Capacity	316 kW	316 kW	Hours of Operation	4.162 hrs/yr	0 hrs/yr
Mean Output	84,7 kW	0 kW	Energy Out	742.033 kWh/yr	0 kWh/yr
Minimum Output	0 kW	0 kW	Energy In	781.087 kWh/yr	0 kWh/yr
Maximum Output	316 kW	0 kW	Losses	39.054 kWh/yr	0 kWh/yr
Capacity Factor	26,8 %	0 %			

Regardless of losses, the photovoltaic system produces 105,8% of the electricity that the community needs each year. Despite this, only the necessary load is consumed during the hours of solar production and the surpluses, which represent 459.396 kWh of the 786.019 kWh generated, are dumped into the grid. In this way, 282.636 kWh are self-consumed, which represents 38,1% of the needs. In Figure 37 and Figure 38, the monthly averages of production according to source and cash flows according to the component are shown.

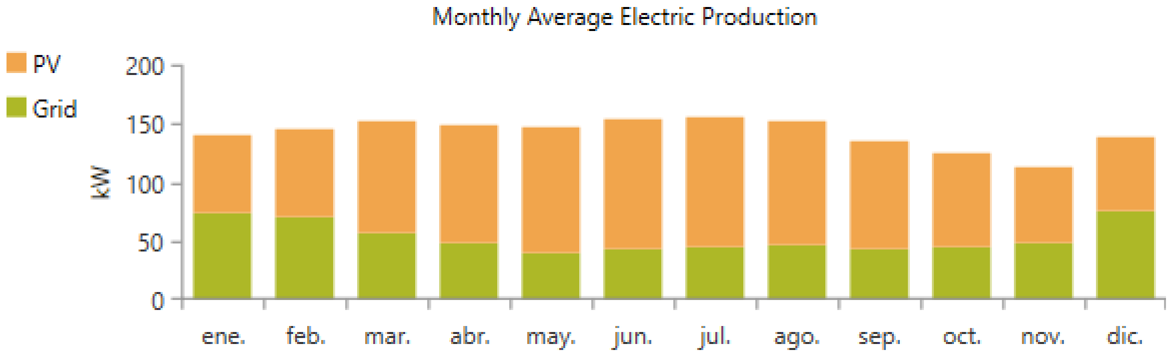


Figure 37: Monthly average of electricity production by source. Source: [52]

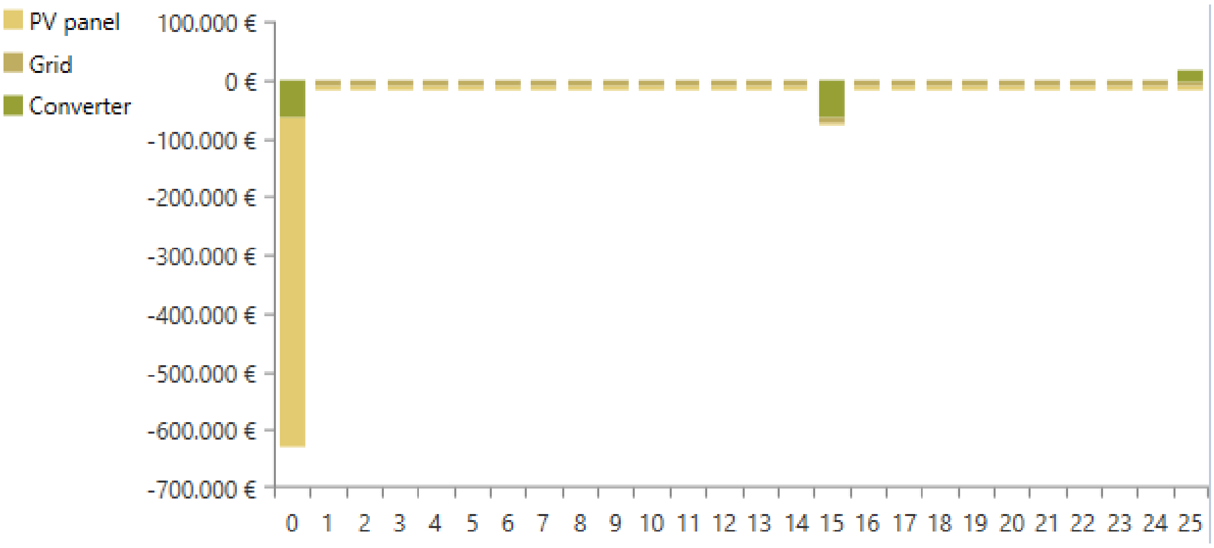


Figure 38: Nominal cash flow costs. Source: [52]

Although all the necessary electricity is being generated, the truth is that electricity from the grid continues to be consumed with equal emission factors, until the energy mix improves. In this way, the consumption of the network shown in Table 28 implies the emission of 356.127 kg of CO_2, which represents an annual reduction of only 38,1%.

Table 28: Simulated system emissions. Source: [52]

Quantity	Value
Carbon Dioxide	356.127 kg/yr
Carbon Monoxide	0 kg/yr
Unburned Hydrocarbons	0 kg/yr
Particulate Matter	17,5 kg/yr
Sulfur Dioxide	488 kg/yr
Nitrogen Oxides	795 kg/yr

Compared to scenario 2, which has the same characteristics, the 25-year net present value has decreased to 163.277 €. This value can be broken down into profits obtained in the summer months when there are greater surpluses to sell and savings on the bill in the winter months. Discounted payback, as shown in Table 29, has also been reduced to 17,28 years.

Table 29: Economic comparison between the proposed system and the current one. Source: [52]

Metric	Value
Present worth	163.277 €
Annual worth	11.585 €
Return on investment	4,9 %
Internal rate of return	7,5 %
Simple payback	10,87 yr
Discounted payback	17,28 yr

4.6. Scenario 6

As in the previous scenario, this one also limited energy production to what the community consumes in a year. The only difference for scenario 5, is that now the value of the purchase price from the network is the highest, at 0,2 € / kWh.

The optimal architecture offered by Homer and presented in Table 30 and Table 31 is the same as before, with 473 kW of installed photovoltaic power and a 316 kW converter system. Unlike the previous scenario, the installation of wind turbines is profitable in this scenario, but having set annual production limits, the technology that can generate that amount of energy at a lower cost has been chosen.

Table 30: Optimized solar panels system. Source: [52]

Quantity	Value	Quantity	Value
Rated Capacity	473 kW	**Minimum Output**	0 kW
Mean Output	89,7 kW	**Maximum Output**	395 kW
Mean Output	2.153 kWh/d	**PV Penetration**	106 %
Capacity Factor	19 %	**Hours of Operation**	4.162 hrs/yr
Total Production	786.019 kWh/yr	**Levelized Cost**	0,0585 €/kWh

Table 31: Optimized converter system. Source: [52]

Quantity	Inverter	Rectifier	Quantity	Inverter	Rectifier
Capacity	316 kW	316 kW	**Hours of Operation**	4.162 hrs/yr	0 hrs/yr
Mean Output	84,7 kW	0 kW	**Energy Out**	742.033 kWh/yr	0 kWh/yr
Minimum Output	0 kW	0 kW	**Energy In**	781.087 kWh/yr	0 kWh/yr
Maximum Output	316 kW	0 kW	**Losses**	39.054 kWh/yr	0 kWh/yr
Capacity Factor	26,8 %	0 %			

The behaviour of the system with respect to the network is the same as in scenario 5. In this new one, 105,8% of the electricity that the community needs continue to be produced, some 786.019 kWh per year without counting losses. Of these, and having deducted the losses in the converter system, 459.396 kWh are sold to the grid and 282.636 kWh are self-consumed. Figure 39 represents the monthly averages of production according to source and Figure 40, the cash flows according to the component.

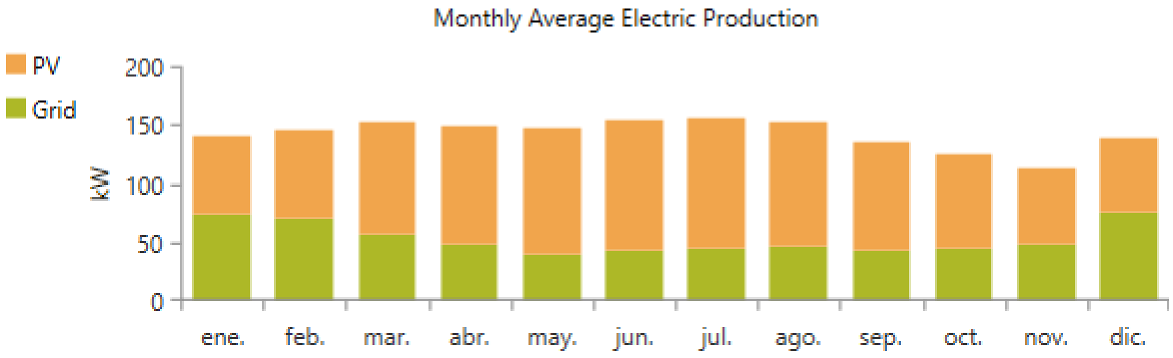


Figure 39: Monthly average of electricity production by source. Source: [52]

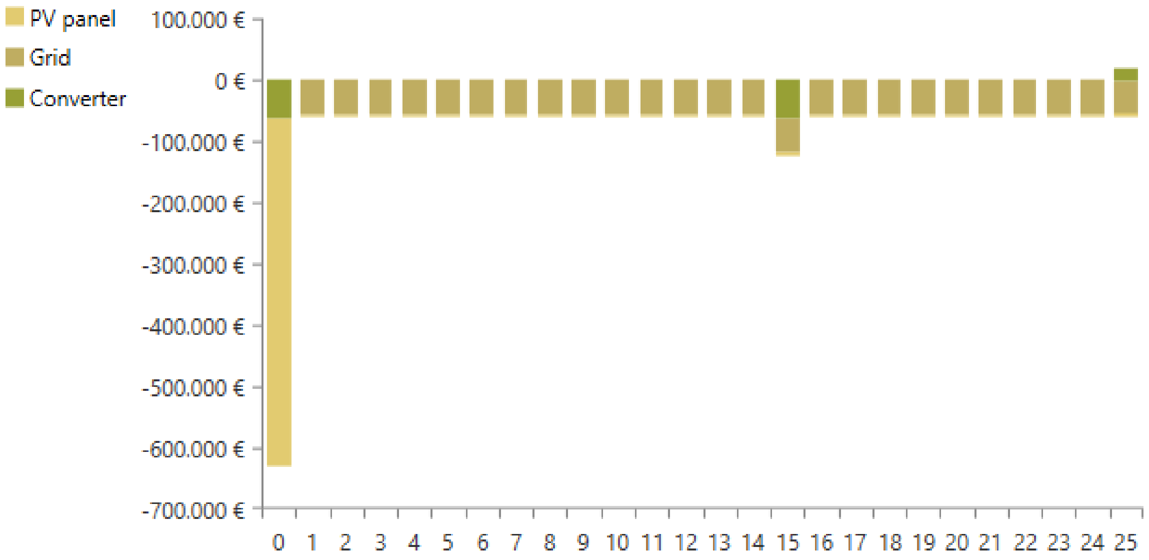


Figure 40: Nominal cash flow costs. Source: [52]

The levels of CO_2 emissions, shown in Table 32, are also the same as in scenario 5 and represents a reduction of 38,1% compared to current levels.

Table 32: Simulated system emissions. Source: [52]

Quantity	Value
Carbon Dioxide	356.127 kg/yr
Carbon Monoxide	0 kg/yr
Unburned Hydrocarbons	0 kg/yr
Particulate Matter	17,5 kg/yr
Sulfur Dioxide	488 kg/yr
Nitrogen Oxides	795 kg/yr

Finally, the important aspects of this scenario are presented in Table 33 and analysed concerning the previous one, those of economic viability. In this case, a net present value of 561.623 € was obtained at the end of the 25 years and a discounted payback of 9,33 years. This is a rather important difference to scenario 5, with which only the purchase price of electricity from the grid has been varied.

Table 33: Economic comparison between the proposed system and the current one. Source: [52]

Metric	Value
Present worth	561.623 €
Annual worth	39.849 €
Return on investment	9,4 %
Internal rate of return	12,8 %
Simple payback	7,31 yr
Discounted payback	9,33 yr

4.7. Scenario 7

In this seventh simulation, a scenario with pessimistic aspects regarding the sale of the surplus produced is proposed again, in which they would be paid at 0,04 € / kWh; the price paid for the electric kilowatt is in the value of 0,10 €. On the other hand, it has been assumed that public subsidies such as those existing for the year 2020 could be received. These subsidies would consist of aid to the initial investment in the installation of the solar panel system, the small wind turbines system and the energy storage system.

For all the mentioned systems, a subsidy of 50% would be received up to a limit of power or capacity and with a maximum amount per installed unit. Because the costs per unit of power or capacity of the systems presented are less than the maximum amounts mentioned in section 3.8, the aid to be received will be guided by the limits of power and capacity. In the case of the solar panel system, which would also include the converter system, aid would be given up to 50kW installed; in the case of wind turbines up to 10kW; and in the case of the storage system up to 12 kWh. Therefore, the new installation costs would be as follows:

- For the photovoltaic panel system, an installation cost of 0,6 € / W for the first 50 kW installed and 1,2 € / W for the rest.
- For the converter system, an installation cost of 100 € / kW for those for the first 50 kW installed and 200 €/ W for the rest.
- For the installation of small wind turbines, an installation cost of 15.000 € for the first turbine, since it has a capacity of 10kW. For the rest of the turbines, the unit would be paid at the price of 30.000 €.
- For the energy storage system, an installation cost of 355,5 € / kWh for the first 12 kWh installed and 711 € / kWh for the rest.

Once the simulation has been carried out, the optimal system proposed by the Homer Energy software is the installation of 166 kW of power in photovoltaic panels, a 105 kW converter system and a wind turbine. By installing only one wind turbine, there are costs per unit of energy produced of 0,0794 € / kWh; on the other hand, if a second wind turbine is installed, the average cost amounts to 0,103 € / kWh, a price slightly higher than that paid for the energy supplied by the electrical network. Also, the installation of a battery system has been ruled out again, as its storage cost continues to be higher than 0,10 € / kWh of the network, even for the 12 kWh capacity that may be subsidized. The final optimal system is the presented in Table 34, Table 35 and Table 36.

Table 34: Optimized solar panels system. Source: [52]

Quantity	Value	Quantity	Value
Rated Capacity	166 kW	**Minimum Output**	0 kW
Mean Output	31,4 kW	**Maximum Output**	138 kW
Mean Output	754 kWh/d	**PV Penetration**	37,1 %
Capacity Factor	19 %	**Hours of Operation**	4162 hrs/yr
Total Production	275.249 kWh/yr	**Levelized Cost**	0,0508 €/kWh

Table 35: Optimized wind turbines system. Source: [52]

Quantity	Value	Quantity	Value
Total Rated Capacity	10 kW	Minimum Output	0,209 kW
Mean Output	2,58 kW	Maximum Output	9,42 kW
Capacity Factor	25,8 %	Wind Penetration	3,05 %
Total Production	22.604 kWh/yr	Hours of Operation	8.760 hrs/yr
		Levelized Cost	0,0794 €/kWh

Table 36: Optimized converter system. Source: [52]

Quantity	Inverter	Rectifier	Quantity	Inverter	Rectifier
Capacity	105 kW	105 kW	**Hours of Operation**	4.162 hrs/yr	0 hrs/yr
Mean Output	29,4 kW	0 kW	**Energy Out**	257.923 kWh/yr	0 kWh/yr
Minimum Output	0 kW	0 kW	**Energy In**	271.498 kWh/yr	0 kWh/yr
Maximum Output	105 kW	0 kW	**Losses**	13.575 kWh/yr	0 kWh/yr
Capacity Factor	27,9 %	0 %			

In this proposed scenario, the penetration of photovoltaic and wind energy is 37,1% and 3% respectively, which means that in total the system generates 40,1% of the community's needs at the end of the year. Considering the sales and purchases of the conventional electrical network and the losses in the converter system, the final fraction of the self-consumed energy is 31,6%.

Of the approximately 741.918 kWh of electricity that the sustainable energy community of Son Espanyol would consume per year, a total of 507.623 kWh would be purchased from the grid and 234.295 kWh would come from the community's production. Besides, during the central hours of the day, there would be an excess production of the photovoltaic plates that would be sold to the network and which total is 46.232 kWh per year. In Figure 41 and Figure 42 are presented the monthly averages of production according to source and cash flows according to the component are shown.

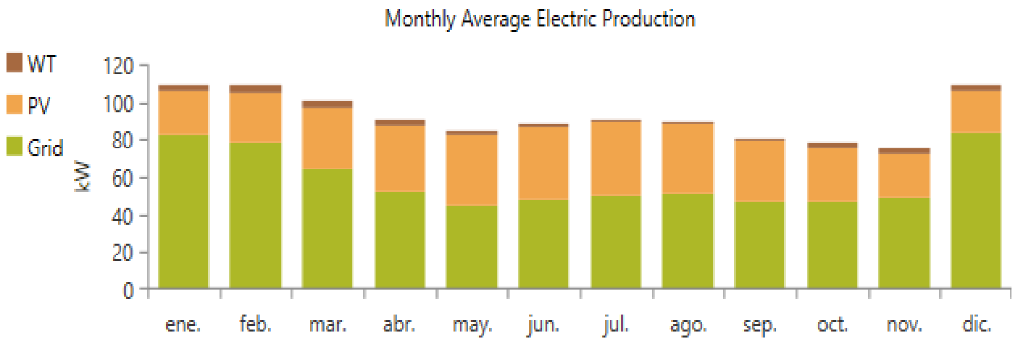


Figure 41: Monthly average of electricity production by source. Source: [52]

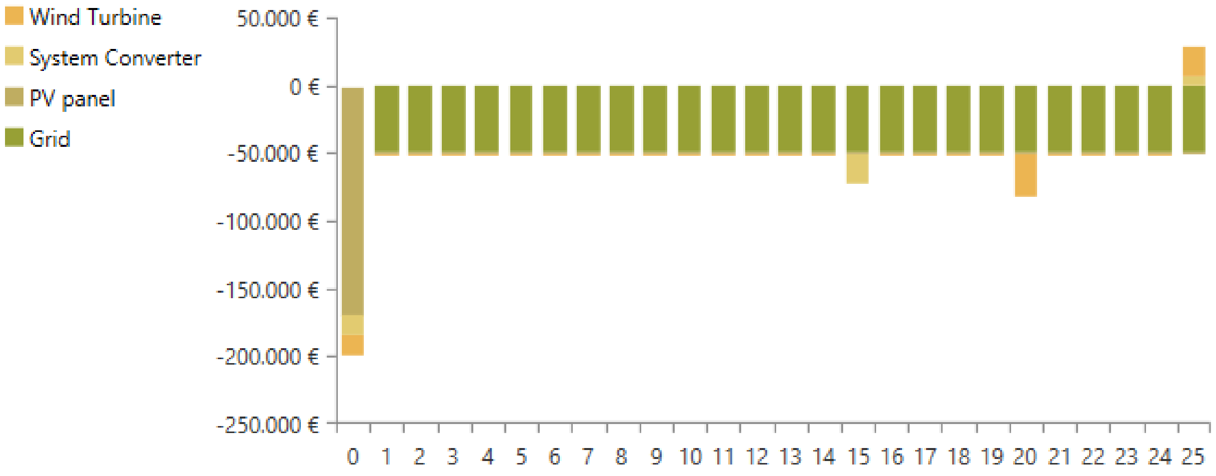


Figure 42: Nominal cash flow costs. Source: [52]

The system has calculated that 393.611 kg of CO_2 will be emitted to the atmosphere per year in this proposed scenario, as can be seen in Table 37. Compared to the baseline scenario, where all electricity is purchased from the grid and the amount of emissions emitted is 575.283 kg of CO_2 per year; the reduction obtained is around 31,6%.

Table 37: Simulated system emissions. Source: [52]

Quantity	Value
Carbon Dioxide	393.611 kg/yr
Carbon Monoxide	0 kg/yr
Unburned Hydrocarbons	0 kg/yr
Particulate Matter	19,3 kg/yr
Sulfur Dioxide	539 kg/yr
Nitrogen Oxides	878 kg/yr

Regarding the economic viability of the project, whose results appear in the Table 38, a discounted return period of 12,07 years is obtained, assuming the investments made as monetary outflows and the annual savings between the electricity purchased with the current system and with the proposed one as inputs. As for the net present value at 25 years, this is 103.950 € and corresponds to the total accumulated savings.

Table 38: Economic comparison between the proposed system and the current one. Source: [52]

Metric	Value
Present worth	103.950 €
Annual worth	7.375 €
Return on investment	6,8 %
Internal rate of return	9,8 %
Simple payback	8,9 yr
Discounted payback	12,07 yr

4.8. Scenario 8

In the last proposed scenario, the simulation has been carried out assuming a sale price of the electrical surplus produced by 0,04 € / kWh, a purchase price of 0,20 € / kWh and accepting that public subsidies can be received for the initial investment; these are the same characteristics as in scenario 3. The amount of these grants and the power or capacity limits set to be subsidized are the same as those specified in the scenario 7.

Thus, the optimal architecture for the system offered by Homer Energy is like that of the scenario 3. The only existing difference is that of the installed power of photovoltaic plates and the converter system, which would be 152 kW and 97 kW, as indicated in Table 39, Table 40. As for the wind power system, shown in Table 41, the optimal system is the same; consisting in 16 wind turbines with a total installed power of 160 kW.

It is important to mention that this scenario is the only one in which the installation of an energy storage system with lithium-ion batteries is profitable if the investment is made with the help of subsidies. Even so, only aid is received for the first 12 kWh of batteries and future reception for replacement is not guaranteed. By carrying out the simulation, in which Homer Energy uses the replacement price and not the initial investment price, the same costs per energy unit have been obtained as in previous scenarios, of 0,25 € / kWh.

By carrying out a parallel simulation in which a replacement price has been established in which subsidies would continue to be received, it has been obtained that the viable storage system would only have a useful life of approximately 8 years and its autonomy would be less than half an hour. Therefore, this option has been ruled out because it has no relevance in the community and the first simulation has been followed in which the replacement cost could not be helped by grants.

Table 39: Optimized solar panels system. Source: [52]

Quantity	Value	Quantity	Value
Rated Capacity	152 kW	**Minimum Output**	0 kW
Mean Output	28,9 kW	**Maximum Output**	127 kW
Mean Output	694 kWh/d	**PV Penetration**	34,1 %
Capacity Factor	19 %	**Hours of Operation**	4.162 hrs/yr
Total Production	253.218 kWh/yr	**Levelized Cost**	0,0501 €/kWh

Table 40: Optimized wind turbines system. Source: [52]

Quantity	Value	Quantity	Value
Total Rated Capacity	160 kW	**Minimum Output**	3,34 kW
Mean Output	41,3 kW	**Maximum Output**	151 kW
Capacity Factor	25,8 %	**Wind Penetration**	48,7 %
Total Production	361.666 kWh/yr	**Hours of Operation**	8.760 hrs/yr
		Levelized Cost	0,124 €/kWh

Table 41: Optimized converter system. Source: [52]

Quantity	Inverter	Rectifier	Quantity	Inverter	Rectifier
Capacity	96,1 kW	96,1 kW	**Hours of Operation**	4.162 hrs/yr	0 hrs/yr
Mean Output	27 kW	0 kW	**Energy Out**	236.776 kWh/yr	0 kWh/yr
Minimum Output	0 kW	0 kW	**Energy In**	249.238 kWh/yr	0 kWh/yr
Maximum Output	96,1 kW	0 kW	**Losses**	12.462 kWh/yr	0 kWh/yr
Capacity Factor	28,1 %	0 %			

The penetration of photovoltaic and wind energy on community demand is 34,1% and 48,7%, respectively. Considering the interactions with the conventional electrical grid and the losses produced in the system, the final fraction of self-consumed energy is 60,6%.

Of the approximately 741.918 kWh of electricity that the sustainable energy community of Son Espanyol would consume per year, a total of 292.380 kWh would be purchased from the grid and 449.538 kWh would come from the community's production. Besides, there would be an excess production that would be sold to the grid and which total is 149.456 kWh per year. The monthly average production by source is the one presented in Figure 43.

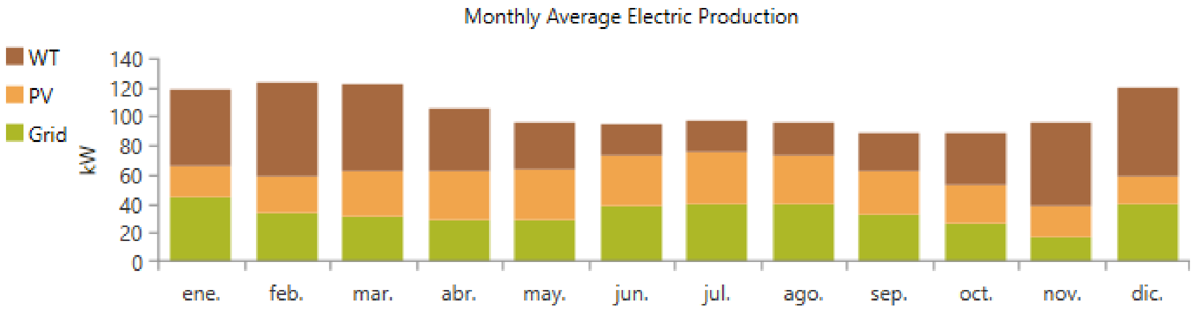


Figure 43: Monthly average of electricity production by source. Source: [52]

In Figure 44 it can be seen the costs associated with each component of the installation in the nominal cash flow during the 25-years project, including the purchase of electricity from the grid.

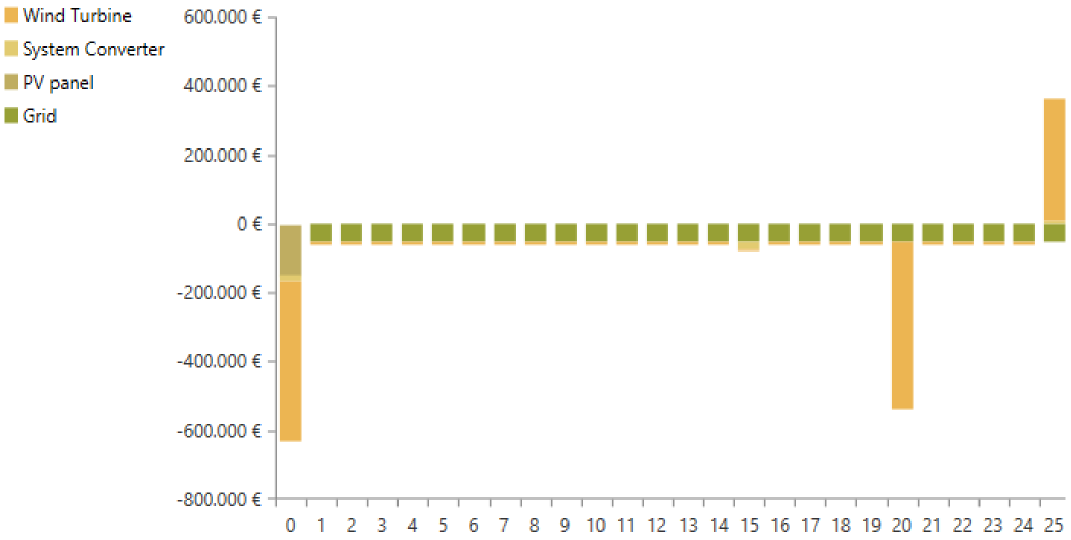


Figure 44: Nominal cash flow costs. Source: [52]

Regarding emissions into the atmosphere, shown in Table 42, the system has calculated that 226.712 kg of CO_2 will be emitted per year in this proposed scenario. Compared to the baseline scenario, where all electricity is purchased from the grid and the amount of emissions emitted is 575.283 kg of CO_2 per year; the reduction obtained is around 60,6%.

Table 42: Simulated system emissions. Source: [52]

Quantity	Value
Carbon Dioxide	226.731 kg/yr
Carbon Monoxide	0 kg/yr
Unburned Hydrocarbons	0 kg/yr
Particulate Matter	11,1 kg/yr
Sulfur Dioxide	311 kg/yr
Nitrogen Oxides	506 kg/yr

Finally, and regarding the economic viability aspects of the project in the proposed scenario, a discounted payback of 8,51 years is obtained, considering as monetary outflows the investments made and as inputs the annual savings between the electricity purchased with the current system and the proposed one. As for the net present value at 25 years, as indicates Table 43, this is 172.402€.

Table 43: Economic comparison between the proposed system and the current one. Source: [52]

Metric	Value
Present worth	515.686 €
Annual worth	36.589 €
Return on investment	9 %
Internal rate of return	12,5 %
Simple payback	7,24 yr
Discounted payback	9,22 yr

5. Results and discussion

5.1. Results

Once the simulation and optimization of the sustainable energy community architecture of the eight proposed scenarios have been carried out, the similarities and variations between their results are analysed to obtain a response that explains how the different variables affect the viability and success of the project.

Table 44 shows the three characteristics that have defined and differentiated one scenario from the others and the optimal capacities to install for each technology. As explained in Chapter 4, two types of price have been devised for the purchase of surplus production from the future energy community of Son Espanyol, and for the purchase of electricity from the grid. Regarding the first, two prices have been designed, one more pessimistic at 0,04 € / kWh and the other optimistic at 0,08 € / kWh. And for the purchase of electricity, a price lower than the current average of 0,10 € / kWh has been established. On the other hand, a situation has also been proposed in which the project can apply for the subsidies mentioned in section 3.8 and another in which it could not. In this way, and with the eight scenarios characterized, it can be seen how the architecture of the installation varies considerably. On the one hand, the two scenarios that are proposed to qualify for subsidies, have optimized results of higher installed photovoltaic power. Furthermore, only with the help of the government is feasible the installation of wind technology on stage with a purchase value to the network of 10 cents per kilowatt. This fact is due to the circumstances of the place, with a low potential to produce wind energy. And that is why the recommended power to install wind turbines is 10 kW, the maximum that could qualify for a subsidy.

On the other hand, the price increase that would be paid for the surpluses generated also implies a recommendation for a slight increase in the installed photovoltaic power. This increase is maximum since as the cost of sales increases, the cost of solar production ends up being below this and the sale of surpluses becomes profitable to obtain direct benefits and not only to save on the electric bill. For its part, the increase in the price of electricity implies greater savings for houses at the end of the year and leads to improved economic viability. Finally, only in one of the proposed eight scenarios is the installation of a proposed lithium-ion battery system feasible and may qualify for subsidies; even so, it has been ruled out because only the first 12 kWh are eligible for a subsidy and that capacity does not represent any visible improvement in the system architecture.

Table 44: Characteristics and optimal architecture of each scenario

Scenario	Sale price	Purchase price	Grants	PV	Wind turbine	Converter	Batteries
1	0,04 € / kWh	0,10 € / kWh	No	145 kW	-	92,9 kW	-
2	0,08 € / kWh	0,10 € / kWh	No	1.657 kW	-	1.035 kW	-
3	0,04 € / kWh	0,20 € / kWh	No	121 kW	160 kW	75,9 kW	-
4	0,08 € / kWh	0,20 € / kWh	No	1.659 kW	170 kW	1.035 kW	-
5	0,08 € / kWh	0,10 € / kWh	No	473 kW	-	316 kW	-
6	0,08 € / kWh	0,20 € / kWh	No	473 kW	-	316 kW	-
7	0,04 € / kWh	0,10 € / kWh	Yes	166 kW	10 kW	105 kW	-
8	0,04 € / kWh	0,20 € / kWh	Yes	152 kW	160 kW	96,1 kW	-

As a result of the increase in installed photovoltaic power and wind turbines, the volume of energy produced and self-consumed is also increasing and, therefore, the community is reducing its purchases from the conventional electricity grid. Regarding sales, the large increase that occurs between the scenarios with a sale price of 8 cents and those of 4 cents, denotes the moment in which the community goes from making profitable its investment through savings on the invoice to making it profitable, obtaining benefits for the sale of electricity. Table 45 shows the system self-consumption, purchases and sales to the grid.

Table 45: Results of energy self-consumption and purchases and sales to the grid per year

Scenario	Self-consuming energy	Energy purchased from the grid	Energy sold to the grid	Losses in the converter system
1	201.855 kWh	540.063 kWh	24.498 kWh	11.913 kWh
2	309.017 kWh	432.901 kWh	2.260.554 kWh	135.241 kWh
3	441.438 kWh	300.480 kWh	107.933 kWh	9.879 kWh
4	493.447 kWh	248.471 kWh	2.462.530 kWh	135.353 kWh
5	282.636 kWh	459.282 kWh	459.396 kWh	39.054 kWh
6	282.636 kWh	459.282 kWh	459.396 kWh	39.054 kWh
7	234.295 kWh	507.623 kWh	46.232 kWh	13.575 kWh
8	449.513 kWh	292.405 kWh	148.929 kWh	12.462 kWh

Once the different capacities for each system and scenario are known, the costs that the community has to face each year are analysed according to the modelling explained in Chapter 3. As the installed powers increase between the different scenarios, also it does the money that will have to be spent at the end of the year on maintenance.

On the other hand, the income received from the sale of electricity to the grid also increases. If the difference between annual costs and income is analysed, as in Table 46, it is seen that the fact that the surpluses are sold at 0,04 € / kWh or 0,08 € / kWh has an important relevance. The scenario in which the community must pay a greater amount of money is the number 3, where the installed power in wind turbines is high and the electric sale price is low. On the other hand, in the scenarios where the sale price of the surpluses is higher, the maintenance costs are assimilated by the benefits produced by these sales and even results in a positive economic difference for the community member.

Table 46: Maintenance costs according to system and benefits for electricity sales per year

Scenario	PV costs	WT costs	Converter costs	Total costs	Energy sales benefits	Difference
1	1.744 €	-	372 €	2.116 €	980 €	-1.136 €
2	19.885 €	-	4.140 €	24.025 €	180.844 €	156.819 €
3	1.451 €	6.400 €	304 €	8.155 €	4.317 €	-3.838 €
4	19.906 €	6.800 €	4.140 €	30.846 €	197.002 €	166.156 €
5	5.680 €	-	1.262 €	6.942 €	36.752 €	29.810 €
6	5.680 €	-	1.262 €	6.942 €	36.752 €	29.810 €
7	1.989 €	400 €	421 €	2.810 €	1.849 €	-961 €
8	1.828 €	6.400 €	385 €	8.613 €	5.957 €	-2.656 €

Analysing the impact that the implementation of the project would have on the location and the results of the environmental impact, which after all are the objectives set by the European Commission, there are notable differences between the eight scenarios. As mentioned in Chapter 1.1, by 2030, targets have been set to reduce greenhouse gas emissions by 40% and a renewable energy share of 32%.

All the scenarios have a renewable energy penetration above the established limit of 32%. Even so, a part of the energy is sold to the grid and that means that if you look at the percentage of self-consumed energy, the first and seventh scenarios are slightly below that value.

Regarding the reduction of emissions, the results range between 27,2% and 66,5%. This is the variation with respect to the emissions that occur in the current system and that have been calculated using the emission factors of the Balearic electrical system in 2018 [40]. Because the European Commission marks a reduction of 40% compared to 1990 data are not comparable values. Still, it can be considered that the results are a good path and that this reduction could be increased as new technological options emerge, or current ones mature.

The repercussion that the sustainable energy community project would have in the Son Espanyol neighbourhood has been measured in a simplified way using two factors. On the one hand, the area needed for the installation of the solar panels has been calculated. If an average value of 9 m^2 is considered for each kWp of the photovoltaic plate [68], it is obtained that the total occupied surface would be between 1.305 m^2 of the first scenario and 14.931 m^2 of the fourth. Considering that the average surface of the plots in the Son Espanyol neighbourhood is over 2000 m^2 and that 200 houses are included in the community; values close to 1.000 m^2 of solar panels do not represent an inconceivable loss of useful space and even useless space could be used as house roofs. Those that are around 4.000 m^2 should be studied to establish if its installation is possible without harming some of the community members. And the scenarios where the necessary surface is greater than 10.000 m^2, if that can be a problem to find the necessary land.

On the other hand, the acoustic contamination that the installation of the wind turbine would generate has been considered. According to the manufacturer's data, the noise levels it produces is around 60 dB and if it is more than 60 m away, these values are below 40 dB. From the World Health Organization, noise levels produced by wind turbines below 45 dB are recommended so as not to have effects on people's health and rest [69]. Again, due to the large area of the neighbourhood, it is considered feasible to install the proposed turbine in the seventh scenario at a great distance from any of the houses, but for scenarios three, four and eight, it is likely that the occupation of several plots to maintain the necessary distance between wind turbines and homes. The Table 47 shows the environmental impact calculated.

Table 47: Environmental impact results for each scenario

Scenario	Renewable penetration	CO_2 emissions	Emissions reduction	Total surface solar panels	Acoustic impact
1	32,5%	418.764 kg	27,2%	1305 m^2	No
2	370,9%	335.671 kg	41,7%	14913 m^2	No
3	75,8%	232.992 kg	59,5%	1089 m^2	Yes
4	423,1%	192.664 kg	66,5%	14931 m^2	Yes
5	105,9%	356.127 kg	38,1%	4257 m^2	No
6	105,9%	356.127 kg	38,1%	4257 m^2	No
7	40,1%	393.611 kg	31,6%	1494 m^2	Yes
8	82,9%	226.731 kg	60,6%	1368 m^2	Yes

In the economic aspects, the differences presented between the scenarios in which high purchase and sale prices for electricity have been established and those that have not been, are notable. Both the second and third scenarios require a higher initial capital mainly due to the large installed power in photovoltaic panels. Although the installed power has been limited, in scenarios five and six, the initial investment is also high and is like to the scenarios three and eight in which 16 wind turbines are installed.

In the third column of Table 48 , the savings that would be generated in the total electricity bills compared to the system that currently exists appear. As you can see, in those scenarios where the purchase price is 20 cents per kilowatt-hour, the annual differences are quite large. On the other hand, if the net present value of 25 years is analysed, the factor that seems to most condition its increase is the price of the electricity bill and the consequent savings generated by self-consumption. Finally, it can also see how the variation of the initial investment and the sale price to the grid determines the payback period.

Table 48: Economic results for each scenario

Scenario	Initial capital	Average annual savings	Net present value (25 years)	Discounted payback
1	192.945 €	20.186 €	68.441 €	15,47 yr
2	2.195.528 €	30.902 €	371.004 €	19,37 yr
3	640.275 €	88.288 €	469.555 €	9,77 yr
4	2.707.643 €	98.689 €	866.618 €	15,48 yr
5	631.066 €	28.264 €	163.277 €	17,28 yr
6	631.066 €	56.527 €	561.623 €	9,33 yr
7	199.996 €	23.430 €	103.950 €	12,07 yr
8	632.010 €	89.903 €	515.686 €	9,22 yr

If the initial investment is made in equal parts among the 200 community members who currently have a stake in the Son Espanyol Water Community, the money that each should disburse ranges from 965 € in the first scenario to 13.538 € in the fourth. Although it has not been possible to obtain the average disposable income data for the Son Espanyol neighbourhood, it has been possible to obtain data for the closest neighbourhood, Son Sardina, with very similar characteristics. This value was 29.866 € net in 2017 [70] and it is considered that the one corresponding to our community is very close. Assuming this, the initial investment would represent around 3,2% of the annual income in the scenario of less investment and 45,3% in the one of greater.

Finally, and using the results presented in Table 46 and Table 48, the average annual savings that each home would have on its electric bill and the payments it should make in terms of community expenses are shown in the Table 49. Negative values means that each neighbour must pay an amount of money and positive values, which would receive that money as benefits. Expenses are the difference between system maintenance costs and income from the sale of electricity to the grid; it is a low value and perfectly assimilable by the residents, varying between 5,7 € and 19,2 € per year. In fact, in some of the scenarios, the value obtained from the sale of surpluses exceeds the annual costs and, therefore, it would not be necessary to pay the costs on the part of the community member and could be deducted from the profit item. On the other hand, the average saving that would be produced in each house would be more noticeable in the family economy, having a minimum value of 101 € in the first scenario and a maximum of 493 € in the fourth.

Table 49: Initial investment and annual savings compared to the current system for each house

Scenario	Initial capital per house	Average annual savings per house	Average annual costs per house
1	965 €	101 €	-5,7 €
2	10.978 €	155 €	784,1 €
3	3.201 €	441 €	-19,2 €
4	13.538 €	493 €	830,8 €
5	3.155 €	141 €	149,0 €
6	3.155 €	283 €	149,0 €
7	1.000 €	117 €	-4,8 €
8	3.160 €	450 €	-13,3 €

Therefore, these are numbers that regardless of the scenario and the future investment to be made to replace the converter system and the possible wind turbine, are beneficial to the commoners' interests.

5.2. Feasibility

In this section, the feasibility of the project and the different scenarios is analysed. As it has been seen in the optimal sections, all the architectures that provide the maximum net present value at 25 years are economically viable and in what they vary are in the benefits obtained, the payback and on the surface necessary to carry out the installation.

Technologically, none of the proposed architectures does have any complications. The proposed photovoltaic, wind and converter systems are mature technologies with many years of implementation. But on the other hand, a large installation of panels and turbines implies the need for the use of large free land for its placement or distribution on different plots or roofs of houses, which can be a complication to make the connection of the microgrid. In the current pumping system that the water community has, the association has a small parcel of property where the well is located and a house with hydro pumps and electric meters. This option of acquiring land is unfeasible since the current purchase prices of land range between an average of 104 € / m^2 on agricultural land [71] and 290 € / m^2 on urban land [72]. The most viable option is to rent land for the installation of the system, where prices currently range from 0,09 €/ m^2 to 0,12 € / m^2 for periods of 25 years [73]. Below is the Table 50 with the approximate price that should be paid to rent the land necessary for the installation of the solar panels for each scenario if it is paid at an average price of 0,105 € / m^2 ·year , the surface required for the wind turbines has not been taken into account.

Table 50: Land rental costs

Scenario	Annual rent	25-years rent
1	137 €	3.426 €
2	1.566 €	39.147 €
3	114 €	2.859 €
4	1.568 €	39.194 €
5	447 €	11.175 €
6	447 €	11.175 €
7	157 €	3.922 €
8	144 €	3.591 €

Although the cost of renting the land is not very high, it causes the net present value to decrease and the payback to be delayed. Also, it must be considered that in the scenarios with the highest initial investment, this outlay of money is too high for the community members to take over. Therefore, it has been calculated how it would affect economic viability if one of the currently existing loans was requested for the development of energy efficiency projects. This type of loan has a nominal interest of 4,95% and has been calculated for 5 years, the maximum period in which the 8 scenarios would continue to offer a net present value at the end of the lifetime of the project [74].

Table 51: Calculation of loans for initial investment and how it affects NPV

Scenario	Monthly payments	Annual payments	Total payment	NPV - Interests - Rent land
1	3.637 €	43.640 €	218.202 €	39.759 €
2	41.382 €	496.585 €	2.482.923 €	44.463 €
3	12.068 €	144.817 €	724.087 €	382.884 €
4	51.035 €	612.415 €	3.062.074 €	472.993 €
5	11.895 €	142.735 €	713.673 €	69.496 €
6	11.895 €	142.735 €	713.673 €	467.842 €
7	3.770 €	45.235 €	226.175 €	73.849 €
8	11.912 €	142.948 €	714.740 €	429.365 €

As can be seen in Table 51, projects with a high initial investment are not convenient. On the one hand, they oblige to request a loan and due to the enormous capital loaned the interest that must be paid is high and profitability decreases significantly. On the other hand, these are the scenarios with the highest installed photovoltaic power and need to rent larger plots.

Finally, one of the aspects that may most condition the feasibility of the project and that has historically conditioned the formation of energy cooperatives in Spain is the reluctance of citizens. In general, people in Spain have the less financial capacity to invest than in other countries, the population density is lower and it could be that Spanish people do not have the same sensitivity for environmental issues [75].

5.3. Relevant factors

In Chapter 4 the results have been presented for 8 simulations in which three parameters were mainly varied such as the price of purchase and sale of electricity and the use of subsidies. It has been shown that there are three factors with great relevance when it comes to obtaining an economic return on the project.

First, the most delicate factor of the three is that of the purchase price to the grid. At the end of the day, if the project is based on self-consumption and on obtaining savings by reducing demand from electricity companies, the project's sensitivity to price is high. According to statistics from recent years, Spain has increased the price per kilowatt-hour purchase in homes, and therefore, the installation of technology to produce renewable energy is becoming more profitable. Instead, there are some countries such as Portugal, which have decreased the price of electricity and with it the viability of projects. Even so, for energy self-consumption communities to cease to be viable, the price should decrease dramatically. For the community of Son Espanyol, the cost of electric purchase for the project to cease to be viable would have to be below 0,126 € / kWh in the case of wind turbines and 0,585 € / kWh in solar panels. Wind power technology could question its profitability with the variation of this factor, but photovoltaics is far from not being profitable.

The second of the factors that have been varied is that of the sale price of the surplus generated. It is a more targeted factor for those projects that seek to obtain benefits from the sale of electricity. In the case of the community of Son Espanyol, the fact of seeking that objective may lead one to think that the installation of the maximum of photovoltaic power will greatly increase income. Although this is true, as has been seen, it implies a large initial investment that the neighbours will probably not be able to assume and, also, it implies a huge risk of lack of economic profitability if the sale price is below 0,585 € / kWh. Although currently, the prices vary according to the company that buys the surpluses, the prices are around 5 cents and, therefore, it is a great risk to install more power than is necessary for self-consumption.

The third factor that has been varied in the simulations has been that of the subsidies that citizens, companies and associations can currently use for renewable energy projects. These grants only include the first 50 kW of photovoltaic, 10 kW in wind turbines and 12 kWh in lithium-ion batteries. That is why, in the case of the energy community that is proposed in the Son Espanyol neighbourhood with a much higher installed capacity, the only influence it has is in a slight reduction in the initial investment and a reduction in the payback. In projects of small neighbourhood communities or individual houses, these subsidies do have a greater impact and can end up marking the profitability of technologies such as wind and storage. As contemplated in the National Energy and Climate Plans for the next decade, in which the constitution of sustainable energy communities will be promoted, the subsidies will probably cover greater powers depending on the homes to be added and this form will be a more influential factor for the viability of large communities.

Finally, and although its value has not been varied in the simulations due to its low volatility, other factors can vary the viability of the project. The first of these is the legal framework that affects the project. At present, and as it has been commented in Chapter 2, the situation in Spain is favourable for the promotion of electrical production projects and if the objectives set by the European Union are to be achieved, it is unlikely that the legislation will be modified; in any case, it is likely to even improve.

The other factor is the one that includes the situation of the technology that is going to be used. Both wind turbines and photovoltaic panels are mature technologies that have been improving their efficiencies and decreasing their prices in recent years, and it is likely to continue doing so in the coming years, which would slightly improve the profitability of future communities by being able to produce more electricity with lower cost. The converter system is difficult to influence significantly due to the high efficiency it already has and its relatively low price. For its part, the storage system is the one that will make big differences in future projects. Currently, it is not a profitable technology for all communities and homes, but in the coming years, with the multitude of research teams that exist in this field, it will be able to revolutionize the way energy will be stored and it may become economically It is more profitable to save and self-consume energy than to buy it from the grid.

5.4. Limitations and potential applications to other cases

Even having taken several factors into account when analysing the viability of an energy community, it is true that there are still uncertainties and limitations of the approach that can make the results vary.

Although the electric purchase and sale price can be expected to be relatively stable in the short and medium-term, no one can assure for sure that they will vary significantly before the installation has been profitable. An example is what happened with the so-called "Sun Tax" that existed in Spain some years ago, with which self-consumers were forced to pay an amount to contribute to the electricity system and that suddenly changed the profitability of many of the photovoltaic installations.

As mentioned in the previous section, the price of electricity is one of the factors that most conditions the viability of an energy community project. That is why this factor and the productivity of the installation will limit each case. If the four countries compared in Chapter 2.3 are analysed, it can be seen how the potential, especially solar, differs greatly between the pair formed by Spain and Portugal and the one formed by Germany and Denmark. However, these are four countries in which the purchase price of electricity is among the highest in the Euroregion and, therefore, the economic viability of the project is practically positive in all the cases.

On the other hand, a country that is among the cheapest in terms of electricity due to the availability of fossil resources and that has a low potential for wind and solar energy, such as Romania, is going to have a difficult time achieving a return on investment in renewable community projects. It is in these cases when other types of technologies such as biogas must acquire greater potential and try to equate costs with the conventional grid to be profitable. If this is not achieved, it is unlikely that citizens of countries with a lower GDP per capita will decide to invest in energy communities.

Another of the existing limitations, which is of great importance, is that of the organization of the installation. When the community works with large windmills or bioenergy plants, it is perhaps easier to centralize production at one point within the community and sell the surpluses to a trader through a single contract. But when it comes to a solar installation in which an entire community of homes is supplied, the logistics and organization of the space is a factor to consider.

On the one hand, by occupying a large space, it is possible that the panels must be installed in various locations, plots or even on top of rooftops. This is a controversy if the land belongs to the neighbours, who may not give their approval to the use of their properties or do not agree on which neighbours will receive compensation for the rental of the surfaces. If that happens, the installation will likely be divided among several parcels far from each other, which implies a greater complication in terms of distribution control and in terms of initial project resources.

To solve this problem in the control of distribution, it would be useful to implement modern technologies such as the internet of things or the blockchain, which could exchange data in real-time that would simplify energy interactions between all members of the community, the marketers. and the distributors even when the production was dispersed. But there are currently two limitations for this. The first is its degree of maturity, although first experiences have already been carried out in countries such as the Netherlands or the USA [46], it is a technology still to be. On the other hand, all members of the community must have smart meters, and that still does not happen in all European countries.

If energy communities are to be implemented massively, it will be essential to develop a legal framework that provides for the possible variants of communities and to promote the implementation of these new technologies that allow adapting the needs of the community members and the grid in real-time.

6. Conclusion

The objective of this thesis has been to analyse the viability of the constitution of a sustainable energy community including the application to a specific case of a neighbourhood of Mallorca, in Spain. Also, the different types of existing communities and cases of success have been discussed. Also, the key factors that may affect the future of the project have been identified.

The challenges posed by each geographic territory, the country's legislative framework in terms of energy projects and the activities to be carried out, make it possible to consider a great diversity of energy communities and to make their operation very different from each other.

Currently, different countries have proposed energy plans that include proposals for the promotion of sustainable energy communities. Portugal, for example, has facilitated the procedures for projects of up to 30 kW and in Spain subsidies of up to 50 kW of installed photovoltaic power are offered. Although this is an important step, the truth is that these measures only affect small neighbouring communities and not cases like the one analysed, a neighbourhood of 200 homes.

In the case analysed, it has been shown how the implantation of a mature technology such as photovoltaic panels and basing the objectives on self-consumption, is profitable and adapts very well to the characteristics of Mallorca and other places in southern Europe with high radiation. Although factors such as the purchase and sale price of electricity fluctuate or subsidies disappear, the project is profitable since its production cost is around 0,0595 € / kWh.

On the other hand, for the installation of wind turbines, it has been seen that the potential of wind energy in the area is not large enough to be profitable in all the proposed scenarios. For it to be, the purchase price of electricity should be above 0,126 € / kWh and currently, some of the neighbours are below. Given that the profitability of the wind power, in this case, is at the limit, what can be said is that in other places with higher wind speeds, its installation is highly recommended since it eliminates the dependency of the photovoltaic on the hours of production.

For less mature technologies, it has been analysed the feasibility of installing a lithium-ion battery system to store the energy produced during daylight hours for being consumed later. Due to its high price and the short lifetime, it is not recommended for installation in communities that have a network connection. Although their potential is high, batteries and other renewable technologies are not yet cheap and efficient enough for citizens to consider installing them unless the government can subsidize them.

In the future and with the evolution of some technologies, the diversity of energy communities is going to increase even more. It is for this reason that public administrations, especially in southern Europe, should have a very important role in motivating citizens who are already environmentally conscious, but who are not yet investing in medium-sized projects scale. Defining the activity of the community, the technology and how the capital investment will be carried out, are some of the aspects that mark the first steps of an energy community and that today the average citizen is not capable of. resolving. This can and should change with a greater citizen-institution relationship if energy self-production is to be promoted, one of the basic pillars to fulfil the objectives of the plan against climate change.

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Annex I. Characterization of the neighbourhood

This annex presents expanded information on the characteristics of the Son Espanyol neighbourhood and the water community made up of two hundred houses.

In the following Figure 45 provided by the Spanish National Institute of Geography [47], you can see the type of occupation of the land that makes up the Son Espanyol neighbourhood. Mainly, the land is classified as a cultivation area and a large part of the plots are classified as rustic surface.

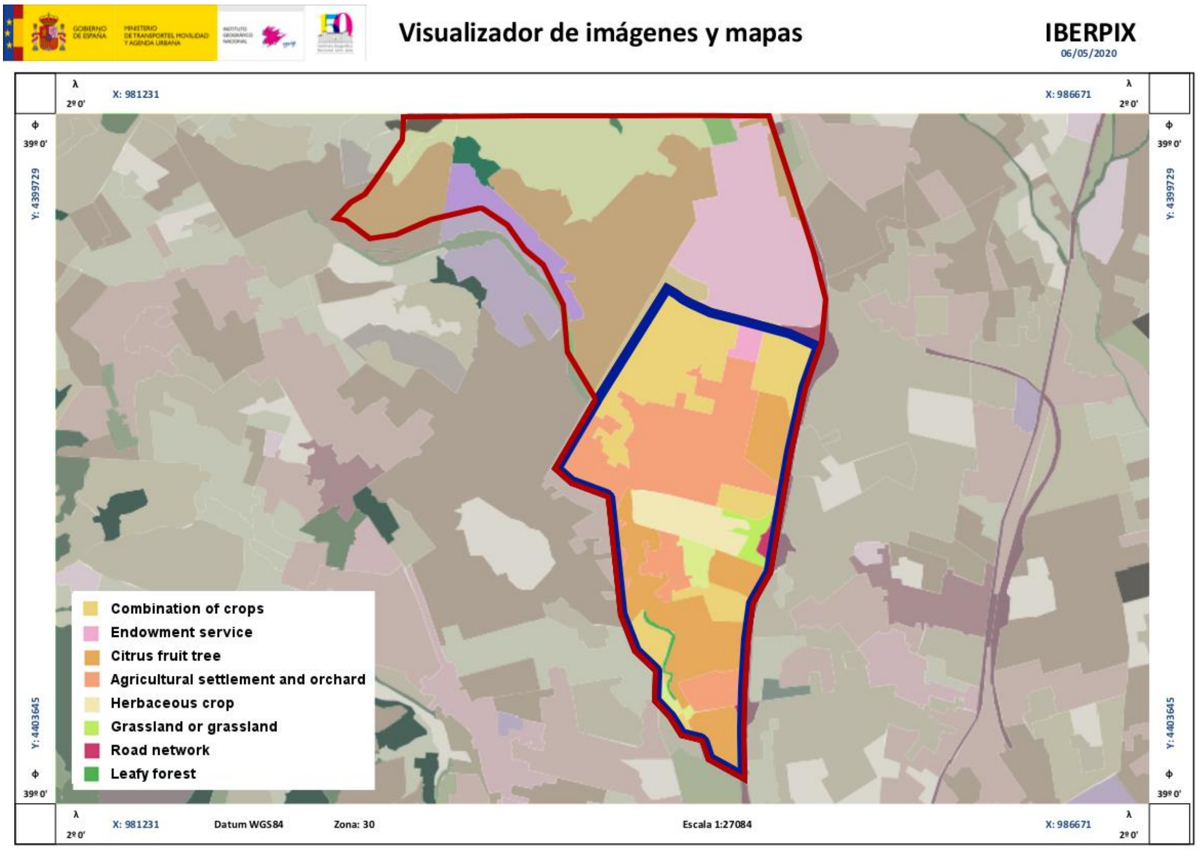

Figure 45: Type of land occupation in Son Espanyol. Data source: [47]

Due to the great extent of Son Espanyol and the difficulty of perceiving its details from a satellite photo that encompasses it in its entirety, a zoom image is provided in Figure 46 that represents the main characteristics of the neighbourhood.

As can be seen, there are lots of different sizes, but most of them with surfaces greater than 2000 m^2. Even though some of the surfaces are unused, the area is characterized by having planted fruit trees that are watered with the water that comes from the Community of Water Users of Son Espanyol.

Figure 46: Son Espanyol's aerial image with zoom. Data source: [47]

The following page shows a map provided by the Community of Water Users of Son Espanyol in which the 200 houses that form it and their respective houses appear. A large part of them is concentrated in what could be called "centre of the neighbourhood", while the rest, and larger, are located on the outskirts.

COMUNITAT D'USUARIS D'AIGUA DE
SON ESPANYOL

GENERAL PLANT OF THE HOUSES
OF THE WATER COMMUNITY OF S. ESPANYOL

SCALE = 1:2000

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Annex II. Data collected from electricity bills

In this annex, is shown the data of the electrical consumption provided by different neighbourhood residents in Table 52 and Figure 47.

Table 52: Monthly electricity consumption for 11 houses in the Son Espanyol neighbourhood. Units in kWh.

House	Apr 19	May 19	Jun 19	Jul 19	Aug 19	Sep 19	Oct 19	Nov 19	Dec 19	Jan 20	Feb 20	Mar 20
House 1				148	224	143	136	155	160	162	210	191
House 2	203	189	190	233	219	212	220	273	296	251	224	262
House 3	162	174	203	408	291	216	382	231	254	247	206	305
House 4	412	550	756	825	820	556	553	401	295	280	268	275
House 5	809	806	546	525	265	360	800	658	1000	1002	982	844
House 6				677	725	513	320	406	880	854	710	531
House 7	184	107	98	95	111	134	162	104	162	148	107	
House 8	210	166	175	136	142	138	151	218	242	350	315	237
House 9				245	316	175	120	138	187	180	136	133
House 10	192	187	140	135	220	177	179	166	151	160	171	159
House 11	269	341	410	635	594	442	412	457	482	526	660	448
Average analysed houses	305,13	315,06	314,77	369,27	357,03	278,65	263,48	291,57	373,61	378,17	362,66	338,51

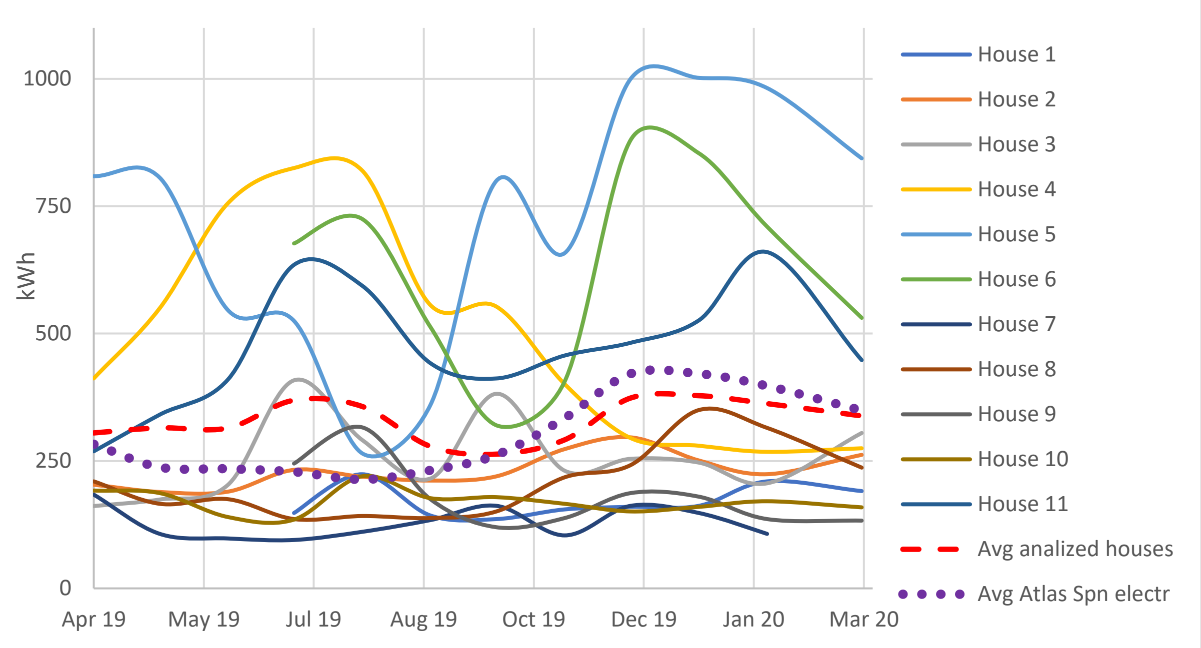

Figure 47: Monthly electricity consumption for 11 houses in the Son Espanyol neighbourhood

In Table 53, the prices per kWh that these 11 residents of the community are currently paying are shown, calculated with and without rates according to the type of contract that they have, which may include different time frames of consumption.

Table 53: Electricity price for 11 houses in the Son Espanyol neighbourhood. Units in € / kWh.

House	Time section 1	Time section 2	Average according to bills' characteristics	Average with taxes
House 1	0,09966	0,17096	0,12937	0,15654
House 2	0,09221	-	0,09221	0,11157
House 3	0,12403	-	0,12403	0,15008
House 4	0,15828	0,15831	0,15829	0,19153
House 5	0,10127	0,20014	0,14247	0,17238
House 6	0	0,158738	0,14551	0,17607
House 7	0,11674	-	0,11674	0,14126
House 8	0,09607	-	0,09607	0,11624
House 9	0,10503	0,13988	0,11955	0,14466
House 10	0,09544	-	0,09544	0,11548
House 11	0,11808	0,15447	0,13324	0,16122
Average analysed houses			0,12299	0,14882

Annex III. Additional simulation results

Below are two figures corresponding to each section that represent the purchases and sales of electricity to the grid in the optimized system. As you can see, in those workshops where a system based solely on photovoltaic technology has been designed, during the central hours of the day, the solar panels generate enough electricity to meet the needs of that moment and send the surpluses generated to the grid. In scenarios with a wind turbine system, electricity production is also generated outside the hours of solar radiation, especially in the autumn and winter months.

Scenario 1

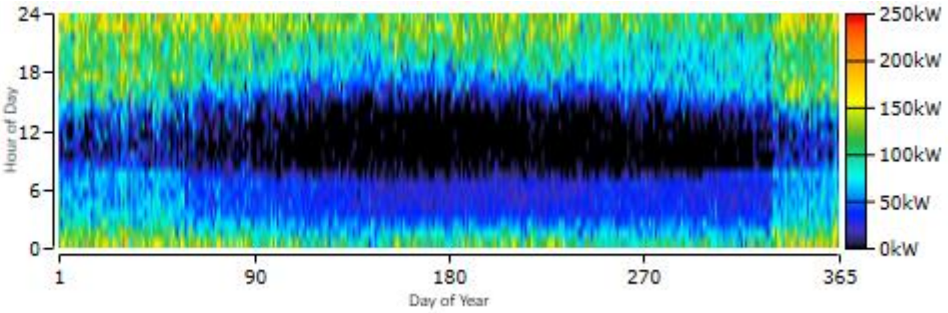

Figure 48: Energy purchased from the grid in the scenario 1

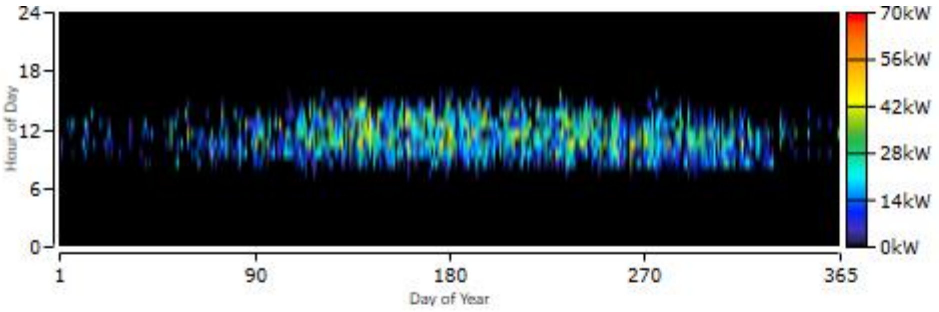

Figure 49: Energy sold to the grid in the scenario 1

Scenario 2

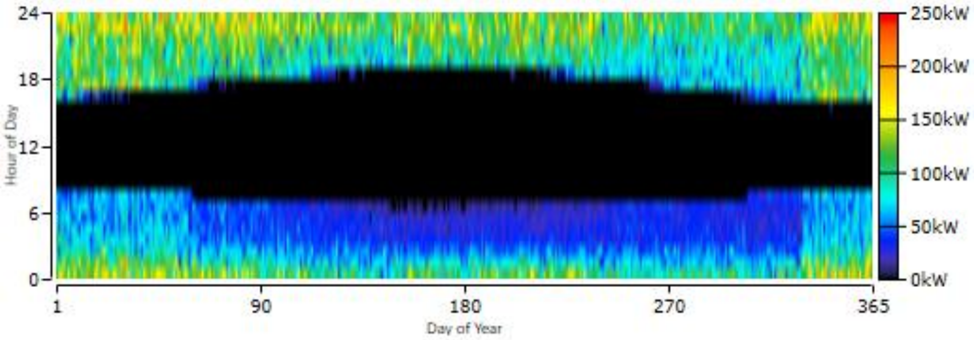

Figure 50: Energy purchased from the grid in the scenario 2

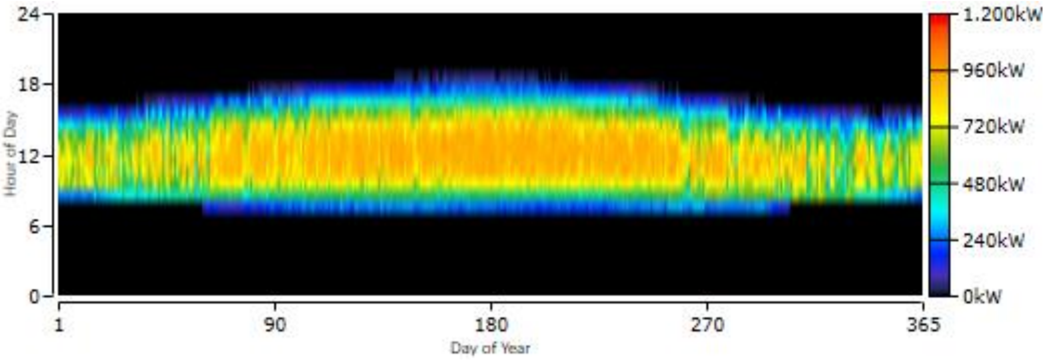

Figure 51: Energy sold to the grid in the scenario 2

Scenario 3

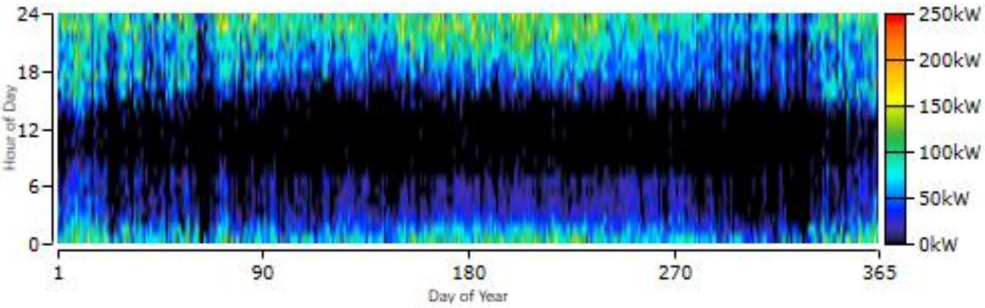

Figure 52: Energy purchased from the grid in the scenario 3

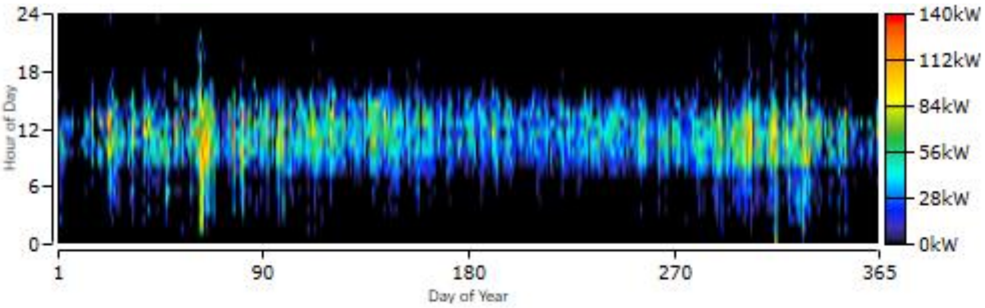

Figure 53: Energy sold to the grid in the scenario 3

Scenario 4

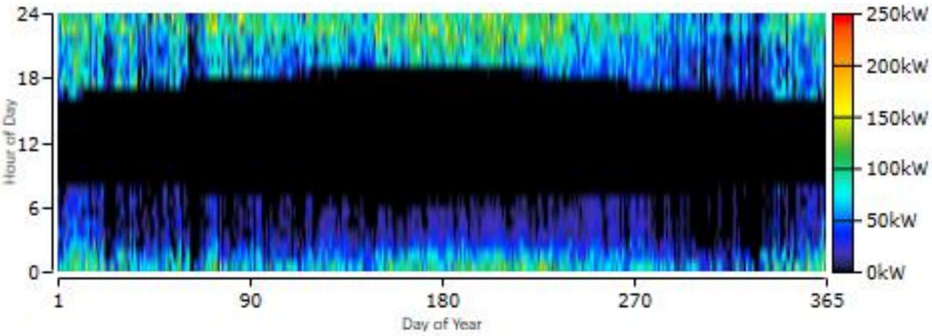

Figure 54: Energy purchased from the grid in the scenario 4

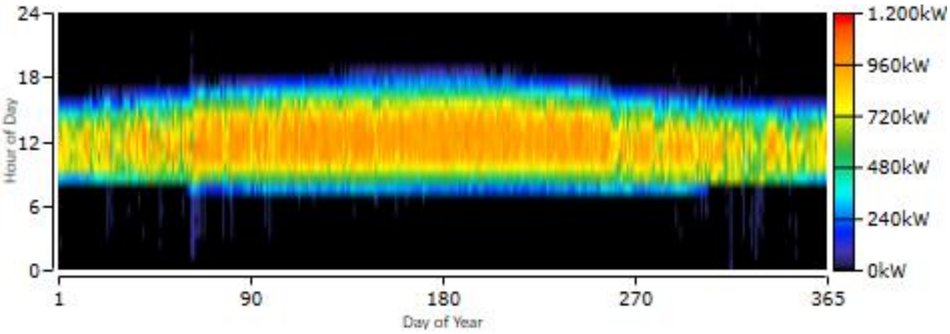

Figure 55: Energy sold to the grid in the scenario 4

Scenario 5

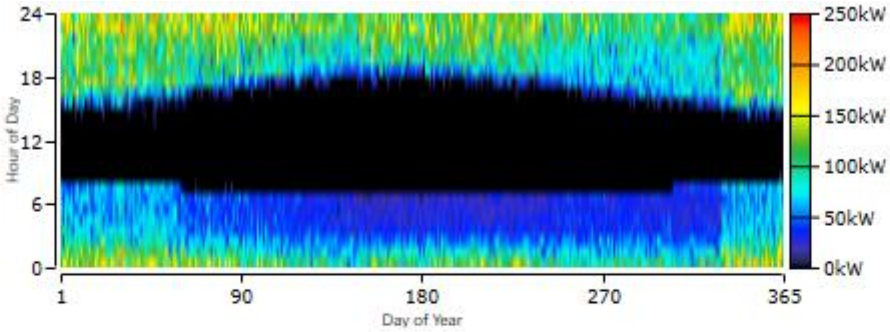

Figure 56: Energy purchased from the grid in the scenario 5

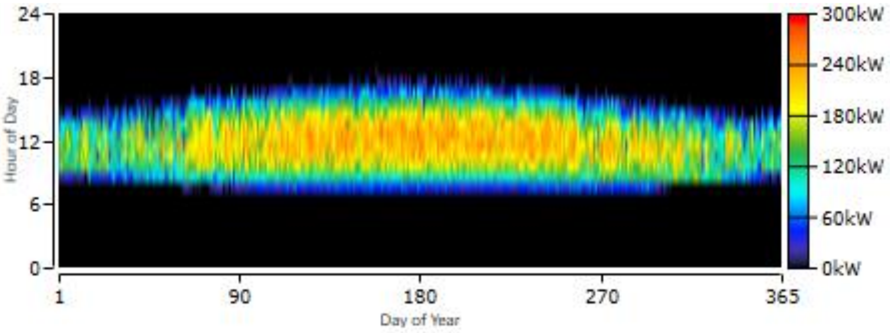

Figure 57: Energy sold to the grid in the scenario 5

Scenario 6

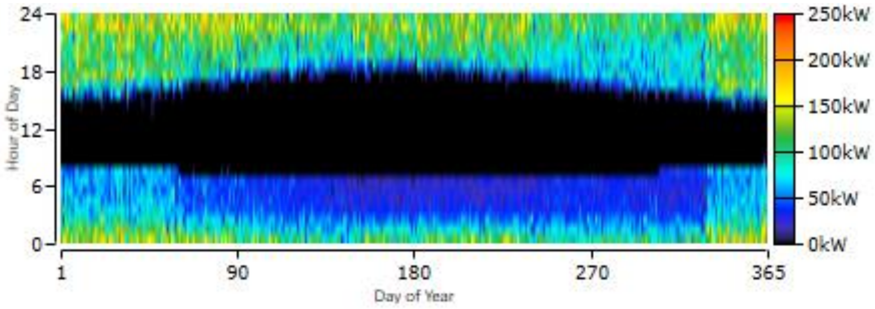

Figure 58: Energy purchased from the grid in the scenario 6

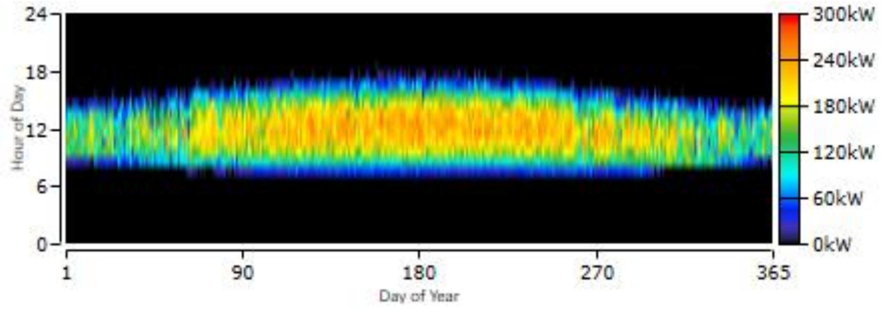

Figure 59: Energy sold to the grid in the scenario 6

Scenario 7

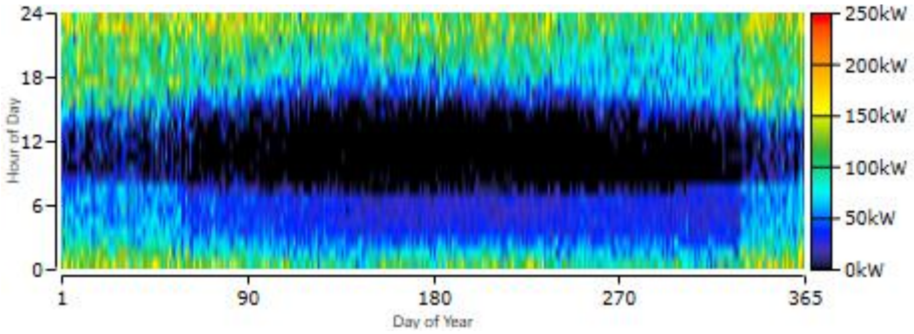

Figure 60: Energy purchased from the grid in the scenario 7

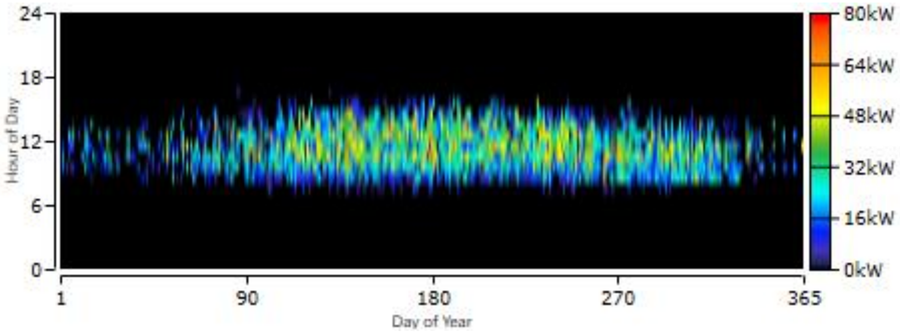

Figure 61: Energy sold to the grid in the scenario 7

Scenario 8

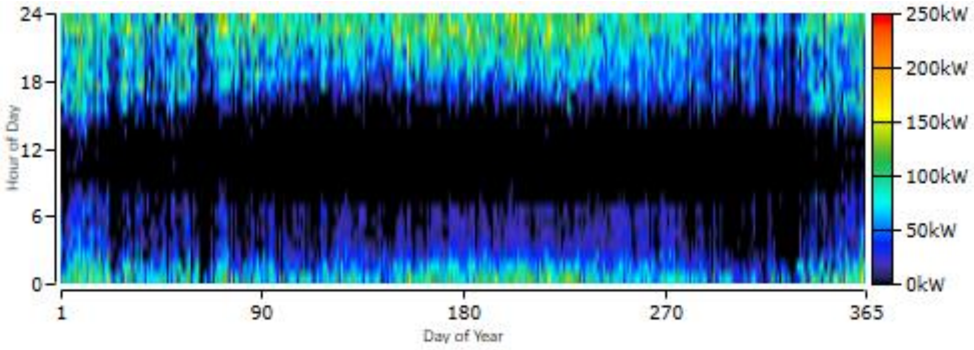

Figure 62: Energy purchased from the grid in the scenario 8

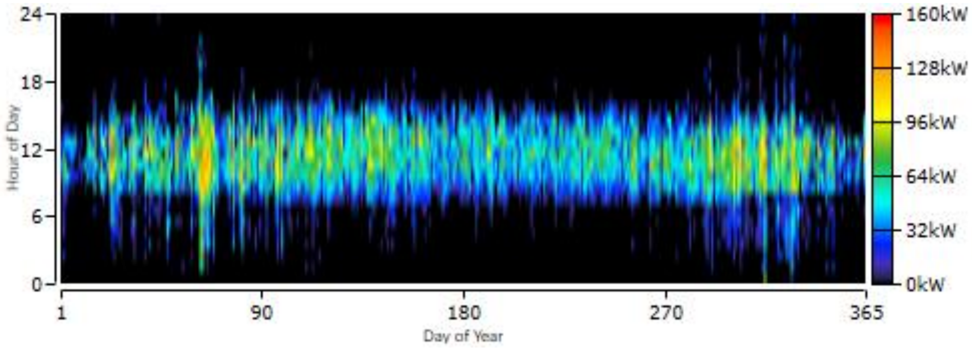

Figure 63: Energy sold to the grid in the scenario 8