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MASTER'S DEGREE IN PROJECT MANAGEMENT

FINAL MASTERS THESIS

Looking for Net Zero Districts: The case of Port District of Seville

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BASIC DATA

- *Studet:* Ander Filgueira Ciriza.
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- *Tittle*: Looking for Net Zero Districts: The case of Port District of Seville.
- *Abstract*: Current climate situation, together with the politics driven by the European Union have inspired the development of Net Zero Districts. This document presents an alternative and economic analysis of a hybrid (PV/Wind turbine) power system projects. The case study is located at the Port District Area in the city of Seville, Spain. The analysis is carried out by investigating the potentials of wind and solar energy and collecting data from different sources. Hybrid Optimization Model for Electric Renewable (HOMER) software is used to analyse the available data and the technical-economic feasibility of the proposed hybrid power system. In this document, both off-grid and grid-connected systems are modelled and optimized for comparison purposes. The simulation results indicate that the proposed model of a grid-connected system is more feasible than the off-grid one in the mentioned region.
- *Resumen*: La situación climática que se está viviendo actualmente, junto con las políticas energéticas impulsadas por la Unión Europea, han inspirado el desarrollo de los distritos Net Zero. Este documento presenta un estudio de alternativas y análisis económico de proyectos de sistemas de generación eléctrica híbrida (solar y eólica). El caso práctico está situado en el distrito portuario de la ciudad de Sevilla, España. El análisis se desarrolla mediante la investigación de los potenciales eólico y solar, junto con la recolección de datos de diferentes fuentes. El software utilizado para el análisis de los datos y la viabilidad técnico-económica del proyecto será HOMER. En este documento se trabaja en un modelo para un sistema aislado y otro conectado a red, con el objetivo de comparar la viabilidad de ambos. Los resultados del proyecto muestran que, para la localización prevista, un sistema conectado a red obtiene mejores resultados en cuanto a viabilidad del proyecto.
- *Laburpena:* Gaur egun bizi dugun egoera klimatikoak, Europar Batasunak bultzatutako politika energetikoekin batera, Net Zero distrituen garapena ekarri du. Dokumentu honek sistema hibridoen (eguzki energia eta energia eolikoa integratzen dituena) alternatiba azterketa eta analisi ekonomikoa aurkezten du. Kasu praktikoa Sevilla hiriko (Espainia) portu-distrituan kokatzen da. Analisia egiteko, haize- eta eguzki-potentzialak ikertu dira, eta hainbat iturritako datuak bildu. Proiektuaren bideragarritasun tekniko-ekonomikoa eta datuak aztertzeko erabiliko den softwarea HOMER izango da. Dokumentu honetan, sistema isolatu baterako eta sarera konektatuta dagoen beste baterako eredu bat lantzen da, bien bideragarritasuna alderatzeko. Proiektuaren emaitzek erakusten dutenez, aurreikusitako kokapenerako, sarera konektatutako sistema batek emaitza hobeak lortzen ditu proiektuaren bideragarritasunari dagokionez.

- *Key Words*: Energy, Renewable Energy Sources, Net Zero District, Economic Analysis.

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LIST OF ABBREVIATIONS

AC ....Alternative Current
COE..................Cost of Energy
CRF..................Capital Recovery Factor
DC ....Direct Current
DES..................Distributed Energy Systems
DN ....Distribution Networks
EC ....European Commission
EU ....European Union
HOMER............Hybrid Optimization Model of Electric Renewable
IRR ....Internal Rate of Return
NPC..................Net Present Cost
NREL................National Renewable Energy Laboratory
NZEB................Nearly Zero Energy Building
NZED................Nearly Zero Energy District
PM....................Project Management
PMk ....Power Market
PV.....................Photovoltaic
RES..................Renewable Energy Sources
TAC ....Total Annualized Cost
TEPS................Traditional Electric Power System
TN.....................Transmission Network

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1 INTRODUCTION

The 2030 climate and energy framework targets proposed at the European growth strategy for the present decade, together with other strategies promoted by the European Union (EU), have settled the objectives of reducing the energy usage and the Greenhouse gas emissions [1].

As a consequence of the goal of the European Union of reducing the energy usage in buildings, *Nearly Zero-Energy Buildings* (NZEB) have become more popular among the community, due to their inherent capacity and objective of reducing buildings' energy usage and, thus, associated CO_2 emissions. Significant work has been done on the proposal of definitions for the NZEB concept and possible variations [2], [3].

The concept of *Nearly Zero-Energy District* (NZED) arises in this context, with the intention of adjusting the nearly zero-energy principles to the urban context. By settling the mentioned principles and objectives to a whole district, the strategy of considering different energy generation and consumption sources brings the possibility of sharing needs costs and resources.

Accordingly, the NZED approach has the objective of addressing the main issues that are already considered in NZEB at the individual level, which are fundamentally based on energy performance and renewable energy generation near its consumption site. Regarding the performance aspect, the influence of buildings and the context of their surroundings are taken into account to obtain a higher energy performance assessment accuracy [4].

Hybrid power systems using *Renewable Energy Sources* (RES) are becoming most popular due to their potential advantages [5]. The concepts of *Photovoltaic* (PV) and Wind energy are well known, as well as the technologies for these energy resources. However, the variation of solar/wind energy generation does not match with the energy consumption, and a storage system must be used to ensure the energy availability. Research developed worldwide indicates that a hybrid system including PV, wind and batteries is a reliable source of electricity [6], [7].

National Renewable Energy Laboratory's (NREL) Hybrid Optimization Model for Electric Renewable (HOMER®) software has been employed to carry out the present study. HOMER® performs comparative economic analysis on a distributed generation power system.

Inputs to HOMER® will perform an hourly simulation of every possible combination of the components, and rank the resulting systems according to the criteria specified by the user, such as cost of energy (COE, €/kWh) or Internal Rate of Return (IRR). Furthermore, HOMER® can perform "sensitivity analyses", where the values of certain parameters (for example, cost of the energy obtained from the grid) are modified in order to analyse their impact on the system configuration [8].

1.1 Background

This Master Thesis demonstrates the knowledge and abilities acquired by the student Ander Filgueira Ciriza throughout the European master's degree in project management – "EUROMPM".

Each chapter of this document titled: "Looking for Net Zero Districts: The case of Port District of Seville", presents a technical and economic analysis of a hybrid energy system, in which Renewable Energy Sources (RES) have been integrated together with the grid.

The technical aspects of this work have been directed and tutored by Professor Dr. José Ignacio Muñoz Hernández, who belongs to the group of "Master's Degree Final Project teachers of European Master's in Project Management EUROMPM" of the University of the Basque Country (UPV/EHU), and moreover professor in the Master of Industrial Engineering of the University of Castilla – La Mancha.

1.2 Motivation

The decarbonization of the economy stimulating energy consumption coming from RES and the objective of making a more efficient use of domestic energy sources are some of the policies adopted by the EU to ensure clean, reliable, and affordable energy supply for all citizens.

Project Management (PM) establishes the guidelines to economically analyse projects, providing tools and methods to determine if a project is economically feasible or not. And at the same time, those guidelines can help to reduce the cost and select the best option in case many different chances are being considered.

This work presents an analysis for a real project that is going to be developed in the Port District of Seville, in which RES are being integrated into the grid, with the aim of reducing the necessity of the grid as much as possible. The work also takes as sources of inspiration the following Energy Policies indicated by the European Commission (EC):

- ***Energy technology and innovation:*** The EU supports deployment of low-carbon technologies such as photovoltaic, wind power, carbon capture and storage (CCS), and energy storage technologies [9].
- ***Secure energy supplies:*** *The EU has to become less dependent on imported energy - by making more efficient use of our domestic energy while diversifying sources and supplies* [9].
- ***Renewable Energy:*** *The EU coordinates work to reach national targets in line with the renewable energy directive. It also promotes alternative energy use in transport* [9].

Therefore, this work tries to encourage the Stakeholders in the implementation of RES into the grid, so that they can reduce their dependency to the grid, and they can produce their own energy on-site.

1.3 Objectives

The main objective of this master's thesis is to analyse the economic feasibility of the integration of RES into the grid for on-site energy generation, and find the best option for a given real project.

And to achieve it, it requires developing the following specific objectives:

- Prepare simulation models that consider all the specific inputs necessary to get conclusive results and adapt them to the specifications of the project.
- Analyse the results maintaining a clear criterion to select, justify and defend the best possible option.

1.4 Document Structure

This document is structured in six chapters plus two appendixes. Below the content of each of them is briefly described:

- **Chapter 1. Introduction:** Explains the context in which the project has been developed, and the motivations of the author to do it.
- **Chapter 2. Previous Concepts:** The operation of the Power Market and the basis of the traditional electric power systems and distributed energy systems are explained in this chapter.
- **Chapter 3. Bibliographic Review and Contextual Framework:** In this section, the importance of the economic analysis of a project is explained. The basis of the Spanish Power Market is also explained here.
- **Chapter 4. Proposed model description:** This section describes the model used to analyse the technical and economic feasibility of the hybrid power system in the Port District of Seville.
- **Chapter 5. Simulation and Results:** The simulations of the model that have been done are mentioned here, together with the technical and economic analysis of the results that are obtained.
- **Chapter 6. Conclusions and Future Work:** The conclusions drawn during the project are explained here, together with the work that should be done in future phases.

2 PREVIOUS CONCEPTS

This document presents the analysis of a system that integrates RES into the grid. The proposed model aims to analyse the possibilities of reducing the consumption of energy coming from the grid, and on-site production using RES.

Therefore, it is important to clearly define and interpret each of the components that interact within the system.

The definitions for the interpretation of the model are indicated below, starting with the description of more general concepts, up to those with more specific concepts.

2.1 Power Market

Power Market (PMk) is the set of markets when the negotiation for the purchase and sale of electricity (power and energy) is made. Short-term and long-term operations are done, where the supply and demand principles are applied to fix prices: Production and Consumption must be constantly adjusted. The units of measurement used for power and energy are:

- **Power [MW]:** Measures the capacity that a generator has to produce power at a specific time, which is generally set to 1 second. Power measures the ability to produce new energy [10].
- **Energy [MWh]:** Measures the power that flows through a point in a given time. Energy measures the power consumption in a period of time [10].

2.1.1 Power Market Activities

In order to explain PMk concepts in an easily understandable way, this document will take as a point of reference the guidelines by the Operador del Mercado Ibérico de Energía – Polo Español (OMIE) [11], which establishes that the Iberian Power Market is structured considering two types of activities:

- **Partially Liberalized Activities:** Are established through the production and trading of power, and any certified agent has the freedom to manage them.
- **Regulated Activities:** Are established through the transport and distribution of power, and specific controls and authorizations are required to manage them.

It is important to remark that, depending on the world zone/region where power is produced, transported and/or distributed, and on the characteristics of the energy sources (renewable, fossil fuels, etc.), financial aids are being received, which allow performing in the PMk with more or less freedom at the time of its trading.

2.1.2 Power Market Sectors

The Iberian Power Market is made up of two main groups, which are described in Figure 1. Power Market SectorsFigure 1 [11].

- **Wholesale Market:** Producers, Distributors and Consumers take part in the wholesale market by selling and buying power. In this market, negotiations are made during all the hours of a quarter agreed (closed) with one year in advance, and even at specific hours agreed (closed) with few hours in advance. In this market, parties can negotiate directly with each other (bilateral negotiations), or through the management of a company similar to a stock exchange (organized negotiations).

- **Retail Market:** Distributors sell power to Consumers who do not acquiere it directly from the Wholesale market. In this market, the own costs of power production are transferred using the consumption rate, as well as the regulated costs.

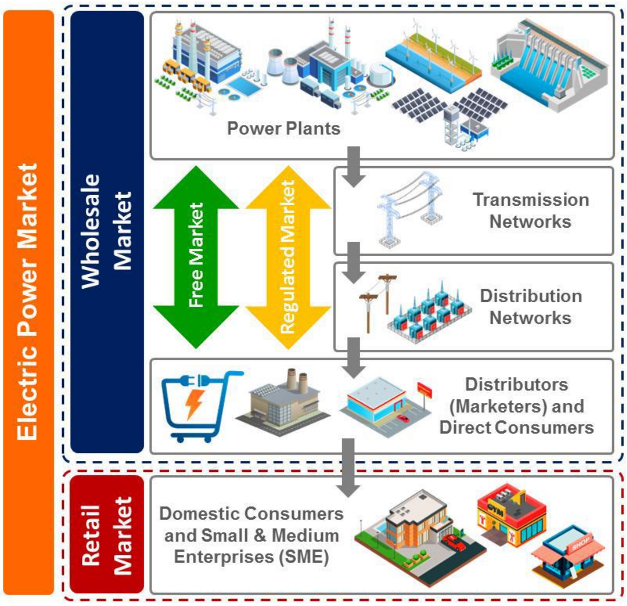

Figure 1. Power Market Sectors.

2.2 Traditional Electric Power System

Traditional Electric Power System (TEPS) is a synchronous set of components that operates in a specific area to cover the power demand of the consumers. TEPS are characterized according to the structure of their network, the size of the area that must be supplied with power, and the sources from which power is produced [10]. TEPS are based in a unidirectional flow system, in which power goes always from the generation point to the consumption point. The main objective of TEPS is to ensure the availability of power anywhere in the network at any time of the day [10], [12].

Main components that make up TEPS are the followings: Power Plants, Electrical Substations, Transmission Networks and Distribution Networks. Those components are distributed geographically depending on the needs of the network [10]. Figure 2 shows a diagram of a TEPS in which unidirectional flow is shown.

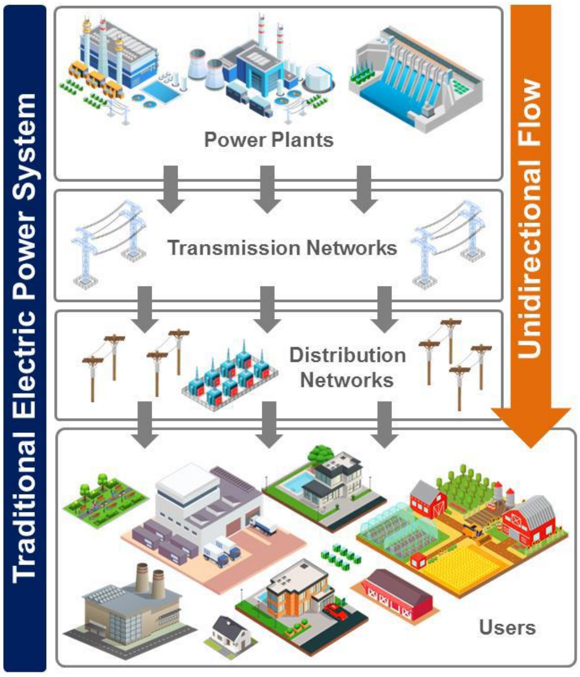

Figure 2. Traditional Electric Power System

In TEPS, most common and technologies used in power plants to generate power from energy sources are [10]:

- Nuclear: A controlled nuclear reaction is used to make heat and produce steam needed to drive a steam turbine generator. In nuclear reactors uranium is used as a primary source (non-renewable source).
- Wind Power: Wind energy is converted into electrical energy by means of windmills.
- Photovoltaic: Photovoltaic panels convert solar radiation directly into electrical energy.
- Hydroelectric: The energy of moving water is used to rotate a turbine and generate electric power.
- Thermal: Different fuels (such as coal, fossil fuels and natural gas) are burnt to make steam needed to drive a steam turbine generator. Non-renewable sources are used.
- Combined cycle: Natural gas is burnt to generate electric power through a combustion turbine. The excess heat is then used to evaporate water and drive a second turbine that also generates electric power. Non-renewable sources are used.
- Other technologies are: Cogeneration, Solar Thermal, Biomass, Waves and Geothermal.

Electric power is generated in generation plants, and then transmitted to distribution plants via the Transmission Networks (TN). Once the power reaches the distribution centres, it is distributed to the final consumers via the Distribution Networks (DN). It must be mentioned that the power that goes through the TN and DN is transferred by passive electrical devices called transformers, which are operated in the Electrical Substations.

The main objective of the System Operators is to keep the balance between the production and consumption of power, considering the losses that are generated by the transmission and distribution of the electricity through the grid, technical failures, incompatibilities between Direct Current (DC) and Alternating Current (AC), etc.

2.3 Distributed Energy Systems

Distributed Energy Systems (DES) encompass a diverse array of generation, storage and energy monitoring and control solutions. DES can be tailored to very specific requirements and users' applications, such as cost reductions, energy efficiency, security of supply or carbon reduction.

DES categories include: power generation, combined heat and power, energy storage (including electric vehicles) and distributed energy management systems. DES can be connected into the grid, or even completely isolated, which allows electrifying areas in which grid connection is not economically or technically possible, and cover energy in the forms of electricity, heating and cooling [13]. Figure 3 shows a graphic illustration of a grid connected DES.

Some of the advantages of DES are:

- Cost savings: DES can be tailored to match the consumer's requirements as well as enabling actors to shape local generation and consumption in response to market price signals to achieve the lowest overall Cost of Energy (COE) [13].
- Energy efficiency: DES coupled with other traditional energy conservation measures can improve system efficiency. Integrated real time data monitoring and multipoint controls at both building, plant and network level can improve asset utilisation and plant efficiency and ensure power is used only when and where it is needed [13].
- Emissions and pollution reduction: Renewable and low carbon technologies are integrated in DES. This allows the integration of such technologies into the network and reduction of the carbon intensity and environmental impact of the system. Having a lower environmental impact helps to maintain a greener and cleaner ecosystem [13].
- Building development consents and permits: Stringent sustainable development standards must usually be accomplished when seeking permission for new constructions. Integrating DES into buildings or networks can help in the objective of achieving the energy efficiency, air quality and carbon emissions targets in a more cost-effective way [13].
- Security and stability of supply: Local, decentralized and controllable DES generation and storage sources can be designed to provide the end user with total resilience or even full independence from the grid. This benefits also affect to grid operators, as DES can manage demand to reduce peak loads and maintain power quality when infrastructure is nearing capacity, so that the risk of blackouts is avoided and the need for major grid reinforcement investments are avoided [13].
- Resilience for cities and communities: Rapid population growth is driving urbanizations of increasingly dense cities with large energy demands. This trends, together with the large-scale environmental changes that are taking

place, make cities a priority for increased resilience to shock events. DES are a potential solution to this problem as energy can be stored within the affected areas [13].

- Extend access to electrification: Independent DES solutions can be deployed completely off-grid in areas where the grid expansion is not economically viable. Electrification enables economic development, as off-grid microgrids can "pump prime" economic growth with full grid extension and connection taking place at a later stage, when the initial growth has reduced the grid investment risk profile [13].

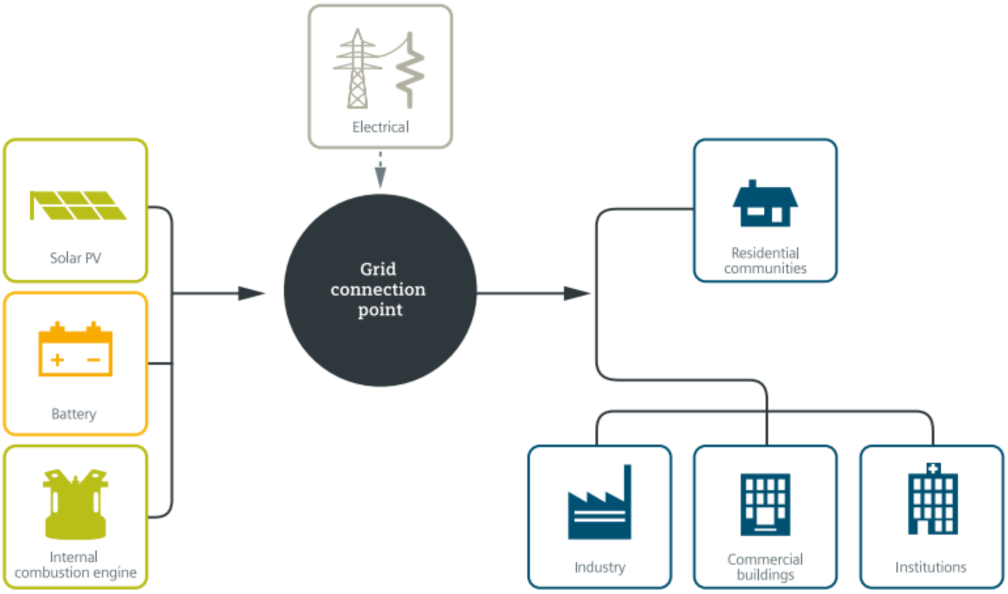

Figure 3. Grid Connected Distributed Energy System.

3 BIBLIOGRAPHIC REVIEW AND CONTEXTUAL FRAMEWORK

Before starting a new project, it is important for the Project Manager to analyse, among many other aspects, the economic feasibility of the project. PMBoK provides a guideline with some parameters that will help in the labour of concluding the economic feasibility of the project.

3.1 Project Management Business Documents

It is necessary to ensure that the project management approach secures the intent of business documents. The two documents are mentioned in Figure 4, and are independent to each other and must be developed and maintained throughout the whole life cycle of the project.

Project Business Documents	Definition
Project business case	A documented economic feasibility study used to establish the validity of the benefits of a selected component lacking sufficient definition and that is used as a basis for the authorization of further project management activities.
Project benefits management plan	The documented explanation defining the processes for creating, maximizing, and sustaining the benefits provided by a project.

Figure 4. Project Business Documents.

The project manager is responsible for providing recommendations and oversight to keep the project business case, project management plan, project charter, and project benefits management plan success measures in alignment with one another and with the goals and objectives of the organization.

Project management documents that have been mentioned above must be appropriately tailored in benefits of the project. The interrelationship between the project management business documents and the needs assessment is shown in Figure 5. This figure also shows and approximation of the life cycle of the mentioned documents against the project life cycle [14].

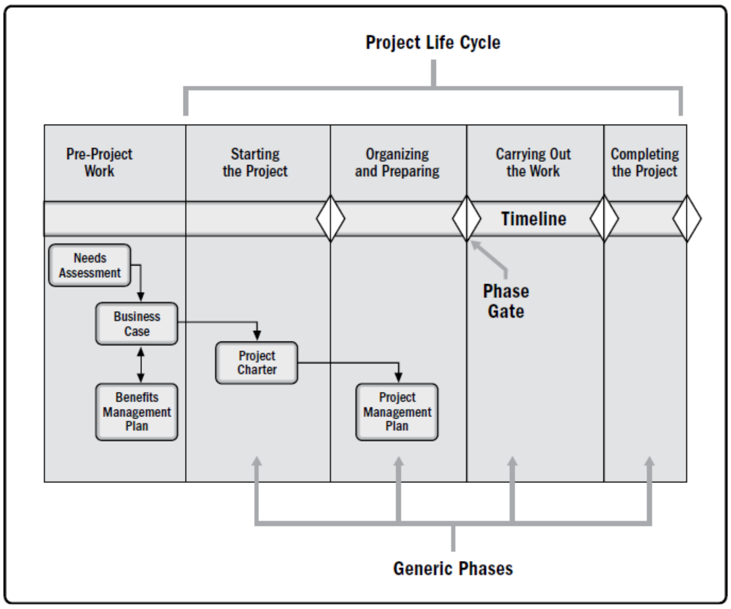

Figure 5. Interrelationship of Need Assessment and Critical Business Documents.

3.2 Project Success Measures

One of the most common challenges in project management is determining if a project is or not successful.

Traditionally, project management metrics of cost, time, scope and quality have been the most important parameters when the success of a project wanted to be concluded. However, in the last years it has been concluded that project success should also be measured considering the achievement of the objectives of the project.

Depending on the stakeholders, many differences may appear among their criteria about what a successful project is, and which factors are the most important. For that reason, it is critical to clearly document the objectives of the project, which must be clearly measurable.

In terms of economic aspects, some of the most important parameters to analyse the viability of the project are the following [14].

- Net Present Cost (NPC): *NPC* indicates the installation and the operating cost of the system throughout its lifetime. The following formula is used to calculate the *NPC* [15], [16]:

$$NPC = \frac{TAC}{CRF(i, Rpr_j)}$$

Where, *TAC*, *CRF*, *i* and Rpr_j are the total annualized cost (€), capital recovery factor, interest rate in percentage, and project lifetime in year, respectively.

- Total annualized cost: It is the sum of the annualized costs of every component of the system, together with operation, maintenance and replacement costs [15], [16].
- Capital Recovery Factor (*CRF*): It is a ratio used to calculate the present value of a series of equal annual cash flows [15], [16]:

$$CRF = \frac{i \cdot (1+i)^n}{(1+i)^{n-1}}$$

where, *n* represents the number of years and *i* the annual real interest rate, respectively.

- Annual real interest rate: Is a function of the nominal interest rate shown as [15], [16]:

$$i = \frac{i' - F}{1 + F}$$

Where *i* is the real interest rate, *i'* the nominal interest rate and *F* the annual inflation rate.

- Cost of the Energy (*COE*): Is the average cost of each kWh of useful electrical energy produced by the system. The *COE* is calculated as follows [15], [16]:

$$COE = \frac{TAC}{L_{prim,AC} + L_{prim,DC}}$$

where, $L_{prim,AC}$ and $L_{prim,DC}$ are the primary Alternative Current and Direct Current, respectively.

3.3 Supply and Demand Power Market

The structure of the Iberian Market is established through two market classifications. They interact with each other according to the Supply and Demand movements established by the Consumers, Distributors and Producers at certain moments or periods of time [11].

3.3.1 Day-Ahead Market

This is a marginalist market and is formalized the previous day to the Delivery-Day of the power. Purchasing Agents (distributors, end consumers, exporters, and other intermediaries) make their offers in the previous day, which is formally called Day-Ahead.

> *As an integral part of the electrical energy production market, the day-ahead market, also called single day-ahead coupling (SDAC), aims to carry out electrical energy transactions by submitting selling and takeover bids for electrical energy on behalf of the market agents for the twenty-four hours of the following day.*
> *Every day of the year at 12:00 CET is the day-ahead market session where prices and electrical energies are set for all across Europe for the twenty-four hours of the next day.*
> *The price and volume of energy at a specific hour are established by where supply and demand intersect, following the model agreed upon and approved by all of the European markets that is currently applied in Spain, Portugal, Germany, Austria, Belgium, Bulgaria, Croatia, Slovakia, Slovenia, Estonia, France, Holland, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Finland, Sweden, Denmark, Norway, Poland, the United Kingdom, the Czech Republic, and Romania* [11].

During this market, the prices and the quantities of power that are going to be generated (by producers) and consumed (by consumers) are established for the 24 hours. Figure 6 shows the hourly distribution of the Day Ahead market.

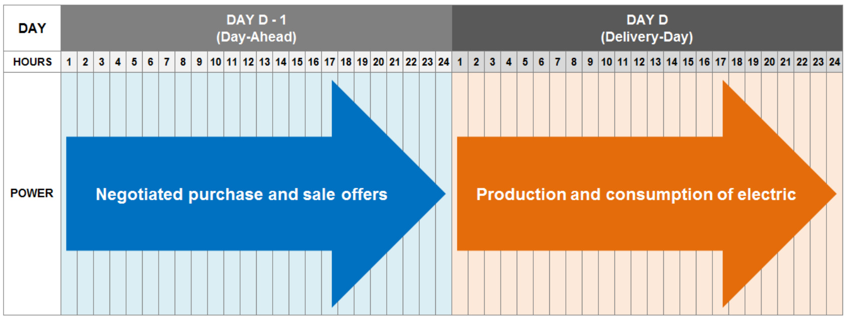

Figure 6. Day-Ahead Market and Reference Points.

Before the terms are agreed in the Day Ahead (D-1), the generating units must present their hourly offers for all the 24 of the Delivery Day (D). A sale offer is an ascending curve containing the relationship between power and prices for each hour.

Purchase offer, however, is a descending curve that contains the relationship between power brackets and prices for each hour.

Figure 7 shows the comparative example of one sale offer and one purchase offer for the same hour.

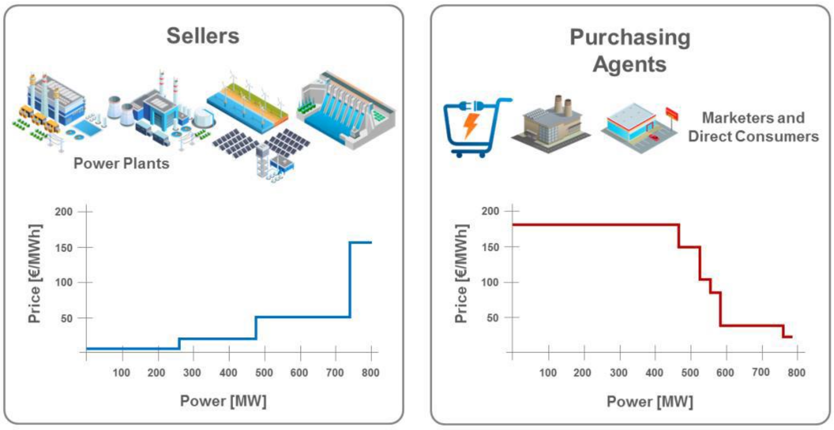

Figure 7. Supply and Demand Curves.

The final price of the energy for that given hour is the given by the point in which both curves "Match". An example of this is shown in Figure 8, where Power Sale Offer Curve and Power Purchase Offer Curve are put together, and the Price Fixing point is pointed.

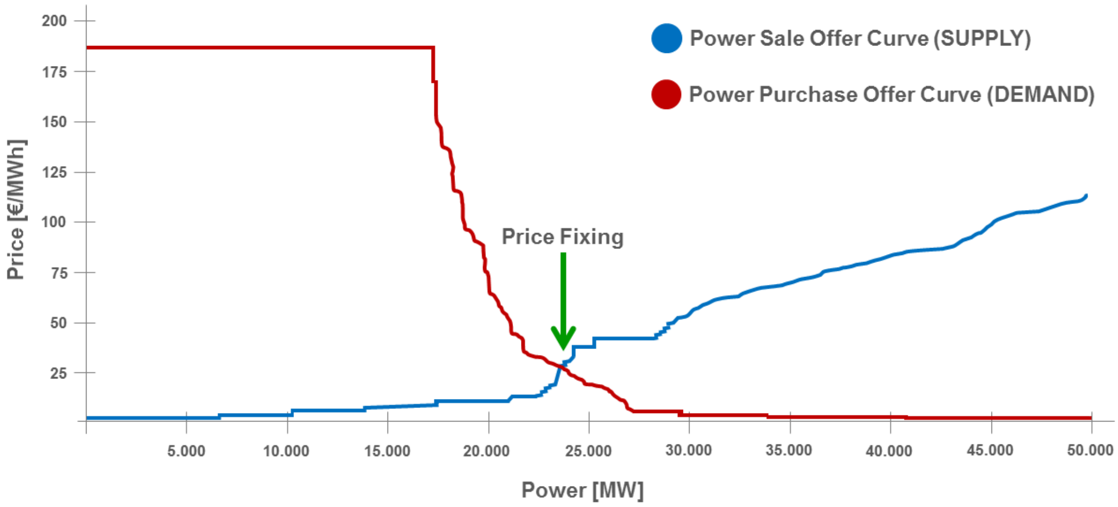

Figure 8. Matching Processes in Day-Ahead Market.

When Power Sale Offers are established, each power source offers a different price, depending on the costs associated with the generation of the energy in each case: nuclear power plants and renewable energy sources (wind and solar energies), for example, offer their energy at a value of 0 €/kWh. However, there are other energy sources, such as hydroelectric plants or combined cycle plants, that offer their energy at very high prices because they can be very flexible and easily adjustable.

On the other hand, when analysing the Demand Curve, distributors usually offer the maximum allowed price, in order to assure the supply for their consumer customers. However, they know that the final price they will pay will be the result of the market "Matching", which will be determined by the offers coming from customers, which will purchase power only if its prices is lower or equal to a certain value.

The market price for each and every hour of the Delivery-Day will be determined by the intersection of the Supply and Demand Curves of power.

This price fixes the purchase and sale offers that were "Matched", in other words, the power that will be exchanged at the fixed price is the one that remains at the left of the intersection point of the curves, which can be seen in Figure 9.

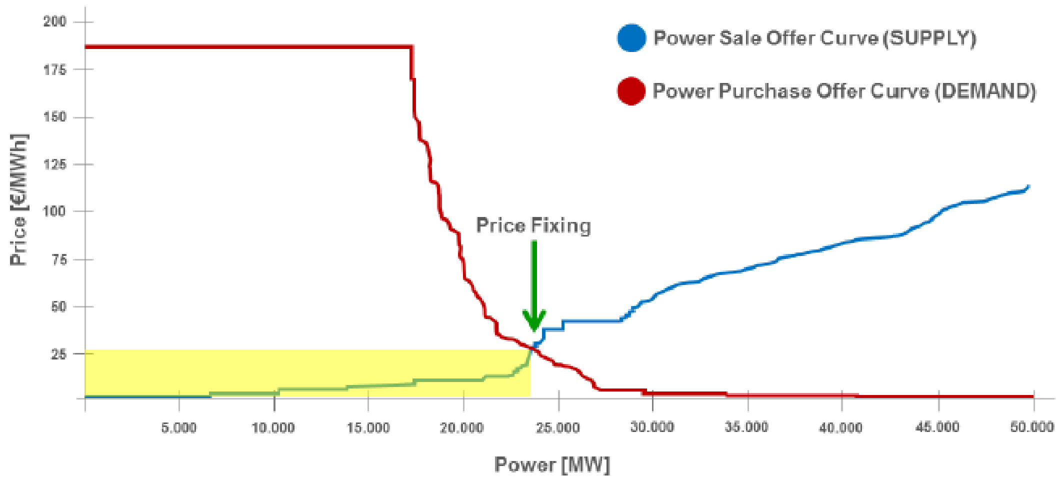

Figure 9. Square of Price Fixing in Sales and Purchases Offers.

When all the Price Fixing generated in the 24 hours of a day are grouped, the hourly Price Curves are generated for the Delivery-Day. Figure 10 shows an example of the mentioned Hourly Price Curve.

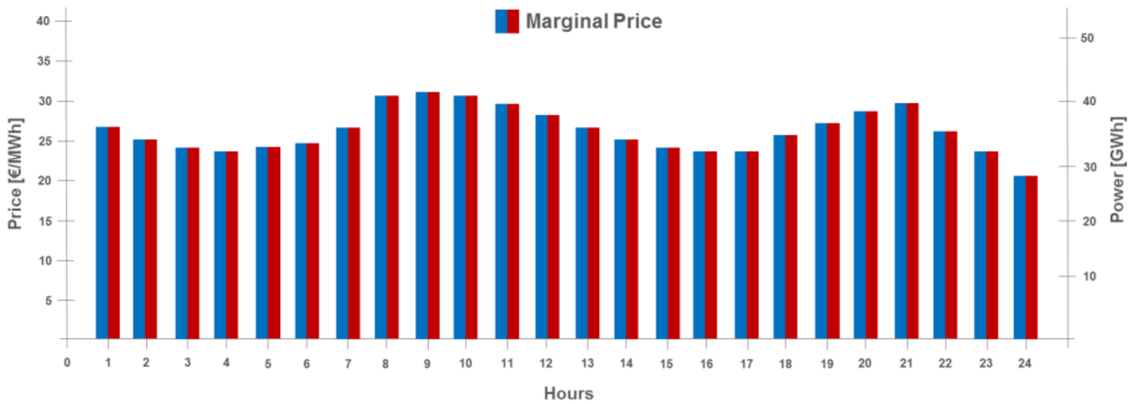

Figure 10. Hourly Price Curve.

4 PROPOSED MODEL DESCRIPTION

The city of Seville, located in the south of Spain, is currently involved in one of its most relevant projects in the last centuries. The city is working on the renovation of its Port District, which will help on the transformation of the port and its adaptation to the new uses for the citizens.

The Port District, located near the river Guadalquivir, is divided into four different areas, depending on their destination and uses.

- Area 1: Is the northern area, and the one located next to the *Puente de las Delicias*. The most important characteristic of this area is its architectural composition, and the protected heritage on it.
  This area is composed of some buildings that are used for the port activities and is directly connected to some of the main streets of the city.
- Area 2: Is the area located in the centre of the port district. It is mainly a natural space, surrounded by vegetation.
- Area 3: The southern area, and the one which is nearest to the *Puente del Centenario*, houses some industrial buildings but also contains many natural areas.
- Area 4: This is the residential area of the Port District. It will house 700 homes after the renovation of the whole area.

¡Error! No se encuentra el origen de la referencia. shows the Port Area of Seville, t ogether with the distribution of the four areas described above. Furthermore, Table 1 shows the composition of areas 1-3, with the data of the space used for construction, undeveloped land, fields or natural areas and communications.

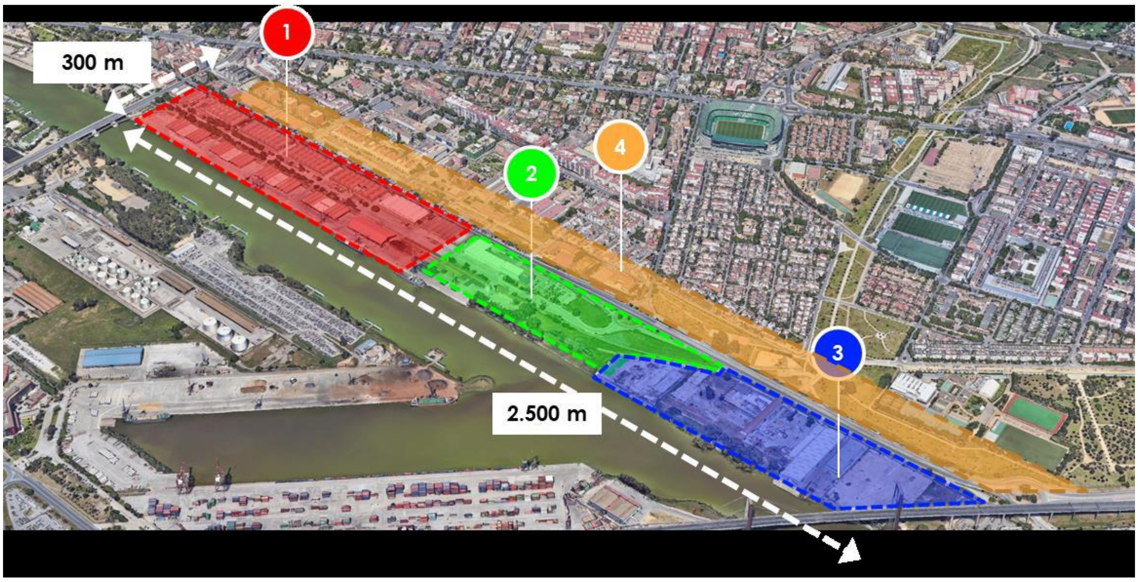

Figure 11. Distribution of Areas in Port District of Seville.

Table 1. Composition of Areas 1-3 of the Port District of Seville.

Area	Type of infrastructure	Constructed surface [m2]
Area 1	Constructions	77.720
	Undeveloped areas	13.490
	Lands and Natural Areas	42.982
	Communications	52.684
Area 2	Constructions	7.986
	Undeveloped areas	42.039
	Lands and Natural Areas	26.832
	Communications	27.858
Area 3	Constructions	13.800
	Undeveloped areas	36.635
	Lands and Natural Areas	85.472
	Communications	52.312

The integration of renewable energy sources in one of the most important aspects in the renovation that they are planning for the district.

As it has been explained above, wind and solar energies are very well-known technologies, and two of the most suitable RES for urbanized areas. On the other hand, energy storage is also becoming more and more popular in the last few years, as generation and consumption are often made in different moments of the day, and it helps to ensure that the energy that has been generated can be consumed whenever the user wants.

For these reasons, during the present document a technical and economic analysis of off-grid and grid-connected hybrid power systems will be done, in which the above-mentioned RES are integrated into the system.

The analysis of the system will be carried out using HOMER® software. *Hybrid Optimization of Multiple Energy Resources* (HOMER®) is a software developed by the *National Renewable Energy Laboratory* (NREL), and which helps the user design off-grid and grid-connected systems. HOMER® analyses the economic and technical viability of RES through optimization and sensitivity analysis and simulations. In other words, HOMER® fins the least cost combination of components that meet electrical and thermal loads, by simulating thousands of system configurations and optimizing lifecycle costs. [8].

The model needs some input data to optimize the results of the simulations.

4.1 Load Profile

As the Port District will include not only apartments but also different business and shops, a combination of different load profiles has been made to determine the total load profile of the whole district. A total amount of six different profiles have been considered, which are mentioned in Table **2**. Apart from that, Figure 12 shows the graphic expression of each load profile for the first and second days of the year. All the profile data have been downloaded from the internal library of HOMER®, which considers the weather and temperatures of the place and adapts the profiles to them.

Table **2** shows the different load profiles, as well as how many times has each of them been used. As it can be seen in the table below, apart from the apartments that have already been mentioned, full-service restaurants, large hotels, supermarkets, warehouses, and medium-sized offices will be included in the profile, with the final objective of creating the most realistic district as possible.

Table 2. Load Profiles for the Port District of Seville.

Profile	Quantity
Apartment (kW)	700
Full-Service Restaurant (kW)	10
Large Hotel (kW)	5
Supermarket (KW)	5
Warehouse (kW)	5
Medium Office (kW)	5

In order to see the difference among all the different profiles that are used, Figure 12 shows the six load profiles together for the first and second days of the year, as an example of the mentioned difference.

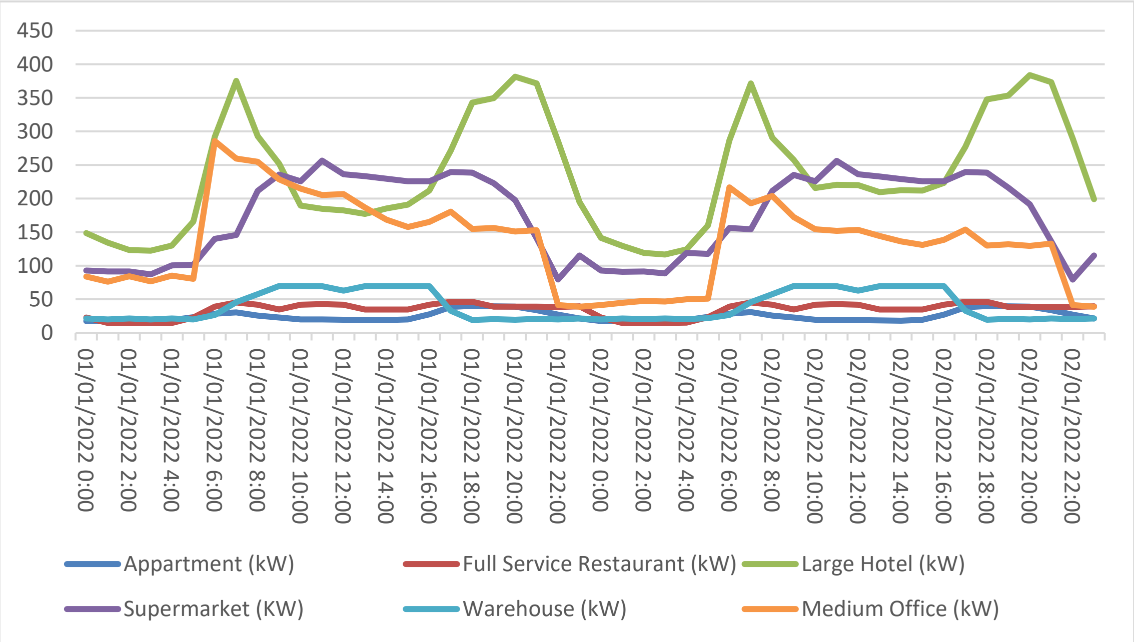

Figure 12. Load Profiles in Port District of Seville.

As a result of the combination of all the mentioned profiles, a total energy consumption of 495.996,00 kWh/day has been stablished. Figure 13 shows the profile of the daily average energy consumption of the whole district, in which 17:00 to 22:00 h time lapse is considered the peak of the consumption, with a peak consumption of 48.032,92 kW.

Figure 13. Total Daily Load Profile.

Furthermore, Figure 14 shows the monthly load profile that will be used for the simulations of the hybrid system in the proposed district.

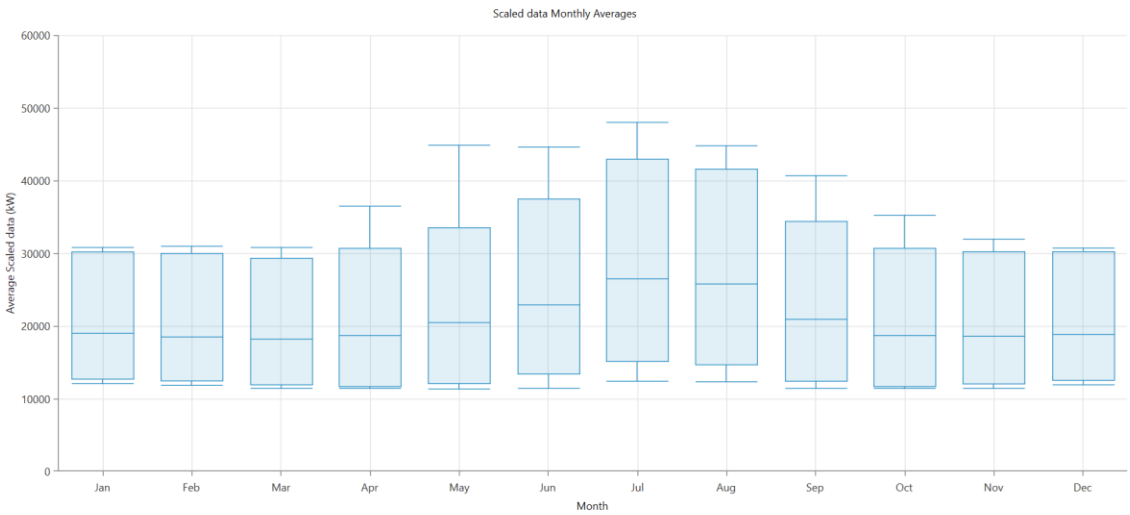

Figure 14. Monthly Average Load Profile.

4.2 Wind Speed and Solar Radiation

Other inputs needed for the simulations are the meteorological data of the location in which the system will be done. HOMER® brings the opportunity of downloading this data from the official NASA surface meteorology and solar energy database.

For the data of solar radiation and clearance index, HOMER® makes and average of the data from the last 22-year period and makes an estimation for the whole lifecycle of the project. In the case of wind speed data, however, a 30-year period is used to do the future prediction.

Figure 15 shows the monthly average wind speed data of Seville, with a minimum value of 4,21 m/s in August, and a maximum of 5,75 m/s in December.

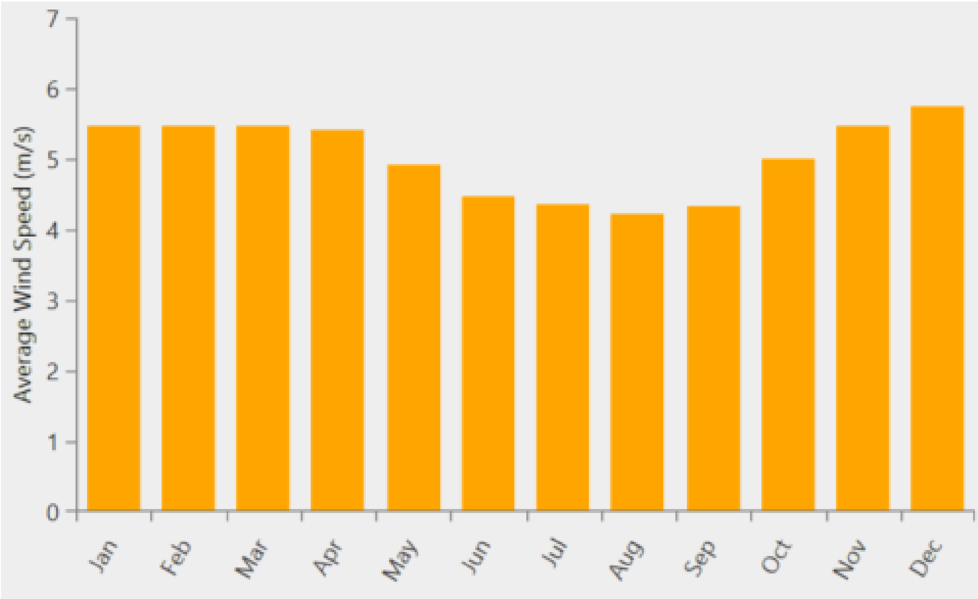

Figure 15. Wind Speed Data.

Monthly average solar radiation data and the clearance index are shown in Figure 16.

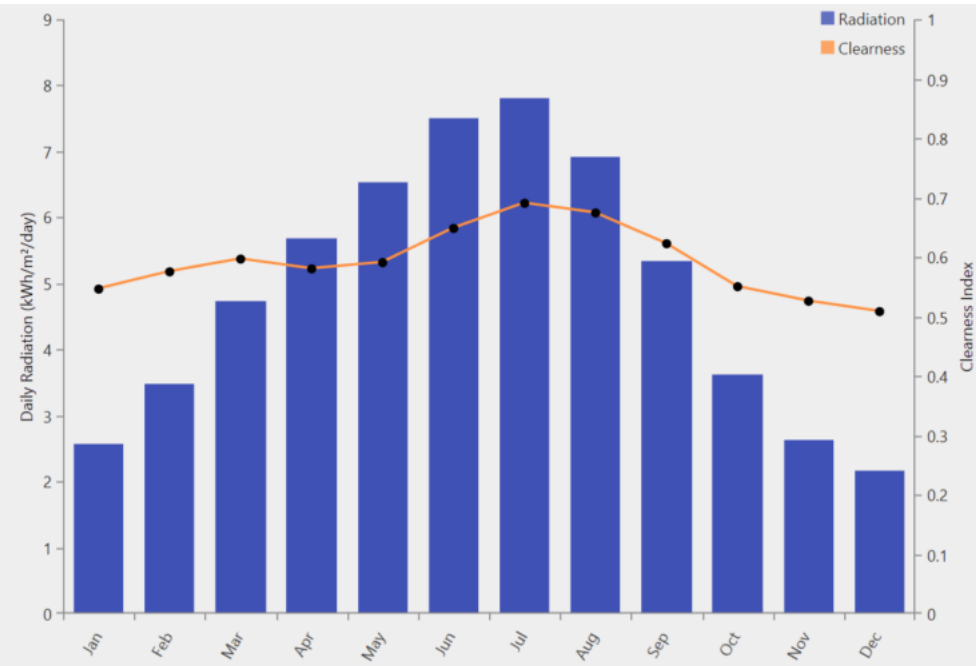

Figure 16. Solar Radiation and Clearance Index.

4.3 Definition of the Power System

Once the meteorology data has been downloaded, the power system can be created in HOMER®. To do so, components from the HOMER® internal library have been used, although the software allows creating new elements if the data is known. The elements that have been configured and introduced in the system are explained in this section. A schematic of the power system for both off-grid (a) and grid connected (b) systems is shown in Figure 17, as they are shown in the model once the elements have been selected.

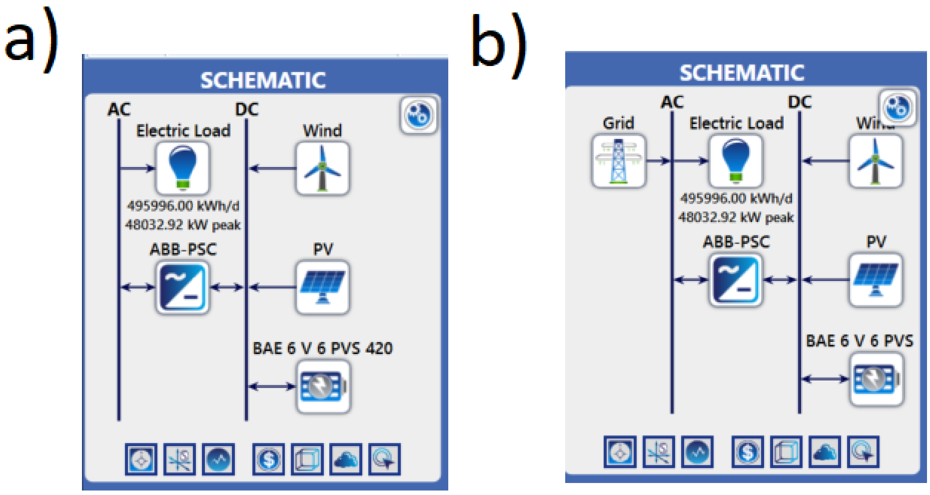

Figure 17. Schematic of Off-Grid and Grid Connected Systems in HOMER®.

4.3.1 Grid

For grid connected designs, a grid is used as an energy source for the periods in which RES are not capable of producing all the energy required to supply the demand of the load. For the estimation of the energy price, the data of the energy price in Spain between August 2021 and July 2022 have been used [11].

In the model, data from weekdays and weekends are treated differently, as load profiles are also different for these two types of days. For that reason, the average price of the energy for weekdays and weekends has been calculated for the twelve months of the year.

Once all the average prices have been calculated, they have been divided into five different sections, and the estimated cost for each section has been calculated, being the price equal to the average between the maximum and minimum limit of the section. For each section, a selling price will be also estimated for the cases in which the energy generated through RES is bigger than the energy required by the load, and it is therefore sold to the grid. For this document, the estimated selling price will be the half of the price of the energy coming from the grid. Table 3 shoes the price of the energy for both purchasing and selling cases.

Table 3. Grid energy purchasing and selling price.

Section	Purchasing Price [€/kWh]	Selling Price [€/kWh]
Section 1	0,3140	0,1570
Section 2	0,2607	0,1303

Section 3	0,2073	0,10371
Section 4	0,1539	0,7698
Section 5	0,1006	0,5030

Table 24 of Annex 1: Averages of the Hourly Energy Prices of the Grid shows the hourly average of the energy cost of the grid for the whole year.

In the current model, each period is defined manually for each hour of the month, for both weekdays and weekends. Thus, Figure 18 shows the hourly data for the energy prices for the whole year, once it has been configurated.

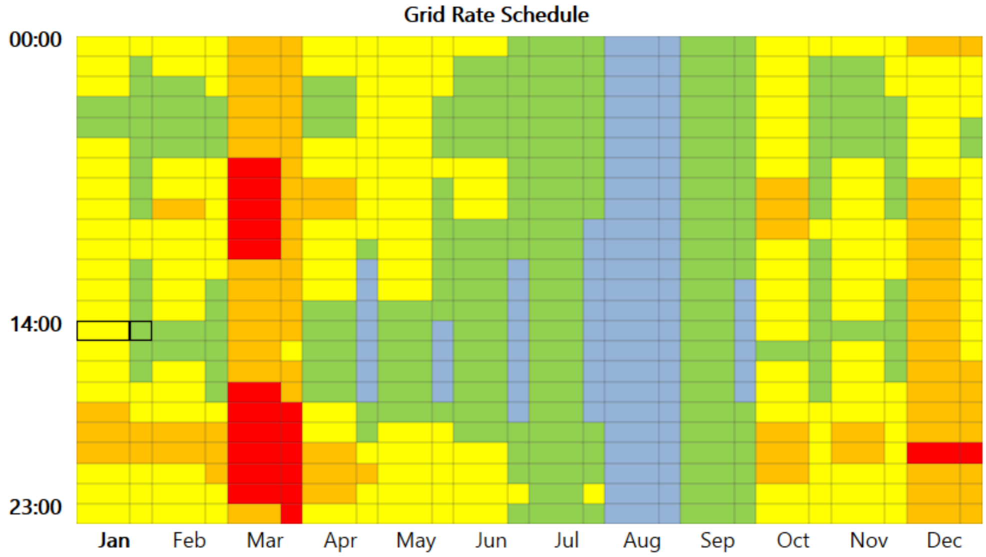

Figure 18. Definition of Grid Energy Prices in HOMER®.

With all these prices, the final Cost of Energy that will be used as a basis for the comparison of all the cases is COE = 0,2749 €/kWh.

4.3.2 Solar Panel

The selected solar panel for the current system is the SunPower E-Series E20-327, which is mainly aimed at residential usage. The main characteristics of the PV panel are summarized in Table 4.

Table 4. PV Panel Characteristics.

Parameter	**Value**
Nominal Power	327 W +5/-0 %
Average Panel Efficiency	20,4 %
V_{mpp}	54,7 V
I_{mpp}	5,98 A
V_{oc}	64,9 V

I_{sc}	6,46 A
Surface	1,235 m^2
Lifetime	25 years

For the PV power that will be installed, three options will be considered, with a different percentage of exploitation for each of them. Table 5 shows the percentage of the surface that will be considered for each option, and the total amount of solar panels and total installed power is shown in Table 6.

Table 5. Alternatives of the exploitation area for each surface.

	Alternative 1	**Alternative 2**	**Alternative 3**
Constructions' exploitation %	35%	50%	70%
Undeveloped areas' exploitation %	15%	25%	40%
Lands and Natural Areas' exploitation %	2%	3%	8%
Communications' exploitation %	1%	2%	5%

Table 6. Number of panels and installed PV power.

	Number of panels	**Installed PV power**
Alternative 1	30279 panels	9.537,88 kW
Alternative 2	45424 panels	14.308,56 kW
Alternative 3	70888 panels	22.329,72 kW

4.3.3 Wind Power

For the installation of wind turbines in the Port District of Seville, the AAER A-2000-84 will be used. **Table 7** shows the main characteristics of this wind turbine.

Table 7. Wind Turbine Main Characteristics.

Parameter	**Value**
Power	2.001 kW
Hub Height	30 m
Rotor diameter	84 m

Lifetime	20 years

For the estimation of the installed capacity, three different alternatives of wind turbines will be used. These quantities, as well as the total installed wind power for each of them are explained in Table 8.

Table 8. Number of Wind Generators and Installed Wind Power.

	Number of wind generators	**Installed Wind power**
Alternative 1	10 generators	20.010 kW
Alternative 2	20 generators	40.020 kW
Alternative 3	50 generators	100.050 kW

4.3.4 Storage

Storage is also considered as part of the hybrid system that is being studied. As it has been said before, storage helps to ensure the availability of the energy coming from renewable sources, and to avoid the necessity of using it in the same moment than it is generated.

The storage system that is used in the current study is a kinetic battery model, the BAE Secura Solar. Table **9** shows the main characteristics of the mentioned battery.

Table 9. Main Characteristics of the Battery.

Parameter	**Value**
Nominal Voltage	6 V
Nominal Capacity	2,41 kWh
Maximum Capacity	402 Ah
Roundtrip efficiencty	85 %
Maximum charge current	137 A
Maximum Discharge Current	561 A
Maximum Deep of Discharge	20%

In terms of the amount of the installed batteries, it has been considered that batteries will only be installed in residential areas, so a total capacity of 8.646 kWh will be used as the installed capacity for the simulations in which batteries are also used.

4.3.5 Converter

For this project, both DC and AC loads and sources are included. Wind and PV generation are done in DC, as well as the storage in the batteries. The load and the grid, however, are in AC. For that reason, a converter-inverter is needed so that energy can be converted from DC to AC and from AC to DC.

In the current model, ABB PSTORE-PCS will be used, as it provides the option for both types of transformation. The nominal power of the inverter is of 2.880 kW, but more power must be installed if the whole capacity needs to be supplied. Table **10** shows the different powers that are installed in the simulations.

Table 10. Installed Converter Power.

Installed Power
11.520 kW
14.400 kW
20.160 kW
23.040 kW
51.840 kW
100.800 kW

5 SIMULATIONS AND RESULTS

With all the inputs and equipment that have been explained in Section 4, the model will be simulated, and the technical and economic results will be analysed. During this section, the development, and results of all the simulations will be evaluated, and a comparison among all the combination of renewable energy sources will be done.

5.1 Net Zero District

The first objective of the current document is to research the feasibility of creating a Net Zero District, in other words, having a district in which the load is completely supplied by energy coming from renewable energy resources and which is generated on-site, without being connected to the grid.

To do so, the optimization model will be run so that it finds the best possible solution for three different cases:

- PV + Batteries: This model will include only energy obtained through PV panels. Apart from that, it will also include a storage system to ensure the availability of the energy in the moments in which generation is not enough to supply all the load.
- Wind + Batteries: The second model that will be simulated will get energy only through wind generation. As in the case of the model with PV panels and Batteries, this Model will also have a storage system to save energy that is not used and ensure that the load can be supplied when the generation is not enough.
- PV + Wind + Batteries: The third model will be a combination of the two previous ones. In this case both energy sources will be combined, with the objective of finding the combination that better fits the given load. As it happened in the two previous cases, this model will also include a storage system on it.

As the objective of these three simulations is to find the best system from both a technical and an economic aspect, there will not be any inputs for any of the sources in terms of installed power. The model itself will be capable of finding the combination that better fits the load's requirements.

Table 11 shows the results obtained for the three cases, including the installed power and the economic analysis results for all of them,

Table 11. Results of Net Zero District Simulations.

	PV + Batteries	**Wind + Batteries**	**PV + Wind + Batteries**
Installed PV power [kW]	201.481,00	-	105.845,00
Installed Wind power [kW]	-	276.000,00	44.000,00
Installed battery capacity [kWh]	1.693.587,00	2.755.859,00	1.218.608,00

Inverter power [kW]	78.169,00	70.244,00	68.758,00
Initial cost	473.615.091,93	612.877.158,35	319.736.075,09
Present worth [€]	- 35.940.900,00	- 411.075,00	- 85.043.550,00
Annual worth [€/year]	- 33.073.720,00	- 57.623.690,00	11.921.240,00
ROI [%]	1.9%	0,4%	5.6%
IRR [%]	3.0%	N/A	8.2%
Simple payback [years]	15.44	N/A	9.63
Discounted payback [years]	N/A	N/A	N/A
Levelized COE [€/kWh]	0,4166 €/kWh	0,5524 €/kWh	0,2997 €/kWh

During the next paragraphs, the three different models will be analysed separately first, and then all of them will be compared and joint conclusions will be drawn.

In the off-grid model based on solar energy, we can see that the installed power needed to supply all the load during a year is higher than 200 MW. If we make a fast calculation based on this result and the data coming from the datasheet of the panel, we can easily calculate the needed surface to install all this power (for the calculations in the equation below, the area of the panel has been multiplied times 1,2 to consider the free area from one panel to the other.

$$A = 201.481\ kW \cdot \frac{1\ panel}{0{,}327\ kW} \cdot \frac{1{,}235\ m^2 \cdot 1{,}2}{1\ panel} = 913.134{,}07\ m^2$$

If we compare the result obtained in the equation above with the total area available in the district, we can see that almost the double surface would be needed to be able to supply the load of the whole district.

Apart from that, an immense number of batteries would be needed to store the energy that the load would demand when sun does not bright, and it is therefore impossible to generate solar power.

In terms of economics, the results are not much better either, as almost all the measurement parameters that help in the analysis of the economic viability have very bad results. The first point to focus is the present worth and the annual worth of the project, which are both negative, as it can be seen in **Table 11**. This means that the money generated in the future because of the performance of the system is not worth compared to the initial investment cost. Finally, the COE gives us the information of the cost of the energy in comparison to a typical system based only on grid connection. In this case, each kWh would cost 0,4166 € which, compared to the grid system (COE = 0,2749 €/kWh) is much more expensive.

Figure 19 shows a general vision of the energy flows in the system during a whole year, with the participation of PV Generation (in purple), Storage system (in blue) and the total electrical load (in red).

As it can be barely seen in the figure, the generation is much bigger than the load in the most part of the year. This is because the model is configured so that there is not any moment in which a load cannot be supplied. For that reason, during almost the whole year there will be much extra energy which will be lost.

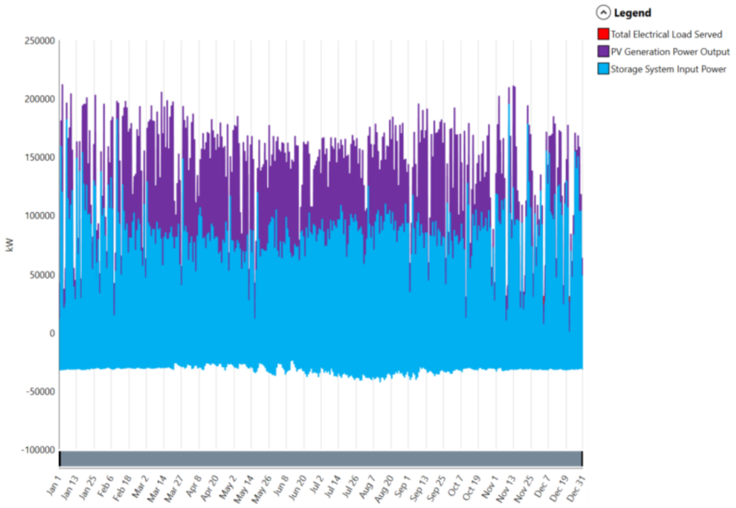

Figure 19. Generation and Consumption in Net Zero District with PV and Batteries.

Figure 20 shows a detailed view of the situation explained above. The generation through PV panels is much higher than the energy required to supply the load and charge the batteries, both together. This figure also shows the participation of the storage system in the model. The negative values of the "Battery input Power" mean that the battery is supplying energy to the load, and it is therefore being discharged. As it can be seen in the figure, this happens when there is not enough solar generation (because the energy to supply the load is required at night, for example).

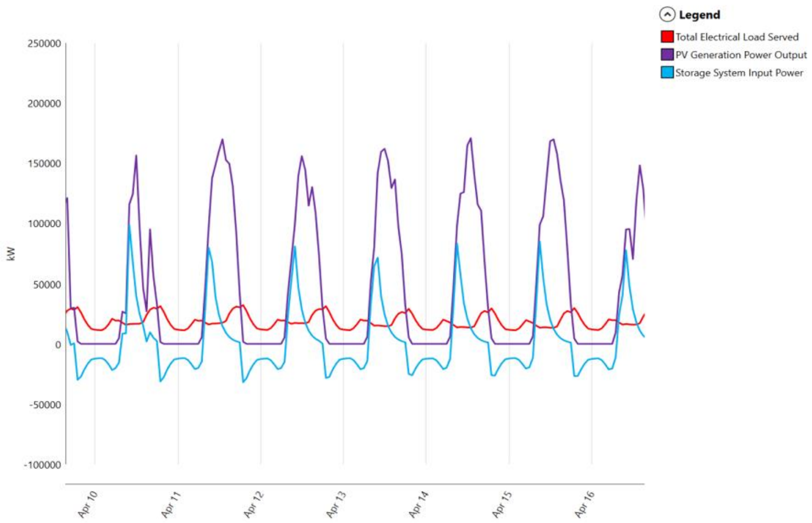

Figure 20. Detail of the Generation and Consumption in NZD with PV and Batteries.

Looking at the model based on wind power and a storage system, according to the model that has been used a total amount of 138 wind generators would be necessary to guarantee the energy supply in the district, apart from, once again, a very big storage capacity (even more than in the case of solar power system).

In terms of economics, the results are not much better for this model. Although it is true that the Present Worth is higher than the one achieved in the first case, it remains being negative, and the rest of the parameters are not good either. In terms of the cost of the energy, which is a very representative parameter to see the consequences of the system in the society, the achieved result of this system is COE = 0,5524 €/kWh, which is exactly de double of the COE of a system based only on supplying the load with the energy coming from the grid.

Apart from that, Figure 21 shows the endless amount of energy that gets loss because it cannot be used. As it has been already explained before, this happens because the model is configured not to allow any moment in which the load is not fully supplied.

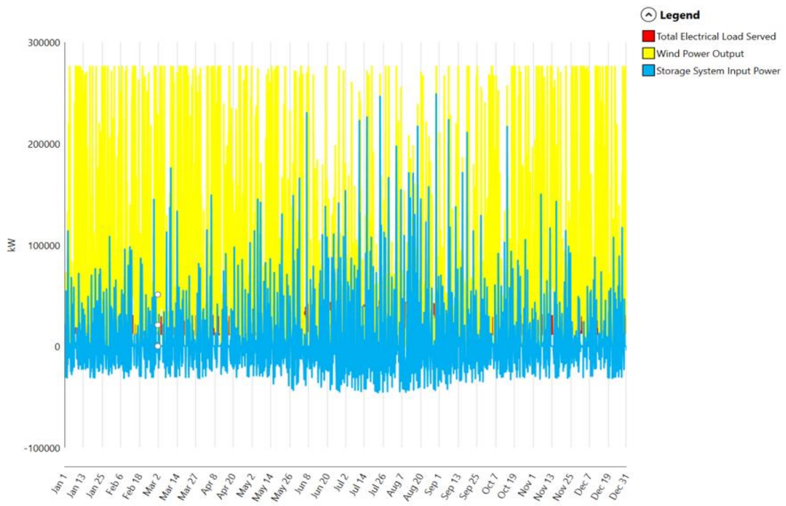

Figure 21. Generation and Consumption in Net Zero District with Wind Generators and Batteries.

A detailed vision of the problem explained above is shown in Figure 22, in which we can see that almost all the energy generated is lost because it cannot be used nor stored. Apart from that, as it happened in the case of the PV + Batteries model, the figure shows the use of the energy stored in the batteries when there is not enough wind power generation.

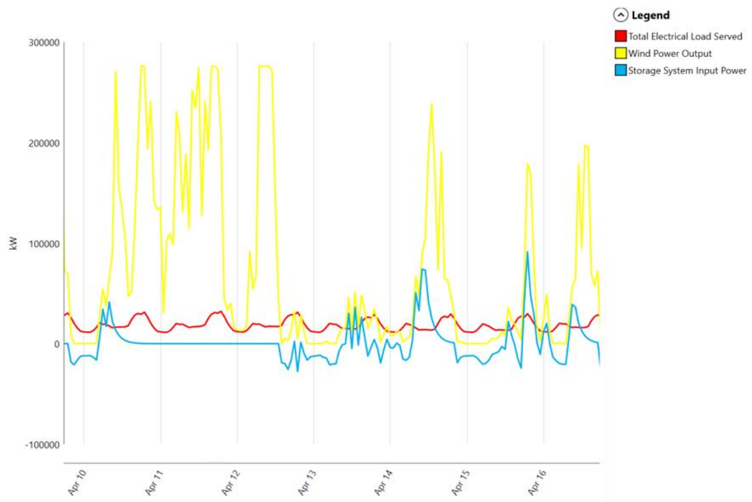

Figure 22. Detail of the Generation and Consumption in NZD with Wind and Batteries.

Finally, the model of the combination of both energy sources shows us that installing both technologies together bring the best results in both technical and economic aspects.

The needed installed power for both technologies is much lower than when they are installed alone. On the one hand, in the case of wind power, only 22 generators would be necessary. On the other hand, looking at the results of installed PV power, the achieved result is 105.845,00 kW which, making the same calculation that is has been made for the first simulation model, means the necessity of the following surface:

$$A = 105.845\ kW \cdot \frac{1\ panel}{0{,}327\ kW} \cdot \frac{1{,}235\ m^2 \cdot 1{,}2}{1\ panel} = 479.701\ m^2$$

Considering that the total area available in areas 1 to 3, which is 479.810 m^2, this means that the whole district would have to be covered with panels to achieve the required installed power, which is clearly not feasible.

In terms of economics, the present worth for this project is not positive either. In fact, it is worst than the one achieved in the wind + batteries model. The other parameters that are used to measure the economic availability of the project are not good either, although some of them are the best among the three options. In terms of the cost of energy, which has been also analysed for the previous two models, this model is the closest one to the basis (the system based on the grid), with a result of COE = 0,2997 €/kWh, although it remains being more expensive than the basis.

Looking at the graphics, as it has been done with the two previous models, Figure 23 shows that, compared to the other models, this one loses less energy. The main reason for this is that, as both technologies complement each other, less power must be installed, and less total power is therefore generated.

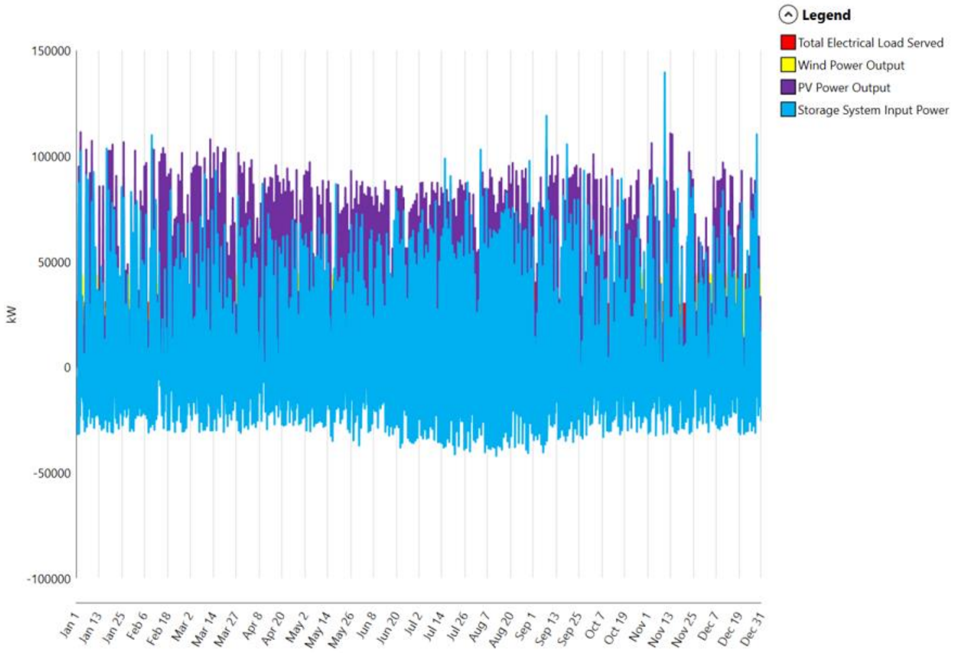

Figure 23. Generation and Consumption in Net Zero District with PV Power, Wind Generators and Batteries.

Figure 24 shows a detailed vision of the question explained above. As it can be seen in the figure, the generation is clearly more accurate to the load, although it remains being higher. The figure also shows how both energy sources complement each other, making possible to have some energy generation in almost every moment of the day. This also brings a lower necessity of storage, as there is not any moment in which the whole load must be supplied through the energy stored in the batteries.

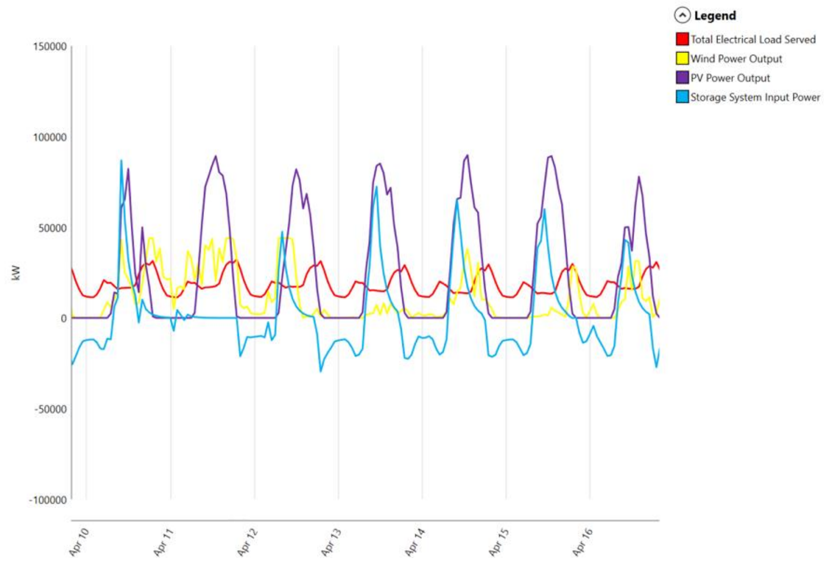

Figure 24. Detail of Generation and Consumption in NZD with PV, Wind and Batteries.

Making a comparison of the three models together, the main conclusion that can be drawn is that it is no longer feasible to contemplate the option of looking for an off-grid system for the Port District of Seville.

On the one hand, the technical necessity of installed power is so big that there is not enough space for it. Installing so much power also brings that much energy is lost in the three cases (in ones more than in others), since there is not enough storage capacity to save all the energy that is generated but not used by the load.

On the other hand, the economic predictions of this kind of project are not positive in any of the three cases that have been proposed. The initial inversion needed for all of them is too high, and the benefits that would be obtained through the lifetime of the project would not be enough to amortize the investment. The economic consequences on the final cost of the energy are not good either, as the COE is in the three cases bigger than the one at a system working only with the grid.

To sum up, and taking into account all the things that have been mentioned during the current section, it is clear that the option of looking for a Net Zero District in the Port District of Seville is not a completely good idea.

5.2 Grid Connected System

After seeing that achieving the objective of creating a Net Zero District in the given distribution is not feasible, the option of creating a Hybrid Power System will be studied, in which PV power, Wind power or a combination of both together will be integrated in a way that they interact with the grid, both with and without storage.

To do so, three different power alternatives will be done for each combination: a first one with a lower installed power, another one with a medium installed power, and a final one which will be more optimistic, with a high installation power. Once the model has been run and all the simulations have been done, a technical and economic analysis will be done, as it has been previously done for the off-grid system.

Fist a short technical analysis of each of them will be done separately, to analyse the main conclusions of the simulations and, afterwards, an economic analysis will be done for the three Alternatives together, so that they can be compared, and the main conclusions can be achieved.

5.2.1 PV Power, Batteries and Grid

The fist system that will be studied is a Hybrid Power System in which PV power generation and a storage system will be integrated together with the grid. To estimate the installed power of the system, the procedure explained in section 4.3.2 will be followed, in which different percentages of the available surfaces are exploited to install PV panels on them. Table 12 shows the installed power of each technology for the three alternatives of the current model.

Table 12. Installed power alternatives for the Hybrid System Consisting of Grid, Batteries and PV

	PV Power [kW]	**Wind Power [kW]**	**Inverter Power `[kW]**	**Storage Cap. [kWh]**
Alternative 1	9.537,89	-	11.520	8,683
Alternative 2	14.308,56	-	14.400	8.683
Alternative 3	22.329,72	-	23.040	8.683

After doing the simulation of the first alternative, Figure 25 shows that the generation of solar power is not very high in comparison with the contribution of the grid, although it helps to reduce the dependency of it. According to the model, the 8,97% of the total energy produced in the system comes from renewable sources (PV panels in this case).

The contribution of the storage system is also a remarkable aspect. The model considers decides whether it is a better option to charge/discharge the batteries, or to avoid using them, depending on the economic consequences of each option. Thus, some periods of the year can be found in which batteries are no longer used, neither to charge them non to use energy stored there.

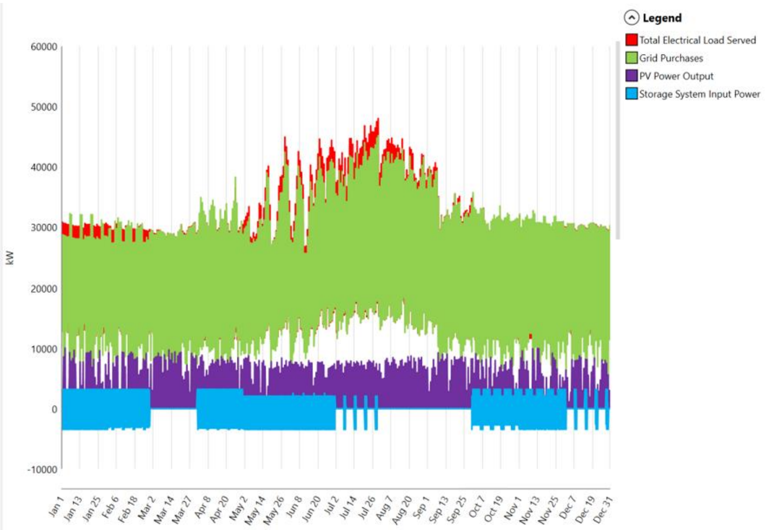

Figure 25. Generation and Consumption in a Hybrid System with the grid and a low alternative of PV Power and Batteries.

Figure 26 shows the results of the simulation for the second alternative of installed power. A higher contribution of PV power is shown there, which brings higher economic savings in terms of buying energy from the grid. Looking at the data of the amount of energy coming from renewable sources, this simulation has a renewable penetration of a 13,4%, which is still not very big, but is higher than in the first alternative.

As it happened in the first one, the use of storage in this alternative is also different depending on the period of the year. As it has been said before, the model analyses the economic consequences of using or not batteries and makes a decision in consequence.

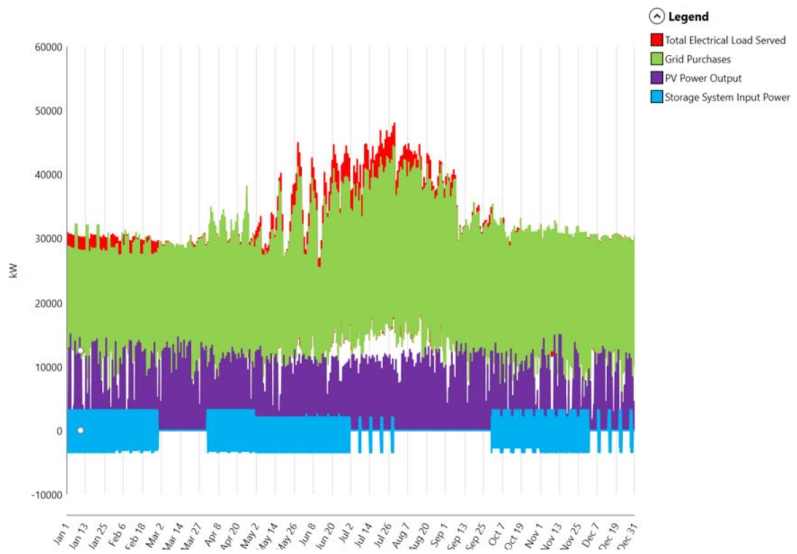

Figure 26. Generation and Consumption in a Hybrid System with the grid and a medium alternative of PV Power and Batteries.

For analysing the simulation of the third alternative, Figure 27 shows that the PV generation in this case is significantly higher than in the previous two cases, which can be also seen when looking at the percentage of the renewable penetration of the system, which in this case is 20,7%.

The use of batteries is also interrupted depending on the year period, as it has been already mentioned in the previous cases, being the reason the same that has been explained before.

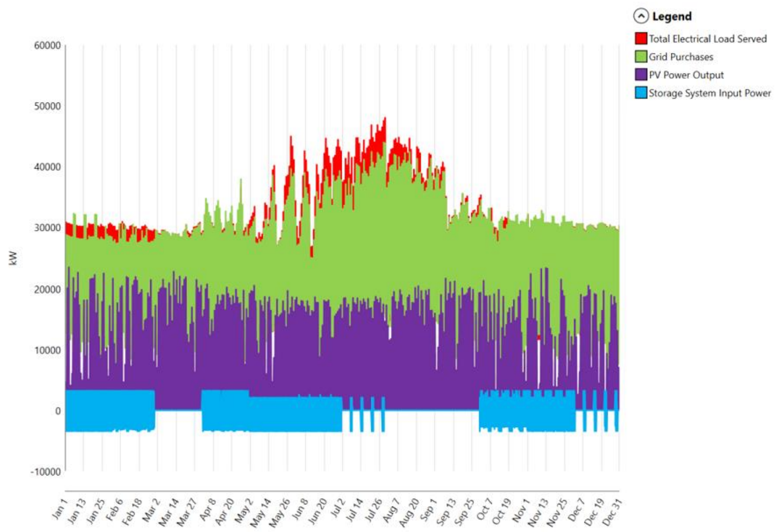

Figure 27. Generation and Consumption in a Hybrid System with the grid and a high alternative of PV Power and Batteries.

Figure 28 shows the problem that has been pointed during the analysis of the three cases. During the period between the 24th and the 31st of July, the storage system has not any power input or output, except in two very certain moments. These two moments coincide with a moment in which energy coming from the grid is more expensive, and the system therefore uses the energy stored in the batteries to supply the load, assuring a cheapper price for the system in these moments.

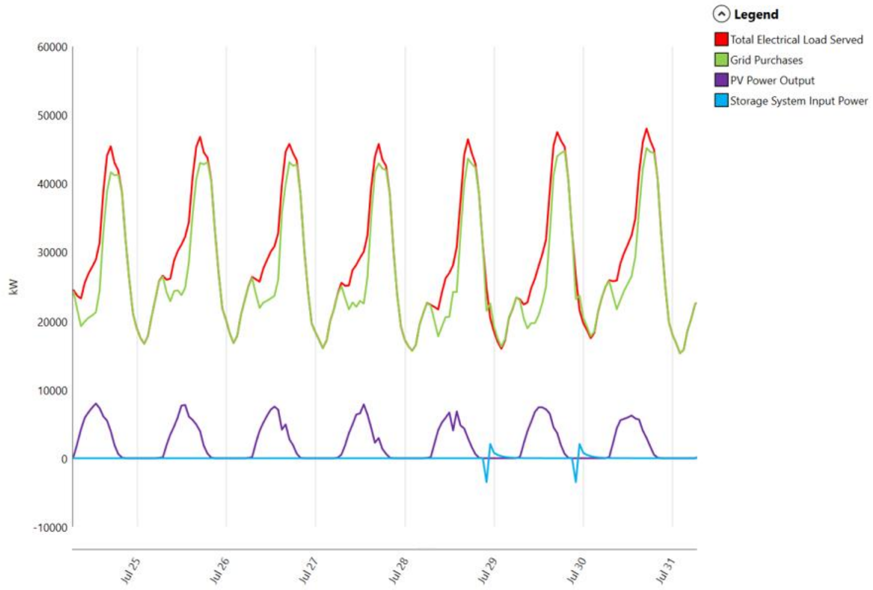

Figure 28. Detail of the Use of Batteries in a Hybrid Model with PV and Storage.

In terms of economics, Table 13 shows the main parameters used to measure the economic results of a project, which have been already explained during this document.

As it can be seen in the table below, the economic results are positive for the three alternatives, although they are better as the installed power gets bigger. However, there is not such a big difference from one alternative to the other. The return of investment, for example, is bigger as the installed power increases, but it only evolves from the 18,20% to the 19,90%, which is not such a big difference.

If we pay attention to the present worth and the annual worth of the system, however, the difference from one case to the other gets bigger. The present worth of the second alternative, for instance, is almost a 70% more than the one coming from the lowest alternative; and the result of the system with the highest installed power is more than 2,7 times bigger.

Finally, looking at the cost of the energy for each of the systems, a very low difference can be noticed from one to the other, being the difference among the thre cases less than 0,01 €/kWh.

Table 13. Economic Results for the Simulations of a Hybrid System with the grid, PV Power and Batteries

	Alternative 1	Alternative 2	Alternative 3
Initial cost [€]	15.281.929,82	22.192.678,90	34.267.772,48
Present Worth [€]	7.910.943,00	13.413.960,00	21.443.610,00
Annual worth [€/year]	1.108.940,00	1.880.342,00	3.005.922,00
ROI [%]	18,20%	19,50%	19,90%
IRR [%]	20,30%	21,40%	21,60%
Simple payback [years]	5,12	4,80	4,76
Discounted payback [years]	6,14	5,77	5,72
Levelized COE [€/kWh]	0,2694	0,2657	0,2596

5.2.2 PV Power and Grid

In this section a Hybrid System with only PV power will be simulated, so that the contribution and consequences of removing the storage system can be analysed, in comparison to the previous model. Table 14 shows the installed PV power for each one of the three alternatives of the current model.

Table 14. Installed power alternatives for the Hybrid System Consisting of Grid and PV.

	PV Power [kW]	Wind Power [kW]	Inverter Power `[kW]	Storage Cap. [kWh]
Alternative 1	9.537,89	-	11.520	-
Alternative 2	14.308,56	-	14.400	-
Alternative 3	22.329,72	-	23.040	-

Figure 29 shows the results of the simulation of the first alternative of installed PV power, in which a low contribution to the total load can be noticed. However, in comparison to the system in which the storage system was included, in this case the energy generated in the PV panels is directly used to supply the load. As the generated energy is not more than the one required by the system, there is not any extra power that is not going to be used, and therefore there is not any necessity of storing or selling the energy to the grid.

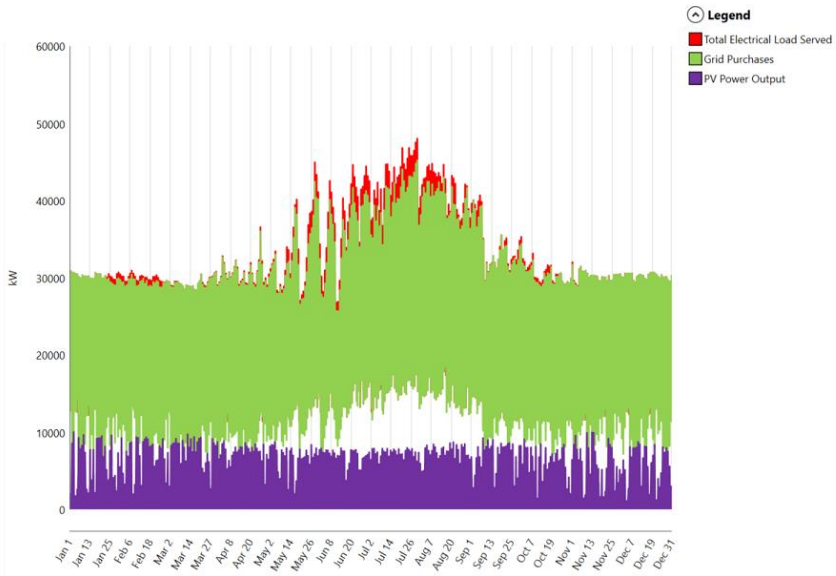

Figure 29. Generation and Consumption in a Hybrid System with the grid and a low alternative of PV Power.

The same situation is given in the medium power alternative, the results of which can be seen in Figure 30. Although the contribution of solar power is higher in this case (13,4% vs 8,97%, just the same contribution as in the case of the system with the batteries included), it is still not enough to supply all the demand in any time of the year, so there is not any necessity of installing a storage system either.

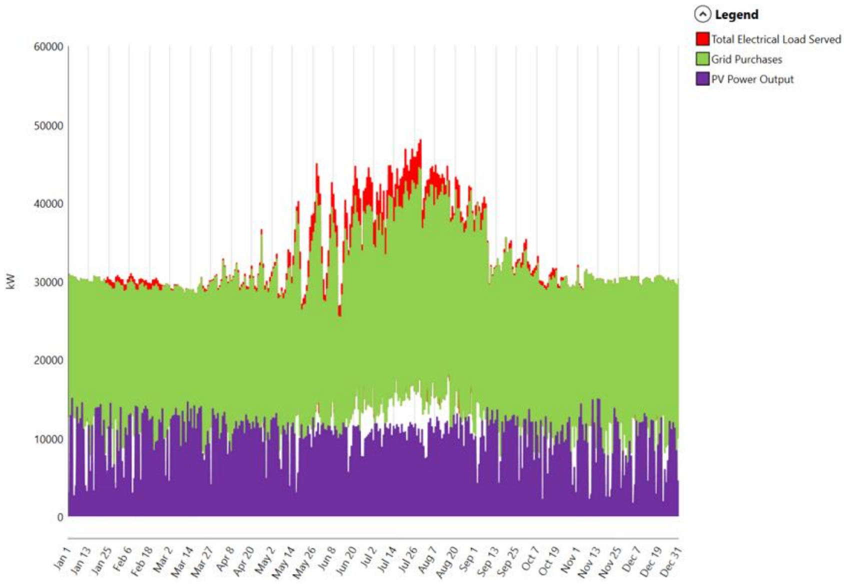

Figure 30. Generation and Consumption in a Hybrid System with the grid and a medium alternative of PV Power.

The technical conclusions for the third simulation model are practically the same than for the previous two cases. The contribution of solar power to the whole system is bigger than in alternatives 1 and 2, but it is still not enough to require the necessity of a storage system.

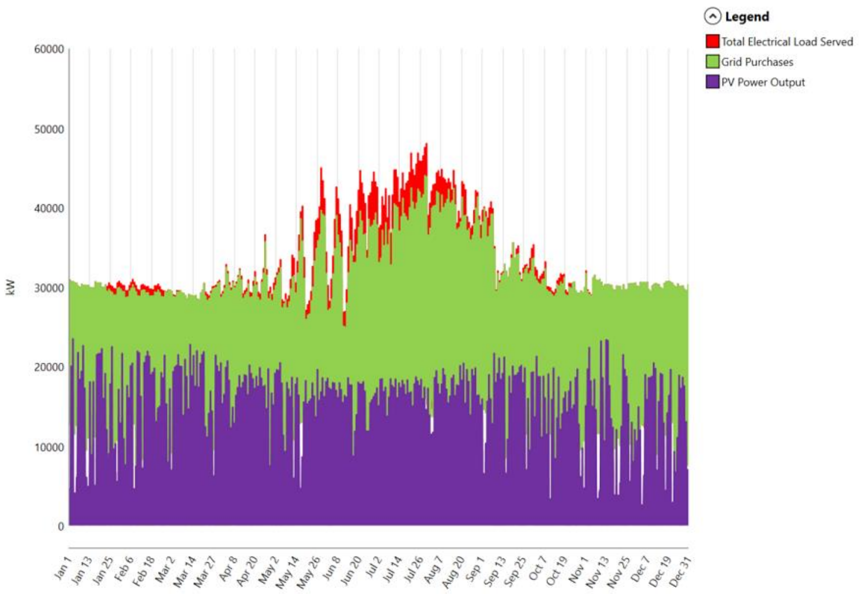

Figure 31. Generation and Consumption in a Hybrid System with the grid and a high alternative of PV Power.

A more detailed vision of what has been explained before can be seen in Figure 32. This figure shows how the contribution of PV power directly affects the energy demand coming from the grid. In fact, in every point of the graph, the sum of the energy coming from the grid plus the one coming from the PV power is equal to the load on that moment. The same happens in the three alternatives, although the contribution of each source is different depending on the installed PV power.

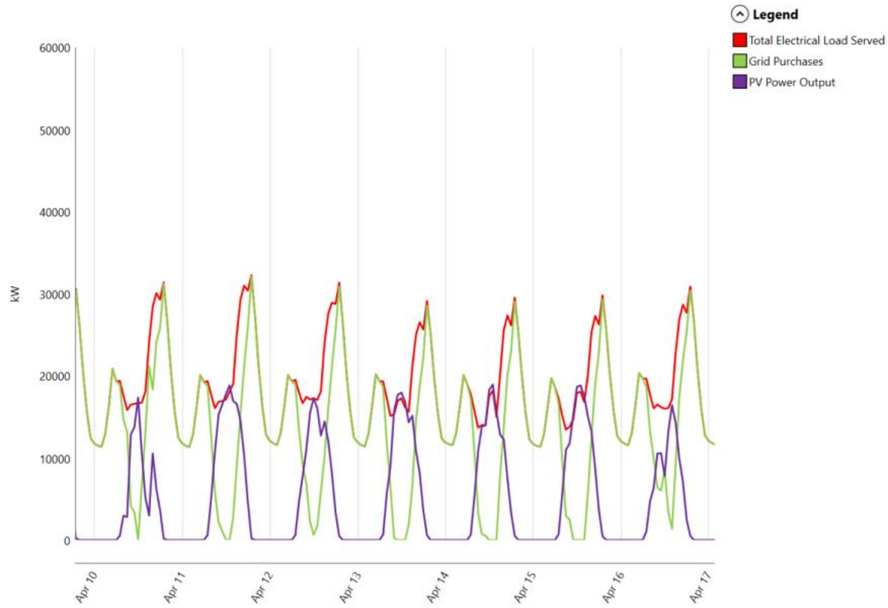

Figure 32. Detail of Generation and Consumption in a Hybrid System with the grid and PV Power.

In the same way that has been done with the system in which batteries were also integrated, an economic analysis of the three alternatives will be done. Table 15Table **13** shows the main parameters used to measure the economic results of a project.

As it happened in the previous case, the economic results are positive for the three alternatives. In fact, if we compare the results with the ones in section 5.2.1, the results for this hybrid system are better than the ones obtained in the system including the storage. The difference from one system to the other is not denigible: comparing the results for the present worth, for example, the benefits obtained through the system without the batteries are almost 2.000.000 € bigger for each of the three alternatives.

The difference in the ROI of both systems is also remarkable. As it has been seen before, the ROI in the model in which storage is considered is settled between 18,20% and 19,90%; in this case, however, the decision of not using batteries for the system makes this parameter evolve up to values between 20,60% and 21,20%.

Finally, looking at the cost of the energy for each of the systems, also a very low difference can be noticed from one to the other, being the difference among the two models about 0,0015 €/kWh.

Table 15. Economic Results for the Simulations of a Hybrid System with the grid and PV Power.

	Alternative 1	**Alternative 2**	**Alternative 3**
Initial cost [€]	14.507.929,82	21.418.678,90	33.493.772,48
Present Worth [€]	9.880.764,00	15.374.080,00	23.341.820,00
Annual worth [€/year]	1.385.066,00	2.155.107,00	3.272.010,00
ROI [%]	20,60%	21,20%	21,00%
IRR [%]	22,40%	22,90%	22,50%
Simple payback [years]	4,58	4,48	4,57
Discounted payback [years]	5,47	5,33	5,45
Levelized COE [€/kWh]	0,2681	0,2643	0,2582

5.2.3 Wind Power, Batteries and Grid

After analysing a hybrid system in which PV power is only installed as a renewable source, the simulation of a model based on wind generation will be done below, in which a storage system will be also installed. As it has been already made with the previous models, Table 16 shows the installed power of all the equipment considered in the model.

Table 16. Installed Power alternatives for the Hybrid System Consisting of Grid, Wind Power and Batteries.

	PV Power [kW]	Wind Power [kW]	Inverter Power `[kW]	Storage Cap. [kWh]
Alternative 1	-	20.010	20.160	8.683
Alternative 2	-	40.020	51.840	8.683
Alternative 3	-	100.050	100.800	8.683

Figure 33 shows the results of the simulation of the first alternative of installed wind power. According to the graph, the power generated through wind energy with the low alternative is not high enough to supply all the load, but it helps to reduce the amount of energy that must be purchased.

According to the results obtained from the model, the percentage of the renewable penetration obtained in this hybrid system is 22,3%, in other words, almost the quarter part of the total energy consumption in the district comes from renewable sources.

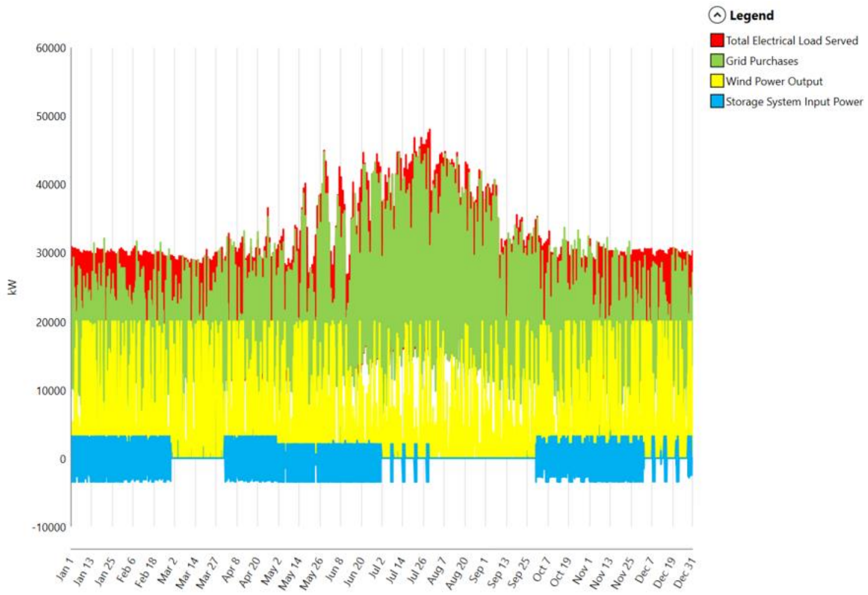

Figure 33. Generation and Consumption in a Hybrid System with the grid and a low alternative of Wind Power and Batteries.

The results of the simulations of the model for the medium power alternative are shown in Figure 34**¡Error! No se encuentra el origen de la referencia.**. In the figure we can see that the energy coming from wind generation is often more than the one required by the load. Although part of the energy is stored in batteries, they are not capable of absorbing all the excess, so much energy must be sold to the grid.

On the other hand, as wind energy is not a constant source of energy, and its variability is high, the necessity of purchasing energy from the grid is still high, as in many times there is not enough generation to supply the energy, and batteries do not have the capacity to fill the demand either.

The total percentage of renewable energy in the system, however, is 40,8 %, which is already a very good result.

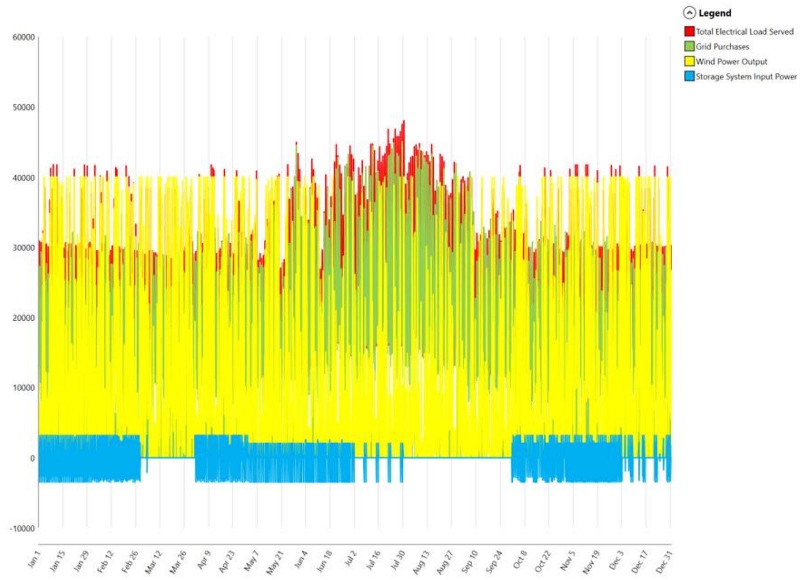

Figure 34. Generation and Consumption in a Hybrid System with the grid and a medium alternative of Wind Power and Batteries.

Finally, Figure 35 shows the results of the optimization model for the highest alternative of power. In this case, the generated energy is in many times much bigger than the requirements of the load, and there are therefore big energy sales into the grid.

However, this oversizing of power brings as a result that the renewable penetration in the system is 70,2%, which is the biggest among all the models that have been considered up to now.

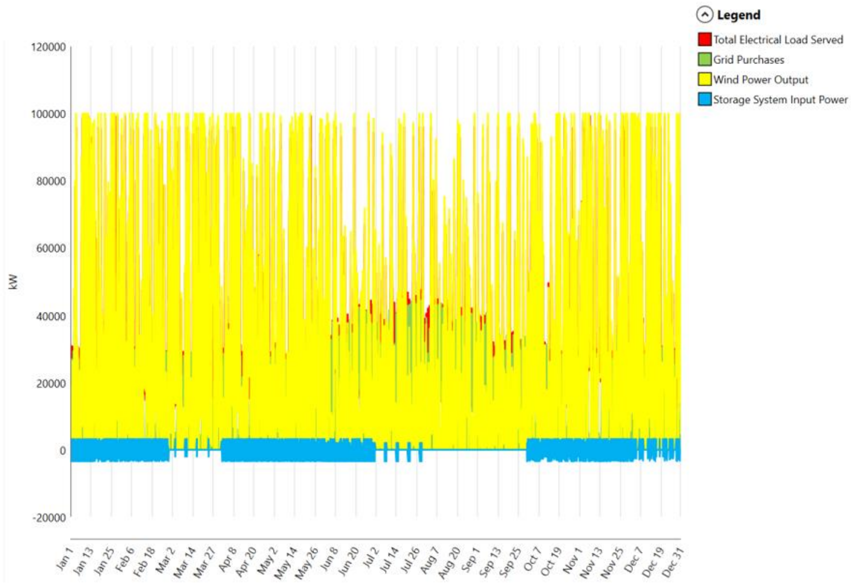

Figure 35. Generation and Consumption in a Hybrid System with the grid and a High alternative of Wind Power and Batteries.

To end with the technical analysis of the model in based on the grid, wind power and batteries, Figure 36 shows a detailed view of the relations between the energy sources that have been explained during this section.

The figure shows that, in certain moments, the generation is bigger than the load's requirements, and that there is therefore some extra energy that is not used, unless batteries are empty, and they can be filled with this extra energy. In the period that is shown in the figure, the differences are not so big, and the loss of energy is therefore not a big deal. However, for the cases in which the installed power is bigger, the unused energy is also much more, and a lot of energy is sold to the grid in those moments.

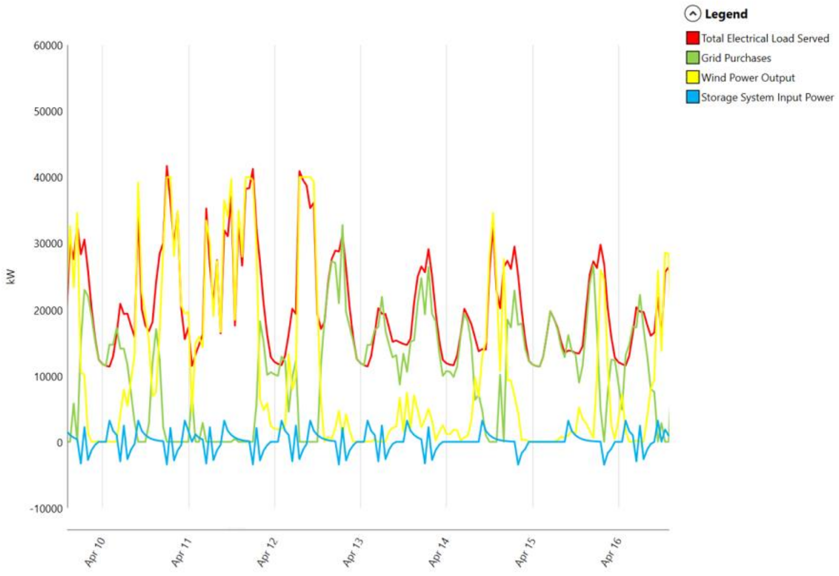

Figure 36. Detail of Generation and Consumption in a Hybrid System with the grid and a low power alternative of Wind Power and Batteries.

In terms of the economic analysis of the system, the results achieved for all the alternatives are positive analysed separately, as all the projects are feasible and bring benefits at the end of their life cycles. However, when comparing one to each other, different readings of the results can be made, and different conclusions can be drawn.

On the one hand, the present worth of the project is bigger as the installed power of wind energy increases, which means that the raw benefits of the project with the highest alternative are more than the ones of the other two projects.

On the other hand, if we pay attention to the other parameters used to analyse the economic feasibility of the project, we can conclude that the project with the lowest alternative of power is the best option. This can be concluded based on the ROI of the three projects. The ROI obtained in the simulation of the project with the lower power is higher than the others, which means that the benefits obtained in comparison with the initial inversion are bigger for this case.

Finally, looking at the COE as it has been done in the previous cases, it can be noticed that the COE in these systems is the smallest among all the ones that have been analysed up to now, and that is the first case in which there is a remarkable difference in comparison with the energy of the price in a usual system based only on the grid.

Table 17. Economic Results for the Simulations of a Hybrid System with the grid, Wind Power and Batteries.

	Alternative 1	Alternative 2	Alternative 3
Initial cost [€]	29.193.200,00	58.994.800,00	142.870.000,00
Present Worth [€]	47.529.400,00	77.818.060,00	119.663.200,00
Annual worth [€/year]	6.662.576,00	10.908.380,00	16.774.150,00
ROI [%]	35,70%	31,30%	23,40%
IRR [%]	33,90%	29,90%	24,10%
Simple payback [years]	3,08	3,52	4,93
Discounted payback [years]	4,11	4,93	6,58
Levelized COE [€/kWh]	0,2416	0,2076	0,1314

5.2.4 Wind Power and Grid

As it has been done when the hybrid system based on PV energy has been analysed, in this section a Hybrid System with only wind power will be simulated, so that the contribution and consequences of removing the storage system can be analysed, in comparison to the previous model. Table 18Table **14** shows the installed wind power for each one of the three alternatives of the current model, which are the same than the ones used in section 5.2.3.

Table 18. Installed power alternatives for the Hybrid System Consisting of Grid and wind power.

	PV Power [kW]	Wind Power [kW]	Inverter Power `[kW]	Storage Cap. [kWh]
Alternative 1	-	20.010	20.160	-
Alternative 2	-	40.020	51.840	-
Alternative 3	-	100.050	100.800	-

Figure 37 shows the results of the simulation of the first alternative of wind power. The graph shows that the contribution of wind power is not higher than the requirements of the load, as it happened in the case of the model analysed before. However, in this case the lack of a storage system, makes it impossible to store the energy that is not used, and it is therefore sold to the grid, instead of keeping it for moments in which energy coming from the grid is most expensive and it is therefore a better idea to use the energy from the batteries.

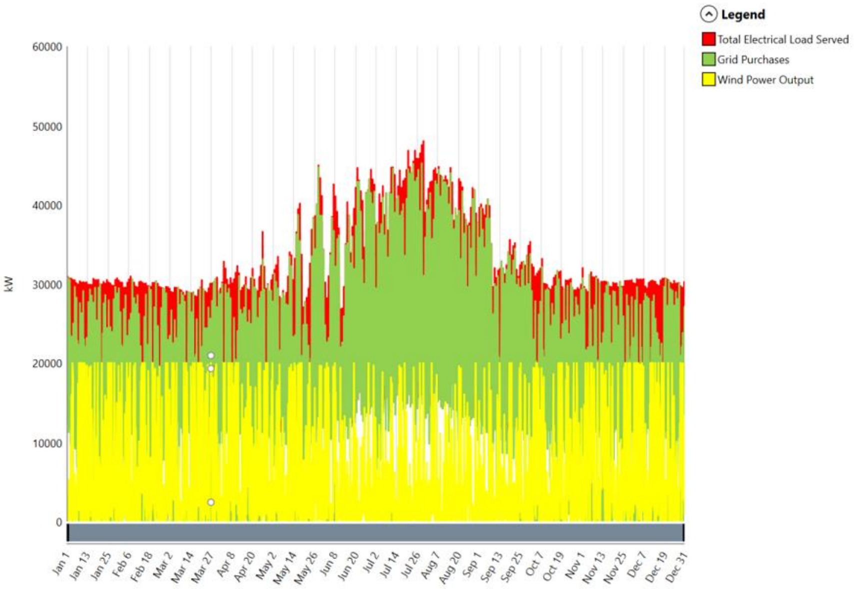

Figure 37. Generation and Consumption in a Hybrid System with the grid and a low alternative of Wind Power.

The same conclusions can be made for the medium alternative too, as it is shown in Figure 38. In this case, however, the amount of energy that is generated and not used is bigger than in the case before, and the quantity of energy that is sold to the grid is therefore also bigger than in the project with the lowest installed power. Technically, and in terms of percentage of renewable penetration into the system does not have any influence, but economically makes a difference, which will be analysed afterwards. Furthermore, Figure 38 also shows the amount of energy sold to the grid in each moment of the year, which is quite remarkable.

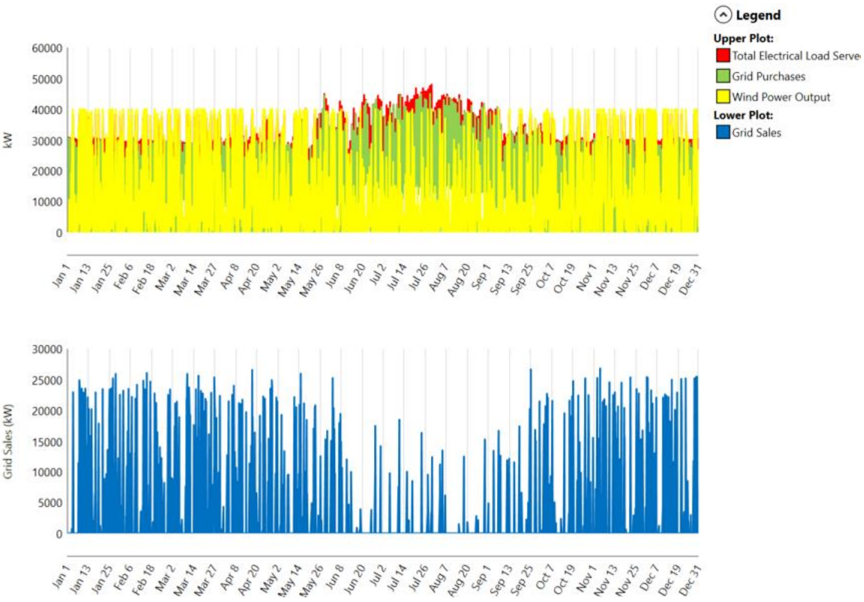

Figure 38. Generation and Consumption in a Hybrid System with the grid and a medium alternative of Wind Power and Energy Sold to the Grid.

Finally, Figure 39 shows the results of the system for the highest installed power of the current model. The only difference with the two other cases is that the extra energy that is not used and is therefore sold to the grid is bigger than before.

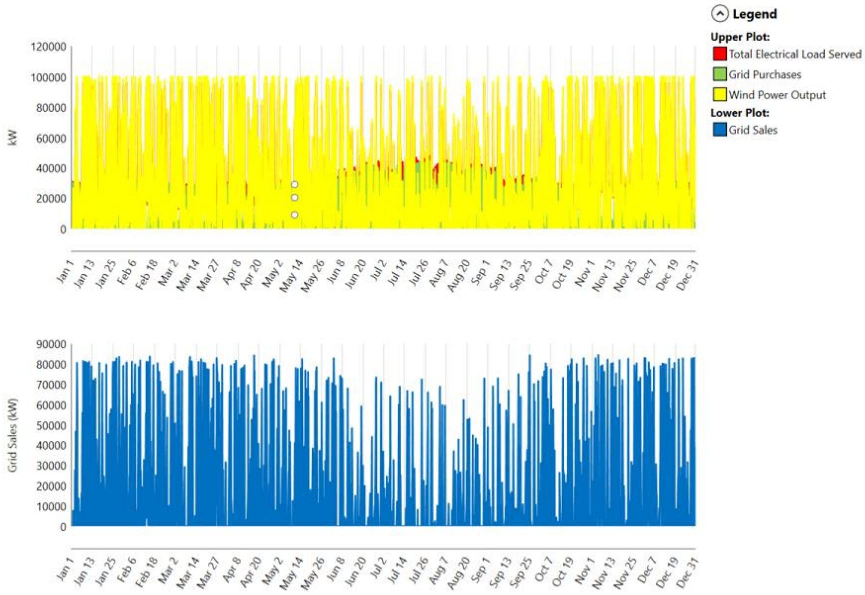

Figure 39. Generation and Consumption in a Hybrid System with the grid and a high alternative of Wind Power and Energy Sold to the Grid.

In the same way that it has been done with the models based on PV power, in which the economic consequences of installing or removing the storage system have been compared, an economic analysis of this model will also be done. Table **19** shows the economic results of the simulations for the model based on wind power, without batteries.

As it happened in the model with batteries, the main conclusions to be drawn in the comparison of the three powers are the same. On the one hand, the present worth of the projects is bigger as the installed power increases. However, as it happened in the previous model, the other measuring parameters, such as the ROI or the IRR, are better for the system in which the lowest alternative of power is installed.

If a comparison is made between the model in which batteries are considered and the one in which batteries are not used, the installation of batteries makes the economic results be worse. This may be a consequence of the high price of the batteries, which have a direct impact on the initial cost of the project and make the total benefits of it be lower. However, since the storage capacity is not changed from one alternative to the other, the economic impact of batteries is more noticeable in the low alternative than in the high one.

Finally, looking at the cost of the energy for each of the systems, also a very low difference can be noticed from one to the other, being the difference among the two models about 0,0013 €/kWh.

Table 19. Economic Results for the Simulations of a Hybrid System with the grid and Wind Power.

	Alternative 1	Alternative 2	Alternative 3
Initial cost [€]	28.419.200,00	58.220.800,00	142.096.000,00
Present Worth [€]	49.236.750,00	79.456.430,00	121.083.200,00
Annual worth [€/year]	6.901.909,00	11.138.040,00	16.973.190,00
ROI [%]	37,30%	32,00%	23,70%
IRR [%]	35,10%	30,40%	23,30%
Simple payback [years]	2,99	3,47	4,32
Discounted payback [years]	3,38	3,98	5,09
Levelized COE [€/kWh]	0,2403	0,2063	0,1303

5.2.5 PV Power, Wind Power, Batteries and Grid

Finally, a combination of the two main technologies will be done in the following two sections. First, the current section will analyse the model in which PV and wind power generations and a storage system are included and see which the results obtained through it are.

Table 20. Installed power alternatives for the Hybrid System Consisting of Grid, PV, Wind and Batteries.

	PV Power [kW]	Wind Power [kW]	Inverter Power `[kW]	Storage Cap. [kWh]
Alternative 1	9.537,89	20.010	20.160	8.683
Alternative 2	14.308,56	40.020	51.840	8.683
Alternative 3	22.329,72	100.050	100.800	8.683

Figure 40 shows the results for the low power alternative model. As it can be seen in the graph at the top, the combination of both energies does not allow the system to be free from the grid, although it makes the necessity of purchasing energy smaller. According to the results obtained through the model, the total percentage of renewable energy in the system is 30,71%, which is bigger than the low alternatives of any of the previous systems.

As it happened in previous cases, batteries are not used in certain periods, since the prince of energy coming from the grid is sometimes cheaper than the cost of energy coming from the storage system.

In the bottom part of the graph, the amount of energy that is sold to the grid can be seen. According to the figure, although energy is sold during almost the whole year, the maximum power of energy sold is not so big in comparison with the load and the total amount of generation. Furthermore, in summer, when the load is bigger because of the use of refrigeration in houses and industrial areas, the energy that is sold is zero.

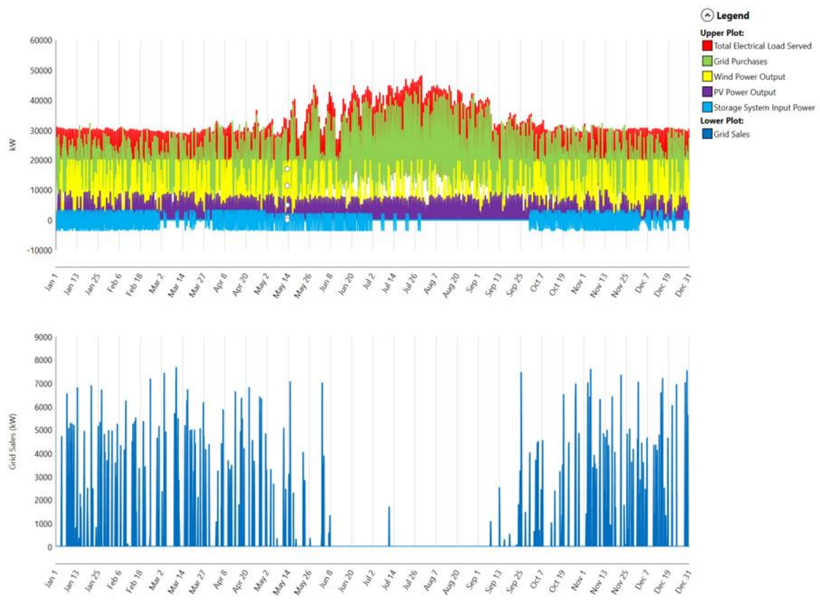

Figure 40. Generation and Consumption in a Hybrid System with the grid and a low alternative of PV, Wind Power and Batteries; and Energy Sales to de Grid.

The graphic results of the simulations for the medium alternative of power for the same model are shown in Figure 41. The technical conclusions that can be achieved through the analysis of this graph are not much different from the ones explained above.

The only difference is that in this case more energy is generated (the total percentage of renewable energy penetration in this case is 49,2%). This also means that much more energy is sold to the grid because it cannot be used in the system when it is generated, both because the load is already completely supplied and de batteries are full of energy.

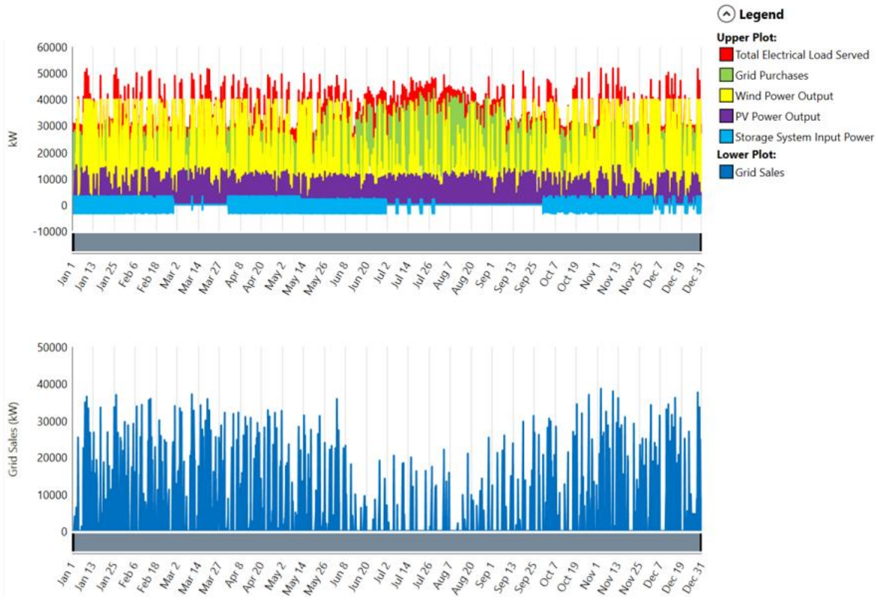

Figure 41.Generation and Consumption in a Hybrid System with the grid and a medium alternative of PV, Wind Power and Batteries; and Energy Sales to de Grid.

Finally, the results of the simulations for the high alternative are shown in Figure 42. As it has happened in the case of the medium alternative, the only difference in comparison with the other alternatives is that the generation of power is bigger than before, In this case, in fact, the energy sold to the grid is even the double than the energy that is consumed by the load, which means that the system is oversized in terms of installed power, and that it is not technically well designed.

Looking at the renewable energy penetration of the system, which has been also checked in the previous models, we achieve the highest percentage of renewable energy in this model, with a total penetration of 77,3%.

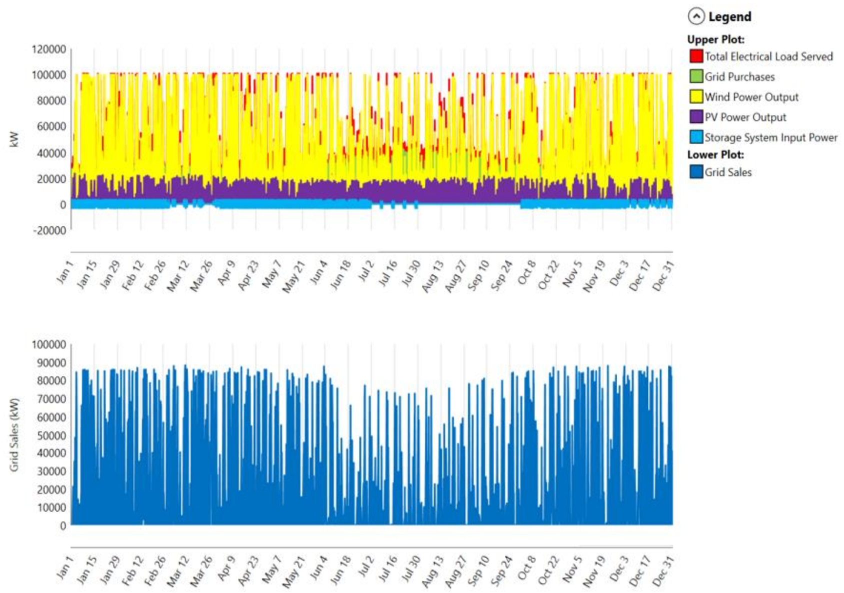

Figure 42.Generation and Consumption in a Hybrid System with the grid and a high alternative of PV, Wind Power and Batteries; and Energy Sales to the Grid.

Table 21 shows the economic results of the model analysed in this section. As it has happened in the analysis of the previous cases, the main results of the model are positive for the three alternatives, although some differences can be noticed when performing a deeper analysis.

As it happened in the simulation of the model based on wind energy, the main conclusions are different depending on the measuring parameters in which the project manager focuses. If the main objective of the project is to achieve as much money as possible at the end of the project, and it does not matter what its relationship with the initial cost of the project is, then the third power alternative would be the best option.

However, if the aim of the project is to be as profitable as possible in comparison to the initial investment, and to get the most benefit compared to it, the project that should be selected is the one with the lowest alternative of power, since its ROI and IRR are the biggest ones among the three options.

Comparing the results with the models based only on one technology (including batteries), the two parameters that have been mentioned in the paragraph above are worse in this system. However, the cost of the energy coming from a system in which both PV and wind energies are combined is lower than the one of the system in which only one of them is used.

Table 21. Economic Results for the Simulations of a Hybrid System with the grid, PV and Wind Power and Batteries.

	Alternative 1	**Alternative 2**	**Alternative 3**
Initial cost [€]	42.318.736,70	78.685.478,90	164.267.772,48
Present Worth [€]	56.743.660,00	87.995.980,00	124.009.000,00
Annual worth [€/year]	7.954.212,00	12.335.100,00	17.383.300,00
ROI [%]	31,20%	28,10%	21,60%
IRR [%]	30,40%	27,50%	22,50%
Simple payback [years]	3,42	3,81	4,64
Discounted payback [years]	3,91	4,43	5,53
Levelized COE [€/kWh]	0,2403	0,2063	0,1303

5.2.6 PV Power, Wind Power and Grid

Finally, and as the final model to be studied, the hybrid power system in which both PV and wind energies are included will be developed, without considering the use of a storage system on in. Table 22 the installed wind power for each one of the three alternatives of the current model

Table 22. Installed power alternatives for the Hybrid System Consisting of Grid, PV and Wind

	PV Power [kW]	**Wind Power [kW]**	**Inverter Power `[kW]**	**Storage Cap. [kWh]**
Alternative 1	9.537,89	20.010	20.160	-
Alternative 2	14.308,56	40.020	51.840	-
Alternative 3	22.329,72	100.050	100.800	-

Figure 43 shows the results of the simulation of the lowest alternative of power. The graph shows that the contribution of wind and PV power is not much higher than the requirements of the load, as it happened in the case of the model analysed before. However, as it has already been mentioned in all the models that do not consider the use of batteries, the lack of a storage system makes it impossible to store the energy that is not used, and it is therefore sold to the grid, instead of keeping it for moments in which is a better option to consume energy that is stored on the batteries than purchasing it from the grid, due to its high price in those specific moments.

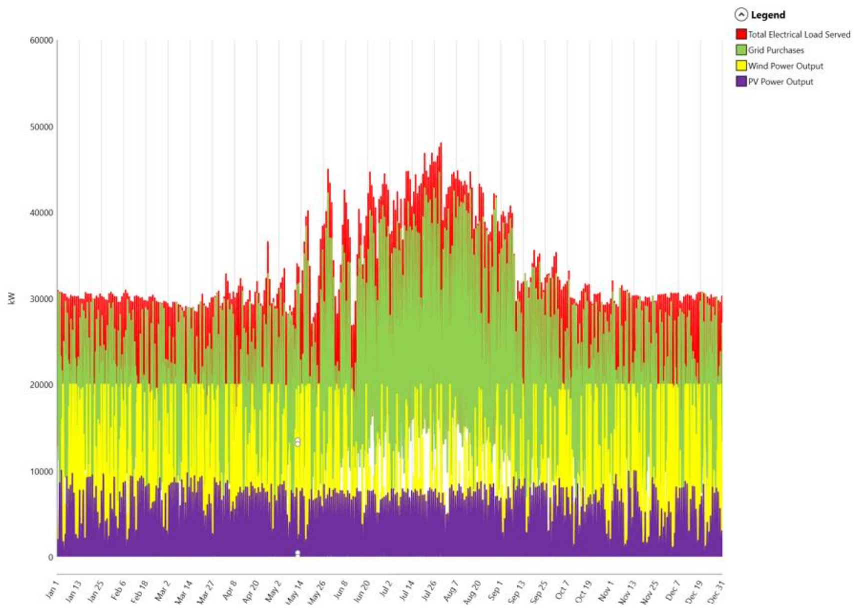

Figure 43. Generation and Consumption in a Hybrid System with the grid and a high alternative of PV and Wind Power.

The same conclusions can be made for the medium alternative too, as it is shown in Figure 44. In this case, however, more energy must be sold to the grid, as the installed power is bigger, and more energy is therefore generated through renewable sources.

For that reason, the main conclusion that must be taken from the technical analysis of this case is that it is oversized, and that it is not a good decision to install so much power.

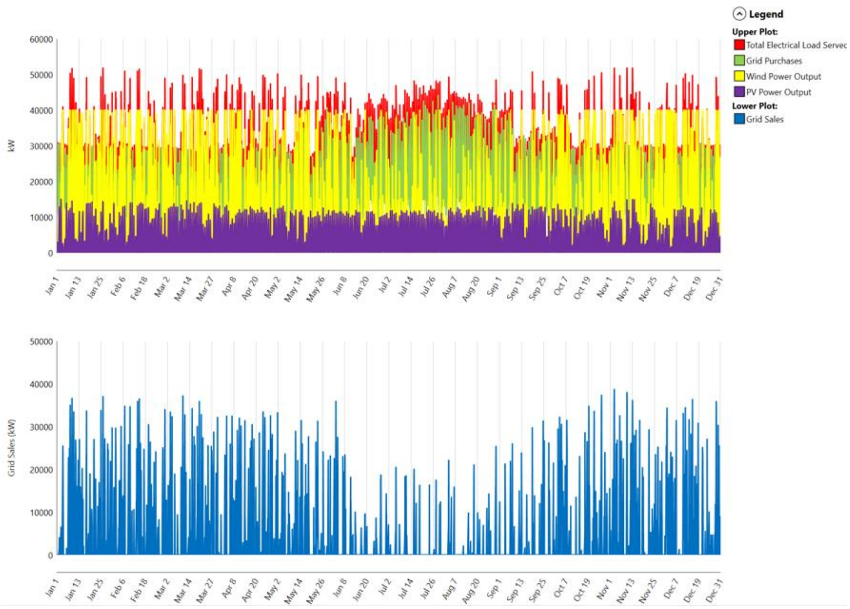

Figure 44. Generation and Consumption in a Hybrid System with the grid and a medium alternative of PV and Wind Power; and Energy Sales to de Grid.

The conclusions of the analysis of the alternative with the highest power are just the same as the ones explained for the medium one. The system is also oversized and, although the percentage of penetration of renewable energy is very high (77,3%), the amount of energy that is sold to the grid makes the project be not a good proposal as project manager.

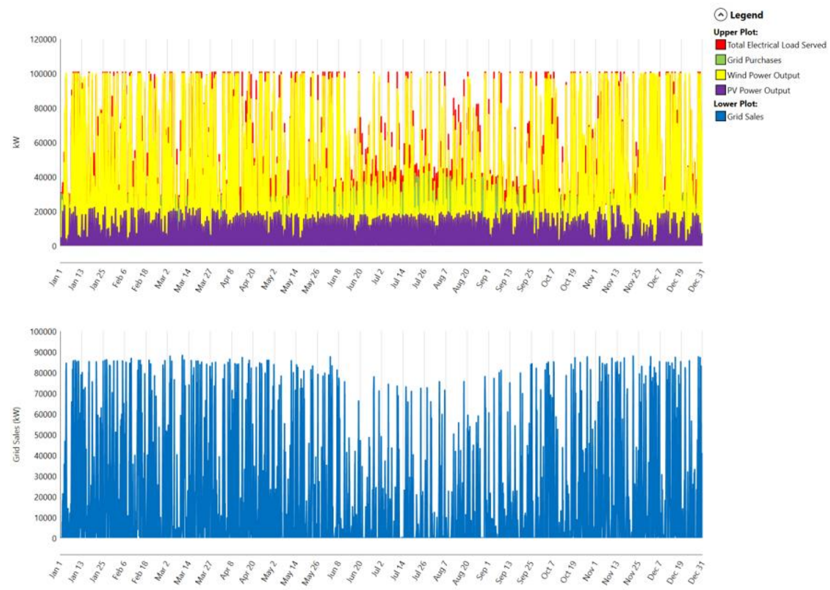

Figure 45. Generation and Consumption in a Hybrid System with the grid and a high alternative of PV and Wind Power; and Energy Sales to de Grid.

Finally, and as it has been done in all the previous system proposals, an economic analysis will be done to end up with the study of the proposed model. Table 23 shows the economic results of the simulations for the model based on PV and wind energies, without any storage system.

As it happened in the model with batteries, the main conclusions taken in the comparison of the three powers are the same. On the one hand, the present worth of the projects increases together with the installed power. However, as it happened in the previous model, the other measuring parameters, such as the ROI or the IRR, are better for the system with the lowest alternative of power.

If a comparison is done between the models with and without a storage system, the conclusion is the same that has been explained in the previous cases: the installation of batteries makes the economic results be worse, due to the high price that batteries have nowadays in the market.

Finally, looking at the cost of the energy for each system, the model that integrates both PV and wind energies does not achieve the lowest cost of energy, but makes it be lower than the COE of the system based only on the grid. Furthermore, if a comparison between both models based on PV and wind (the model with batteries and the one without them) is done, the one that does not include batteries gets a final COE lower than the one that considers their use.

Table 23. Economic Results for the Simulations of a Hybrid System with the grid, PV and Wind Power.

	Alternative 1	**Alternative 2**	**Alternative 3**
Initial cost [€]	41.544.729,82	77.911.478,90	172.824.972,48
Present Worth [€]	57.972.600,00	89.615.290,00	125.170.100,00
Annual worth [€/year]	8.126.483,00	12.562.090,00	17.546.090,00
ROI [%]	32,10%	28,60%	21,70%
IRR [%]	31,10%	27,90%	22,60%
Simple payback [years]	3,37	3,78	4,61
Discounted payback [years]	3,86	4,38	5,50
Levelized COE [€/kWh]	0,2336	0,1941	0,1216

6 CONCLUSIONS AND FUTURE RESEARCH

Performing a good technical and economic analysis in the initial phases of a project is crucial if good results want to be achieved at the end of the life cycle of it. The project manager is the person in charge of doing this work and taking the decision of what is the option that best fits the interests of the stakeholders.

During this document, a technical and economic analysis of a hybrid power system has been done for the Port District of Seville. A load that could properly fit the demands of the district has been created and simulated, and different equipment and energy sources have been selected for the system.

Once the model has been created, the first objective has been to search the option of creating a Net Zero District in the given location, comparing three different systems: one based on PV energy, another one based on wind power, and a last one that uses a combination of both technologies.

After doing the analysis, it has been concluded that it is no longer feasible to look for this kind of objective, as that project would not achieve good results, neither technically non economically.

In the second part of the document, an option in which the mentioned technologies have been used (alone or in combination to each other) to create a hybrid system connected to the grid.

The results obtained during all the simulations that have been done of the model show that a project based on these criteria is a much better idea, since the technical and economic results achieved are positive. All the options that have been studied would satisfy the stakeholders, as the two main objectives of the project would be achieved. On the one hand, the amount of energy purchased from the grid would be reduced, which would bring an economic save into the population of the district. On the other hand, the investor of the project would obtain economic benefits at the end of the life cycle of it.

If all the proposed options are taken into consideration, and after considering all the conclusions and analysis that have been made during the document, the option that fits the objective of the stakeholders the best seems to be the one that combines both PV and wind energies without batteries, being the best power alternative the lowest one, as it generates an amount of energy that is near to the one required by the load.

Finally, and being important all the points that have been mentioned above, the current document only allows an initial analysis of the cases, which must be done in a deeply way if a more accurate result is wanted. For that reason, the future work that should be done is to take the projects that better fit with the objectives marked by the stakeholders, and to perform a deeper analysis of them, in which all the possible constrains and risks are considered.

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8 Annex 1: Averages of the Hourly Energy Prices of the Grid

Table 24. Average of the Hourly Energy Prices of the Grid in [€/MWh]

	January		February		March		April		May		June	
	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends
1	203,79	195,88	196,44	213,21	285,35	283,92	205,63	224,96	196,72	200,59	189,08	179,09
2	191,75	179,13	184,17	202,58	266,36	270,74	187,35	209,03	187,20	188,11	176,38	168,35
3	184,32	170,98	177,48	189,67	256,61	260,60	178,23	205,10	183,26	183,28	168,48	159,79
4	176,96	163,08	169,81	180,03	248,61	241,47	173,54	196,78	181,18	178,66	166,95	156,04
5	174,64	159,48	166,88	176,31	246,03	238,39	175,28	192,65	182,71	176,79	166,45	152,35
6	183,82	159,22	174,52	179,23	258,23	244,96	185,88	193,72	190,35	179,46	171,20	152,54
7	200,77	166,02	195,84	188,91	290,45	256,69	208,72	203,85	210,84	182,67	180,69	150,85
8	218,36	175,10	227,96	199,56	320,88	259,71	237,58	204,97	223,54	180,25	195,99	149,43
9	229,39	177,38	237,25	198,67	328,37	259,74	244,07	199,83	222,03	175,23	193,18	138,86
10	228,30	183,00	229,12	200,33	318,59	265,82	231,70	182,21	209,44	158,55	178,26	129,88
11	219,45	182,88	212,37	192,44	302,40	249,30	214,87	152,24	195,05	151,23	170,62	129,06
12	210,10	177,45	196,86	182,02	285,99	239,46	194,81	124,67	183,41	146,81	166,07	125,02
13	206,60	172,06	189,00	178,32	279,69	236,23	186,19	111,23	183,09	143,26	164,28	120,23
14	204,18	166,85	181,64	174,43	267,53	242,51	176,39	110,30	178,80	132,84	160,30	118,73
15	197,66	163,16	177,30	166,13	262,40	235,64	164,91	98,92	171,87	120,46	154,26	114,23
16	196,07	156,82	173,19	160,92	261,63	227,07	159,48	89,36	168,52	115,10	149,53	100,63
17	203,05	169,44	180,71	163,97	272,24	235,62	160,15	86,69	167,68	118,23	148,50	92,23
18	222,07	198,46	202,83	178,98	294,30	260,31	168,33	96,43	171,35	125,47	151,74	106,23
19	241,85	228,59	232,44	221,05	309,68	295,91	186,54	128,08	179,95	143,43	156,62	113,56
20	251,59	237,83	245,21	236,95	333,09	327,22	212,09	175,30	199,13	185,85	171,13	129,96
21	241,70	234,46	244,92	246,56	340,71	331,05	246,95	227,16	218,43	219,52	190,84	154,99
22	225,69	228,46	233,37	244,50	329,15	319,45	252,44	243,41	230,17	230,15	203,97	179,99
23	211,42	216,62	215,79	225,57	306,07	304,82	237,75	232,78	220,34	224,56	203,32	189,17
24	197,56	201,21	198,05	210,19	282,06	292,56	218,40	214,71	207,11	212,17	187,12	177,75

	July		August		September		October		November		December	
	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends	Weekdays	Weekends
1	156,99	156,76	109,10	109,98	156,08	166,52	208,45	191,68	186,83	200,35	238,12	251,85
2	144,28	150,56	105,10	106,40	148,43	163,35	197,94	177,36	178,33	189,17	216,18	227,58
3	135,53	146,21	102,43	103,28	142,77	160,15	188,63	166,21	167,83	182,01	203,90	214,59
4	130,91	142,57	101,19	102,77	140,05	156,25	187,30	160,00	158,63	168,35	191,09	188,75
5	132,32	144,24	101,55	100,65	140,35	154,44	186,79	155,04	156,81	159,27	187,18	177,51
6	138,05	145,56	103,79	100,83	143,75	154,67	191,34	151,60	173,34	159,40	199,86	177,53
7	146,04	145,01	108,66	104,19	158,78	157,89	210,76	158,69	191,89	163,71	218,45	184,54
8	155,96	136,05	112,61	104,32	169,31	159,48	237,57	172,79	210,88	173,67	245,98	203,44
9	156,12	128,12	116,01	103,74	172,93	156,20	246,42	178,70	215,84	178,65	257,66	218,14
10	149,12	120,95	114,67	99,09	168,81	150,84	240,87	185,86	209,82	185,24	259,52	229,30
11	146,85	118,39	110,72	92,28	164,12	138,63	222,75	178,78	198,65	185,37	252,52	230,44
12	143,73	116,56	109,37	88,96	160,27	129,43	206,75	165,47	187,00	182,12	239,77	227,82
13	148,93	120,09	109,09	87,68	158,98	125,46	200,24	163,57	185,85	179,05	236,24	228,42
14	149,72	123,46	109,53	89,71	156,85	125,24	193,70	163,05	183,48	175,09	235,93	226,25
15	145,29	121,06	109,03	84,94	154,09	123,85	186,79	159,55	179,34	171,80	235,14	220,05
16	140,28	116,27	104,83	76,34	149,28	113,81	180,48	134,67	182,48	171,58	238,23	218,14
17	135,85	112,39	103,33	73,91	150,63	113,73	186,18	135,34	195,03	180,46	248,77	234,03
18	133,84	112,63	104,43	74,29	159,57	126,19	205,76	158,27	212,15	209,80	269,68	261,36
19	133,53	120,38	106,91	80,47	164,80	148,69	226,15	185,80	230,99	223,93	282,57	278,86
20	140,56	129,11	113,57	96,00	173,65	165,21	246,45	207,88	235,62	224,85	287,33	286,05
21	157,57	157,67	118,15	110,10	176,42	171,45	254,49	226,89	234,62	217,51	287,60	287,50
22	166,07	177,12	121,32	116,76	174,90	175,24	244,63	229,06	220,64	212,36	273,48	282,25
23	164,61	186,97	118,79	116,68	167,88	170,94	225,69	207,84	206,60	201,56	255,16	271,40
24	152,74	171,03	113,57	110,96	157,93	166,16	209,71	186,55	196,14	191,88	234,94	255,07

9 Annex 2: Article: Looking for Net Zero Districts - The Case of the Port District of Seville

energies

MDPI

Article

Looking for Net Zero Districts: The Case of the Port District of Seville

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Abstract:
Current climate situation, together with the politics driven by the European Union have inspired the development of Net Zero Districts. This document presents a technical and economic analysis of a hybrid (PV/Wind turbine) power systems for a Port District Area in the city of Seville. Spain. The analysis is carried out by investigating the potentials of wind and solar energy and collecting data from different sources. Hybrid Optimization Model for Electric Renewable (HOMER) software is used to analyse the available data and the technical-economic feasibility of the proposed hybrid power system. In this document, both off-grid and grid-connected systems are modelled and optimized for comparison purposes. The simulation results indicate that the proposed model of a grid-connected system is more feasible than the off-grid one in the mentioned region.

Keywords: Net Zero District, Renewable Energy Sources, Power Market, Economic Optimization, Hybrid Power System.

1.Introduction

The 2030 climate and energy framework targets proposed at the European growth strategy for the present decade, together with other strategies promoted by the European Union, have settled the objectives of reducing the energy usage and the Greenhouse gas emissions [1].

As a consequence of the goal of the European Union of reducing the energy usage in buildings, nearly zero-energy buildings (NZEB) have become more popular among the community, due to their inherent capacity and objective of reducing buildings' energy usage and, thus, associated CO2 emissions. Significant work has been done on the proposal of definitions for the NZEB concept and possible variations [2], [3].

The concept of Nearly zero-energy district (NZED) arises in this context, with the intention of adjusting the nearly zero-energy principles to the urban context. By settling the mentioned principles and objectives to a whole district, the strategy of considering different energy generation and consumption sources brings the possibility of sharing needs costs and resources.

Accordingly, the NZED approach has the objective of addressing the main issues that are already considered in NZEB at the individual level, which are fundamentally based on energy performance and renewable energy generation near its consumption site. Regarding the performance aspect, the influence of buildings and the context of their surroundings are taken into account to obtain a higher energy performance assessment accuracy [4].

Hybrid power systems using Renewable Energy Sources (RES) are becoming most popular due to their potential advantages [5]. The concepts of Photovoltaic (PV) and Wind energy are well known, as well as the technologies for these energy resources. However, the variation of solar/wind energy generation does not match with the energy consumption, and a storage system must be used to ensure the energy availability. Research developed worldwide indicates that a hybrid system including PV, wind and batteries is a reliable source of electricity [6], [7].

National Renewable Energy Laboratory's (NREL) Hybrid Optimization Model for Electric Renewable (HOMER) software has been employed to carry out the present study. It performs comparative economic analysis on a distributed generation power system.

Inputs to the model will perform an hourly simulation of every possible combination of the components and rank the resulting systems according to the criteria specified by the user, such as cost of energy (COE, €/kWh) or Internal Rate of Return (IRR). Furthermore, the tool can perform "sensitivity analyses", where the values of certain parameters (for example, cost of the energy obtained from the grid) are modified in order to analyse their impact on the system configuration [8].

2. System Description

In this paper, both off-grid and grid connected power systems have been analysed using HOMER® to evaluate and determine the cost of different models. Model simulation software needs some input data to optimize the results of the simulations.

2.1 Load Profile

A combination of different load profiles has been made to determine the total load profile of the district. Table 1 shows the different load profiles, as well as how many times has each one been used. As a result, a total energy consumption of 495.996,00 kWh/day has been stablished. Figure 1 shows the profile of the daily average energy consumption of the whole district, in which 17:00 to 22:00 h time lapse is considered the peak of the consumption, with a peak consumption of 48.032,92 kW. Figure 3 shows the monthly average load in the proposed district.

Table 1. Load Profiles.

Profile	**Quantity**
Apartment	700
Full-Service Restaurant	10
Large Hotel	5
Supermarket	5
Warehouse	5
Medium Office	5

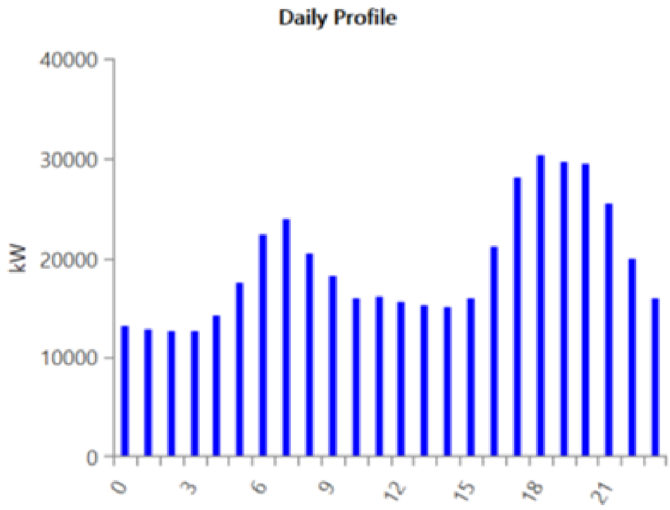

Figure 1. Daily Load Profile.

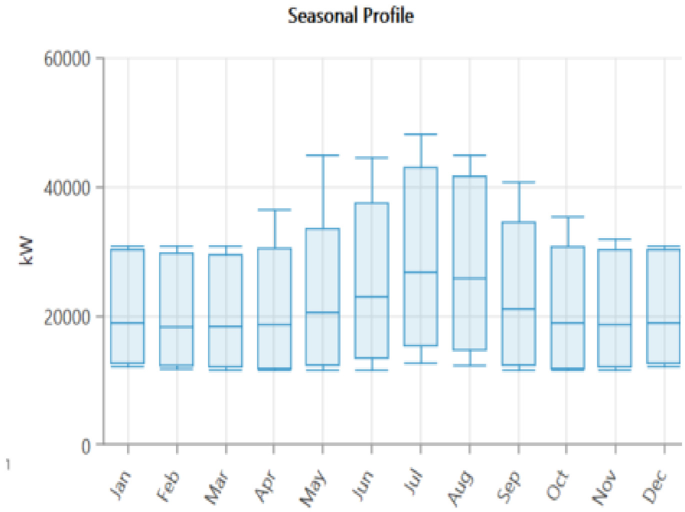

Figure 2. Monthly Load Profile.

2.2 Wind Speed and Solar Radiation

The model brings the option of downloading the data of the wind speed and the solar radiation of the selected location from NASA surface meteorology and solar energy database.

Figure 3 shows the monthly average radiation data and the clearance index. Monthly average wind speed data of Seville are shown in Figure 4, with a minimum value of 4,21 m/s in August, and a maximum of 5,75 m/s in December.

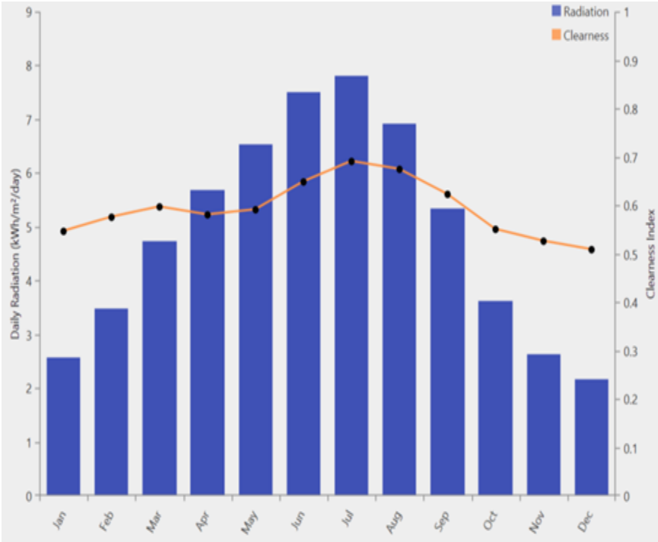

Figure 3. Solar Radiation and Clearance Index.

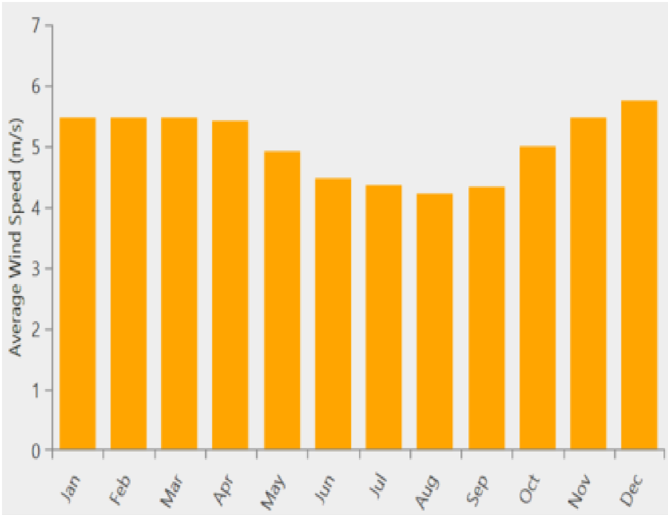

Figure 4. Monthly average wind speed

2.3 Grid

For grid connected design, a grid is used as an energy source for the period in which renewable energy sources are not capable of producing all the energy the load requires. For the estimation of the energy price, the data of the energy price in Spain between August 2021 and July 2022 have been used [9], and all the prices have been divided in five sections. Table 2 shows the energy price of each section.

Table 2. Energy Prices of the Grid.

Section	**Prince**
Section 1	0.3140
Section 2	0.2607
Section 3	0.2073

Section 4	0.1539
Section 5	0.1006
Section 1	0.3140

With these prices, the final Cost of Energy that will be used as a basis for the comparison of all the cases is COE = 0,2749 €/kWh.

3. Methodology

3.1 Modelling Software

The software was developed by the National Renewable Energy Laboratory (NREL) [8], and is generally used for the design and analysis of hybrid power systems. In this paper, the previously explained electrical load, solar radiation and wind speed data are used as input data, together with component details and costs.

3.3 Cost analysis procedure [10], [11], [12].

1) Net Present Cost (NPC): NPC indicates the installation and the operating cost of the system throughout its lifetime. The following formula is used to calculate the NPC [11], [12]:

$$NPC = \frac{TAC}{CRF(i, Rpr_j)}$$

Where, TAC, CRF, i and R_{prj} are the total annualized cost (€), capital recovery factor, interest rate in percentage, and project lifetime in year, respectively.

2) Total annualized cost: It is the sum of the annualized costs of every component of the system, together with operation, maintenance, and replacement costs [11], [12].

3) Capital Recovery Factor (CRF): It is a ratio used to calculate the present value of a series of equal annual cash flows [11], [12].

$$CRF = \frac{i \cdot (1+i)^n}{(1+i)^{n-1}}$$

where, n represents the number of years and i the annual real interest rate, respectively.

4) Annual real interest rate: Is a function of the nominal interest rate shown as [11], [12]:

$$i = \frac{i' - F}{1 + F}$$

Where i is the real interest rate, i' the nominal interest rate and F the annual inflation rate.

5) Cost of the Energy (COE): Is the average cost of each kWh of useful electrical energy produced by the system. The COE is calculated as follows [11], [12]:

$$COE = \frac{TAC}{L_{prim,AC} + L_{prim,DC}}$$

where, $L_{prim,AC}$ and $L_{prim,DC}$ are the primary Alternative Current and Direct Current, respectively.

4. Simulation Model

The components used for the simulation of the system are selected from the internal library. Left side of Figure 5 (a) shows the schematic of the grid connected system used for the simulations, which includes PV generation, wind power generation, batteries for the storage of the energy, an inverter, the grid and the load. Right side of the figure (b) shows the same system, but without the grid. Table 3 shows the selected elements for the system.

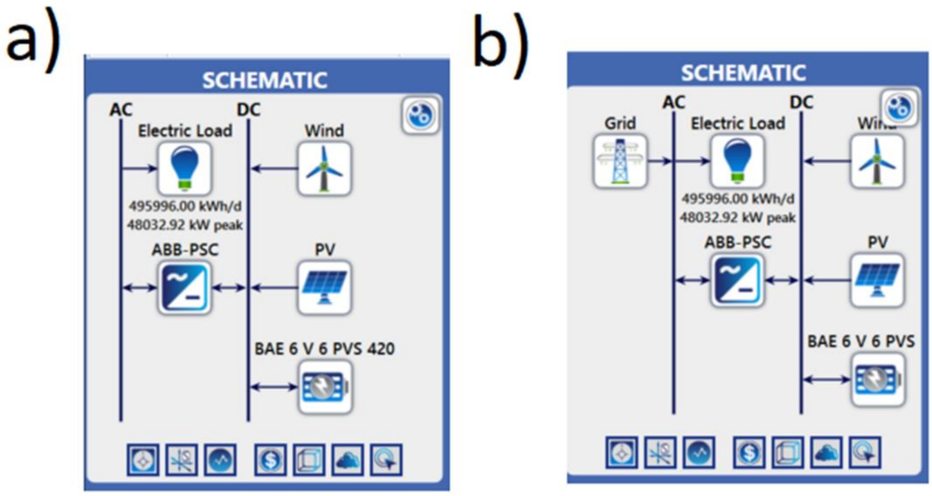

Figure 5. Schematic of the Off-Grid (a) and Grid-Connected (b) systems.

Table 3. Components of the model.

Component	Model	Capacity
Inverter	ABB PSTORE-PCS	2880 kW
PV Panel	SunPower E20-327	327 W
Wind Turbine	AAER A-2000	2 000 kW
Battery	BAE Secura Solar 6V 6 PVS 420	2,41 khW
Grid	-	-

Once the system has been defined, it simulates all the different possibilities for the given PV and wind generation powers, with the objective of finding the best possible combination in terms of costs and benefits.

5. Optimization and Results

5.1 Net Zero District

With the objective of reaching the final goal of a Net Zero District at the given location and load profile, a simulation has been made to find the optimal result for three different cases: PV energy and batteries; wind energy and batteries; and a combination of PV and wind energies and batteries. When performing these simulations, no input has been given to the model in terms of installed power, so that the software could find the best option to fulfil all the load. Table 4 shows the optimal results obtained for each case:

Table 4. Optimization results for Net Zero District.

	PV + Batteries	Wind + Batteries	PV + Wind + Batteries
Installed PV power [kW]	201.481,00	-	105.845,00
Installed Wind power [kW]	-	276.000,00	44.000,00
Installed battery capacity [kWh]	1.693.587,00	2.755.859,00	1.218.608,00
Inverter power [kW]	78.169,00	70.244,00	68.758,00
Initial cost	473.615.091,93	612.877.158,35	319.736.075,09
Present worth [€]	-235.940.900,00	-411.075,00	-85.043.550,00
Annual worth [€/year]	-33.073.720,00	-57.623.690,00	11.921.240,00
ROI [%]	1.9%	0,4%	5.6%
IRR [%]	3.0%	N/A	8.2%
Simple payback [years]	15.44	N/A	9.63
Discounted payback [years]	N/A	N/A	N/A
Levelized COE [€/kWh]	0,4166 €/kWh	0,5524 €/kWh	0,2997 €/kWh

As it can be seen in table 4, the objective of finding a Net Zero District for the Port District of Seville is not realistic. The needed power of both PV and wind energies is too high, as well as the inversion that must be made to achieve it. On the other hand, the economic results show that it is not worthwhile looking for this kind of objective. All the three options bring a negative present worth at the end of the project, which means that the initial cost is bigger than all the benefits that the project will bring during its lifetime. Finally, the COE of the three cases brings cost of the energy that would be much higher than the grid coming from the grid.

Looking at the technical aspects of the proposals, the needed installed power is so big that a total surface bigger than the available one would be necessary to fulfil the whole load. This also makes the objective not realistic

5.1 Grid Connected System

In order to find the best possible solution for a grid connected hybrid system, many simulations have been done in which different combinations of installed PV and wind powers and storage capacities have been taken into account as an input. Table 5 shows the different PV and Wind powers that have been considered, as well as the storage capacity of the batteries.

Table 5. Installed power alternatives for the Renewable Energy Sources.

Component	Alternative 1	Alternative 2	Alternative 3
PV	9.538 kW	14.309 kW	22.330 kW
Wind	20.000 kW	40.000 kW	100.000 kW
Batteries		8.683 kWh	

After analysing the simulations with all the possible combinations among the installed powers that have been mentioned above, the results show that a grid connected hybrid system is a more realistic objective than an isolated one. All the cases show positive results in terms of Present Worth, and a TIR between 18,20% and 37,30%.

Among all the possible combinations, two have been selected in this article. On the one hand, installing PV power together with the grid seems to be the most realistic option, as the needed initial cost is the lowest one among all the possible solutions. On the other hand, the best option according to the model is the combination of the grid, PV power and wind power, without installing any battery for storage. Table 6 shows the comparation of the achieved results for the two mentioned options.

Table 6. Economic results for the analyzed alternatives.

	PV + Grid	**PV + Wind + Grid**
Installed PV power [kW]	9.537,89 kW	22.329,72 kW
Installed Wind power [kW]	-	100.000,00 kW
Installed battery capacity [kWh]	-	-
Inverter power [kW]	11.520 kW	100.800 kW
Initial cost [€]	14.507.929, 82 €	172.824.972,48 €
NPC [€]	9.880,764,00 €	125.170.100,00 €
Annual worth [€/year]	1.385.066,00 €	17.546.090,00 €
ROI [%]	20,60 %	21,70%
IRR [%]	22,40 %	22,60%
Simple payback [years]	4,58 years	4,61 years
Discounted payback [years]	5,47 years	5,50 years
Levelized COE [€/kWh]	0,2681 €/kWh	0,1216 €/kWh

As it can be seen in table 6, the economic results for both options are positive. ROI and IRR are very high for both cases, due to the high prices the energy has had during the time that has been considered, and the high savings that would therefore be obtained. On the other hand, according to the results obtained with the simulations, the high inversions necessary to develop such a big project could be recovered in less than 5 years for both cases. Considering the cost of the energy, we can see that in the case of the first simulation, the final cost of energy would be lower than the one from the grid, but with not a big difference. In the case of the system with PV and wind energy combined, the final COE would be lower than the half comparing with a conventional system, in which only the grid is used as a power source.

In terms of technical results, the fraction of renewable energy that could be achieved in each case is also very different. In the case of the first simulation, in which PV power is considered together with the grid, the 8,60% of the energy is achieved through renewable sources. In the case of the combination of solar and wind energy, however, the 76,2% of the total energy production would be renewable. Figures 7 and 8 show the previously explained percentages.

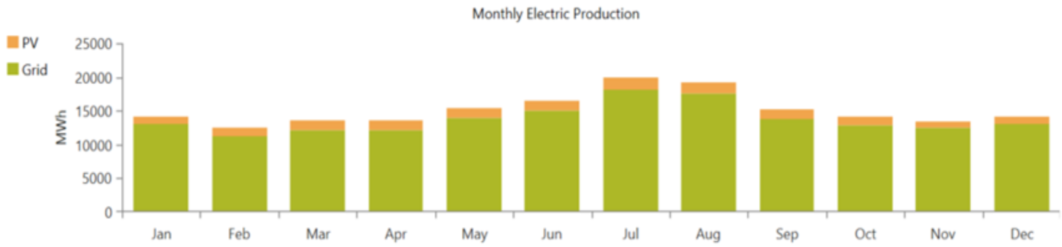

Figure 6. Energy Production sources for PV + Grid case simulation.

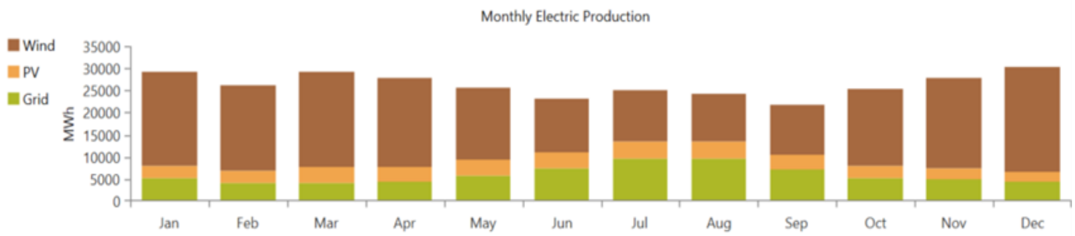

Figure 7. Energy Production sources for PV + Wind + Grid case simulation.

6. Conclusions

This paper presents a comparative analysis between an off-grid and a grid connected hybrid power system in the Port District of Seville, with the objective of studying the possibility of creating a Net Zero District. The optimization and simulations developed show that an off-grid system is not a realistic objective due to the bad economic results. Looking for a grid connected system (Wind + PV) is a more efficient way of integrating renewable energy sources to the system, as they reduce the cost of the energy in a significant way, being able to get a final Cost of Energy that can be even the half of the COE of the energy coming from the grid.

Off-grid systems need much a bigger installed power, and a big number of batteries to store all the energy. However, the system is not able to store or consume all the generated energy, and all the excess go unused. A grid connected system, however, does not require an extra battery bank to be added, as the energy can be sold to the grid when the generation is bigger than the load.

Therefore, it can be said that the proposed grid-connected hybrid systems are a better option, as they get better economic results, and the space needed to the installation is much less than in the off-grid system

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