Department of Mechanical and Aerospace Engineering

Study of the technical-economic feasibility of an electric generation system in a village in the south of Spain

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Signed: Jose Quirantes Date: 22 august 2017

Abstract

The main objective of this thesis has been a technical and economic analysis of the implementation of a distributed generation system for self-consumption in a village in the south of Spain currently connected to the main grid. Spain is suffering some of the highest electricity prices in Europe, and more and more projects of self-consumption are giving electricity.

For this case, the main challenge was to achieve the highest possible level of self-sufficiency using a battery generation system always connected to the main grid for when import is required.

A methodology was carried out which consisted in the study of microgrid, price of electricity in Spain, prices of generation and storage technologies used in the project both in the present and in the future and the presentation of the location of the project. The following study consisted in the estimation of the electric demand by means of the study of electric bills base according to the type of load in the village and a survey to know which was the pattern of consumption in the village throughout a day, and of the week. Once the electric demand profile was obtained a study of the climatological sources was carried out in the location of the project, alluding to the factor of the height above the sea level of the location.

HOMER (hybrid optimization model for multiple energy resources) was used to model three scenarios in order to analyse how much load met by generation is reached and what is the cost of the whole useful life of the project. This last fact was very important, since the capacity of generation and storage was highly conditioned by this, rejecting higher project life costs than the system itself, connected to the grid without any kind of generation.

The first and second case consisted in the installation of 100 kW of PV capacity and this same capacity plus four turbines obtaining the load met by generation of 78.45%. For the latter case, the performance of different types of batteries was simulated in order to know the type that best fit the project. It was obtained the best simulation having the generation already mentioned with addition of 24 vanadium redox reaching the load met by generation of 96.84%.

Finally, a future work and conclusion has been suggested

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Thanks also to the municipality of Capileira for helping me carry out the survey of electrical consumption in the village.

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1. Introduction

1.1. Background

Nowadays nobody imagines a world without electricity. This is the form of energy most heavily used today for our activities in industry and in the home. Electricity is produced relatively easily in a short period of time in large quantities, and it is easy to transport great distances from generation centres to consumers. All industrial processes and almost all human activities use it, therefore it can be considered as the essential basis of our energy system. For its use, it is required to construct a physical system that allows and sustains the whole process from the beginning with its generation until the final consumption.

Despite its importance in virtually all industrial, residential and domestic activities, electricity has a fairly recent history, dating from the last quarter of the 19th century. (Asensi Orosa *et al.*, 2006)

In a general way, an electrical system is understood to mean the set of cables, transformers and infrastructures that carry electrical energy from the production centres to the users. These networks are in charge of transporting and distributing the electricity produced by the generation plants (nuclear, hydraulic, coal or renewable) to the points of final consumption.

However, one of the major problems facing today's networks is that they have been designed in the last century where in many cases, places away from population centres were selected for the location of generating plant. More recently, with population growth and new population centres, these networks are becoming inadequate and must be redesigned to become more robust and with greater capacity, so that they can meet the needs of consumers and the characteristics of Renewable Energies.

This problem leads to another, since where there are wide distances from generation to consumption energy is lost in transport and distribution. The method historically used to reduce transport losses is to transport the electric energy at very high voltage.

Big centralised thermal electricity generating stations waste around two thirds of the energy in the fuels they use by throwing away waste heat in cooling water, up the cooling towers and then in the electricity transmission wires. So 65% of the energy is lost before it even reaches consumers. If we could make use of this waste heat it would make a very large contribution to tackling climate change and improving security of supply.(January, 2007)

The output from large power stations must be processed into a suitable form for use at domestic, commercial and industrial sites. These transformations are made by a range of different devices (transformers, control elements, etc.); like the rest of the infrastructure they may require to be re-designed to meet future needs.(Fedit and Electronica - Tecnologias de la información y telecomunicaciónes, 2011)

Current electrical grid

The conventional electrical system is composed of four elements:

- ❖ There are currently a wide variety of electricity generation technologies, ranging from conventional gas, coal, or nuclear power plants to renewable energy plants such as hydroelectric plants, wind turbines and solar panels. The composition and scale of the generating system in any given country or region is evolving continuously in response to consumer demand and environmental constraints. Power plants are often found far from our homes, and tend to be located where noise and emissions are not a problem for the population.
- ❖ Transmission lines are required to transport high-voltage electricity over long distances and connect generation sites with consumers. Transmission lines are overhead power lines or underground cables. Aerial cables are not insulated and may be affected by climatic factors, however, they are generally less expensive to install than underground cable.
- ❖ The distribution network is the system of cables that start collecting the electricity in the transformers and end with houses, schools and businesses. The transmission network ends when electricity finally reaches consumers.
- ❖ Consumption, is the part of the system where the energy generated and transported is consumed. (Union of Concerned Scientists, 2017)

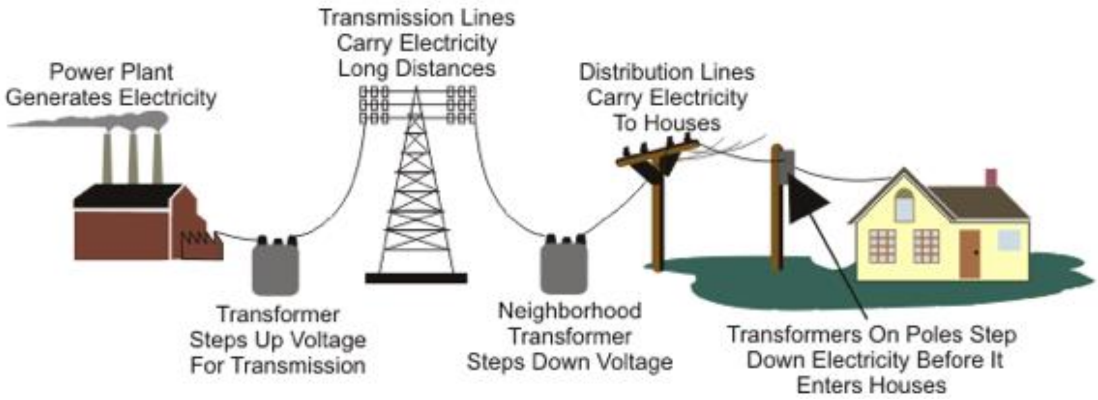

Figure 1: conventional electrical network transmission (Solanki,2017)

In this image, it is observed which are the selected voltages for the transport and distribution of the electric energy. After generation, electricity is transported in voltages of more than 220 kilovolts (kV) to reduce energy losses during transport over long distances, to transformer stations that convert energy into lower voltages between 66 and 11 kV to transport energy areas with significant concentrations of population or industrial activity. With the use of transformer stations again the voltage is reduced further and here the distribution grid supplies hospitals, schools and processing stations that supply private homes through the low voltage network to Voltages between 110V and 400V. Therefore, the closer you are to the consumer, the lower the voltage and the greater the losses due to transportation.(IRENA and IEA-ETSAP, 2012)

The situation described above applies to all 'developed' countries. But of course, the distribution of electrical energy to the parts of the world is far from homogeneous. This electrical distribution in many cases simply does not reach many remote communities, due mainly to economic factors. Here, the increasing availability of small-scale renewable energy conversion systems may provide some hope for the future.

Increasingly over recent years, rural communities have obtained access to the electricity grid, and thus it has been possible to improve the quality of life of consumers in these areas. But we can still see a number of problems related to electricity supply, such as high prices related to energy consumption, distribution failures (supply cuts) related perhaps to the presence of climatic events, and the long waiting time in the restoration of the service, mainly due to the distance of the rural consumers to the points of distribution. Thus, in general, rural areas are remote from the distribution network, and sometimes have low connectivity and accessibility to supply.(Dornan, 2014)

For these areas where these problems are evident, a solution to this problem can therefore be found by carrying out projects for obtaining energy sustainably using the natural resources present in the study area for the generation of energy(Outlook, 2017). For the use of renewable energies at the local level, the concept of a microgrid is used, consisting of distributed generation systems at low voltage, generating near or in the same place as consumers. These have the ability to operate in parallel with the main grid, or be autonomous and operate partially or totally isolated from the main grid. (PwC, 2016)

The first step in designing a microgrid is to calculate the electric demand by differentiating it into sectors and estimating the potential of the available energy resources and the technologies needed to meet this local demand.

Electrical demand is a very important step in the planning of a microgrid. It is necessary to study several factors such as human behaviour, which might result in significant demand peaks at given times. We need to know what generation capacity is required to ensure that the service is continuous, and thus, guarantee a security in the supply. The calculation of electrical demand in rural communities tends to be complicated, being affected by the time of day or the season of the year in which we are and the vagaries of human behaviour, making it notoriously difficult to predict. (Boait, no date)

For this study, a detailed monitoring of user consumption has been required, showing the behaviour of consumers as a function of the time of day, week, month, etc. However, unfortunately it is not easy to obtain truly comprehensive information, so we are frequently forced to use tools such as mathematical models to generate these demand profiles, based on statistical data and field data. And we study factors that may affect demand, such as occupation patterns, socioeconomic factors, family composition, use of household appliances, among other variables. Methods such as surveys and interviews are usually used to obtain this information. (Objectives, Energy and Course, no date)(National Grid, 2005)

Once the demand is known, the next step is the estimation of the potential of the energy resources obtained from different generation sources within an area capable of supplying part or all of the energy required. The generation may be composed of a variety of technologies such as wind, solar, geothermal, biomass, and hydroelectricity, which then form part of a micro-grid system. To take advantage of the available resources, it is necessary to quantify its potential, to know the feasibility of being used as a source of generation. There are several methods to obtain an estimate of the energy potential of a given resource, taking into account different approaches and precision.(Noguchi *et al.*, 2013)(Akella, Sharma and Saini, 2007)

The present work aims to estimate the demand, the potential of existing energy resources and the best combination of these within a rural community in order to design a microgrid.

1.2. Methodology

The main objective of the project is the reduction of electric consumption from the main grid with the implementation of an electric microgrid for the self-consumption in a village of Spain of around 500 people, with a quite fluctuating electric demand due to rural tourism. In the analysis of electric generation solar and wind energy will be used as they are the most mature technologies for this type of system. Two cases will be studied: the first, without any type of storage, reducing the microgrid to a generation system connected to the network; and in the second case, introducing batteries to store the generation surplus for times of high demand.

The calculations will be carried out through a simulation program called HOMER, which models systems from both the economic and technical point of view and can study many options, to obtain an optimal solution.

In the first step of this thesis distributed generation is defined; also, the concept of a microgrid, its functions and the main parts that compose it economically and technically speaking.

Once these concepts are defined, we proceed to introduce the selected village explaining its characteristics; we then estimate its electricity demand curve by quantifying and studying the different electric charges of which the village is composed. Then an extensive study of the renewable technologies that are going to be used in the village is made. Next we move on to the simulation of the renewable energy power plant and its interaction with the supply system. A discussion of the simulation program is presented, with its characteristics and virtues.

Finally, the annexes with information necessary for the realization of the project are added to the dissertation.

Chapter 1	• Introduction of the project • Methodology
Chapter 2	• Literature review • Introduction of concepts
Chapter 3	• Introduction of the place • Climate of the area and project location
Chapter 4	• Electrical demand prediction of the village of Capileira • Differentiation of the types of load of the village, quantification, survey to study the electrical demand and creation of electrical demand profile
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Table 1: Methodology Followed in this thesis

2. Literature Review

2.1. Density of population in Spain

Spain is a country that occupies 85% of the Iberian Peninsula, shared with Portugal, to the southwest of Europe. Africa is less than 10 miles (16 km) south on the Strait of Gibraltar. On the east coast of Spain, in the Mediterranean, the Balearic Islands are situated with a total area of 5,094 km2; the largest island is Mallorca. Also, 97 km west of Africa lies another archipelago (the Canary Islands) with a total area of 7,273 square kilometres.

In January 2017, the Spanish population was composed of 45,999,676 people. Knowing that the total area of the country is 505,370 km2 according to the United Nations Statistics Division, we can calculate density of the population as 91.0 people per square kilometre. (Countrymeters.info, 2017)

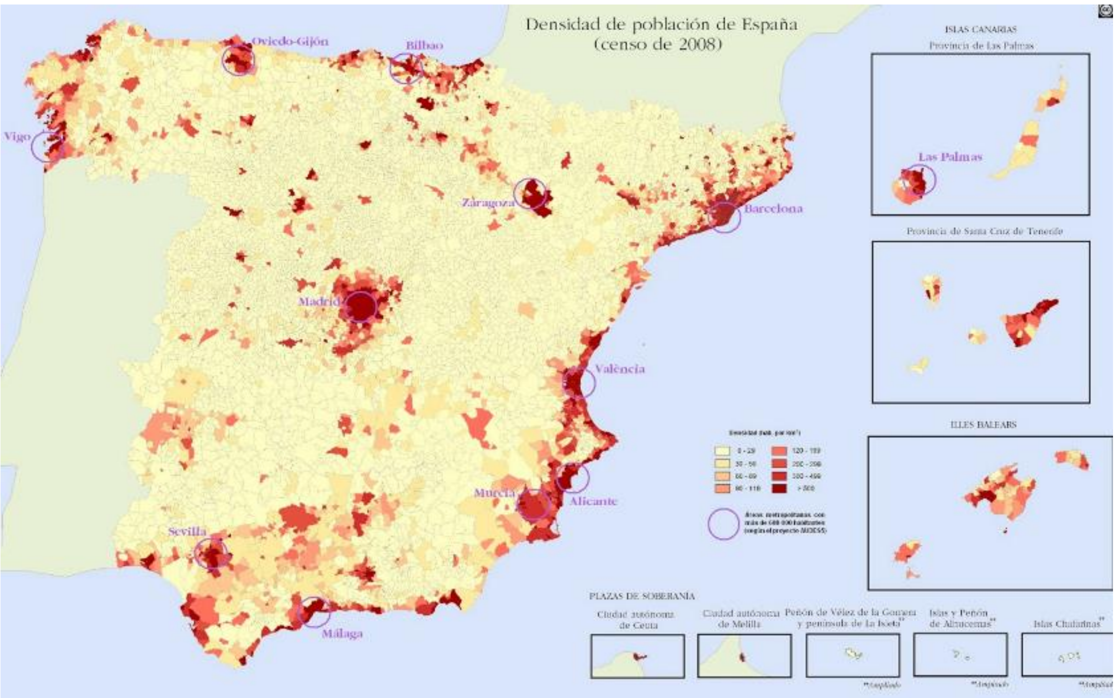

Figure 2: Distribution of population density in Spain (ESTRADA,2017)

The map above represents the population distribution in Spain in 2008. There are seven large metropolitan areas: Madrid, Barcelona, Valencia, Seville, Zaragoza, Malaga and Bilbao. Most of the larger cities and towns are in the eastern part on the shores of the Mediterranean Sea, except Madrid, Seville, Bilbao, Zaragoza and Valladolid.

As might be expected, there is a wide difference in population density between rural and urban areas. One corroborating fact is that 40.1% of the population lives in less than 1% of the municipalities, which have more than 100,000 inhabitants. In addition, this percentage will increase in the future given the present trend of a rural exodus towards the cities. (Ign.es, 2017) Problems in Spain with electricity network

2.1.1. Remote Areas

Due to these differences in population density according to the area of Spain, there are problems such as lack of homogeneity in the electricity supply comparing the large cities with the rural areas.

As expected, there will be a better quality of electrical transmission in densely populated areas, because due to the high number of consumers in the same area, it is more profitable to invest in infrastructures in the supply. However, in less densely populated areas there may be little or no electricity transmission.

The present electrical network in Spain as in many parts of the world does not reach some remote areas. Efforts by public utilities to provide electricity to these areas inevitably become more expensive and less efficient. As the extent of the lines grows, the number of consumers at the end of them decreases correspondingly; the network's capacity for electricity consumption and electricity payment is more limited.

More maintenance is of course required for a more extensive network, the loss of electricity increases by transporting it at low voltage along the conductors, and the quality of service is likely to be lower as the frequency of interruptions and voltage variations increases.

Electrical distribution in these areas is not a profitable business. In many places, it is preferable to invest in the maintenance of existing infrastructure as it is much more profitable to expand as much as possible its capacity to generate electricity for urban demand that increases year after year. For this reason, electricity companies do not continue to expand their territory. In Spain there are several rural communities that, due to low population density, their geographic features and economic problems have been excluded from traditional electrification programs.(Crousillat, Hamilton and Antmann, 2010)

This problem of not being able to supply some areas together with the losses in the electrical production and the climatic change helps us raise the idea of moving from an old centralized electrical system to a distributed system, in which a location or region may be able to self-supply by taking advantage of the area's climate resources to generate electricity locally and meet the demand in these places. Wind turbines, solar PV plant and fossil-fuelled generators are used for these purposes, among others, it is also essential to use storage methods to meet demand in times of low electricity generation.(Rocky Mountain Institute and Carbon War Room, 2015)(Crousillat, Hamilton and Antmann, 2010)

There are several challenges that need to be addressed in order to reduce these problems and to achieve more homogeneity of distribution. A better regulatory system is needed using the existing infrastructure.

In addition there are many remote places that although they have access to the grid would pay in an excessive way the price of kWh and to its normal price would be added other extras such as the one of maintenance of equipment and connections.(Sahu, A. K., Shandilya, A. M. and Bhardwaj, 2014)

2.1.2. Electricity price in Spain

Even in many cases where there is connection to the main grid, there may be a reason for self-consumption due to the high price of energy in Spain, above the European average. Spanish consumers face regulated costs through extra charges and tolls that are included in the electricity bill.

There are different tariff groups depending on the voltage level to which they are applied and their contracted power. The largest group are consumers with low unit consumption (most commonly domestic), who face the highest bills and have a higher cost of supply, as they are usually connected to lower voltage levels, which makes it more expensive to distribute electricity; this price is accentuated in remote areas.

Electricity tariffs

When the Spanish electricity market was liberalized in 2009, customers were free to choose the supplier company. The market was divided into two main rates:

- Fixed annual rate. The characteristic of this modality is a pact between supplier and customer to define a single price over a period of 12 months. This type of billing avoids surprises and avoids the oscillations that are a natural feature of the market
- The price per hour is a new charging mode introduced in 2015, in which the electric price is different for each of the 24 hours of the day. This price is determined by the demand for electricity found in the wholesale market('CONSUMIDORES DE ELECTRICIDAD', 2017)

Figure 3 shows the evolution of the tariffs on July 24, 2017

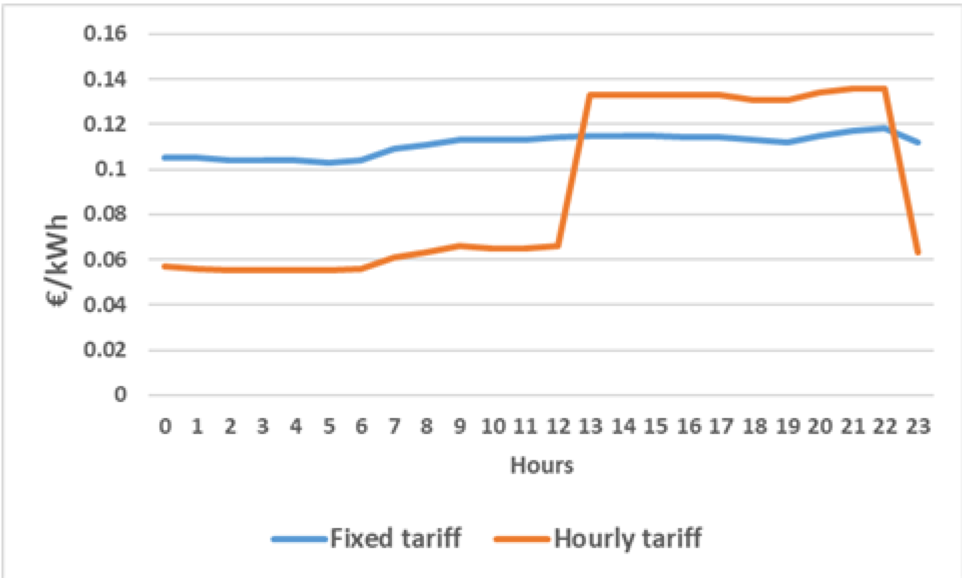

Figure 3: Evolution of different tariff July 24th 2017

For the fixed tariff, it is observed that it remains stable throughout the day in average ranges of 0.13€/ kWh, while the hourly tariff in the valley hours (11 pm-12am) is at 0.06 €/ kWh while in the peak hours is 0.13 €/ kWh.

It should be pointed out that this price represents only 38% of the total electrical bill. The remaining 62% is composed of a charge for power installed (fixed part), which depends on the contracted kW, and tariffs set by the government to pay for regulated activities such as premiums, transportation or distribution, electricity tax and rental of the meter.

Therefore, Spain is among the countries of Europe where the highest rates are paid for electricity, a situation that invites energy awareness and may lead us to a reconfiguration of the electrical system, in which distributed generation and electric self-consumption play an important role..(PwC, 2015)

2.2. Distributed Generation

In previous decades, with the high consumption of oil, climate change and increasing demand for electricity around the world, there was a need for alternative solutions to address these problems and to ensure an efficient and secure supply of electricity. One of these alternative solutions is with the efficient use of natural resources to generate electricity as close as possible to the place of consumption. This type of electrical generation is known as distributed generation

At present, no agreement is reached on the definition of distributed generation. Some people describe it depending on the level of voltage used, while others describe distributed generation as a system using renewable energy. (Purchala *et al.*, 2006)

According to (Wbdg.org,2017), distributed generation may be described as decentralized electricity generation from small-scale renewable and non-renewable electricity generators (typically 3 kW to 50 MW) that produce electricity at a site close to customers or linked to a system of distribution. The two types of distributed generation most used are individual electrification and mini/microgrids.

Domestic electrification usually consists of domestic solar systems (SHS) and focuses on the electrical supply for individual households, not the community at large. However, microgrids within a community or area carry out their function and supply a group of consumers in the selected area.(Foster John , Wagner Liam, no date) .

2.2.1. Technical advantages

From the technical point of view with the introduction of the distributed systems, it will be possible to reduce maximum demand, decrease levels of losses, find a positive impact on system voltage and increase stability, reliability and efficiency of the system. Also, these systems will allow self-adjustment when there is a fault.

Economic

The introduction of these distributed systems has the great advantage of providing economic benefits. One of the advantages in the short term is the reduction of transmission costs given that the generation of electricity is closer to the consumer. In addition to the reduction in the distance between consumer and electric generation, we find another great advantage in the reduction of capital cost in generation plants, since these will have a lower capacity and will require a low capital investment and can hopefully recover the money invested more quickly.(Rujula, Amada and Bernal-Agustin, 2005)

It is also clear that customer services will be improved by the provision of integrated services such as communication, as these consumers thanks to real-time pricing and billing will have the option of finding the most economically attractive deals

.

Environmental

Also, this distributed generation gives rise to a series of environmental benefits, since being based on renewable sources it would curb the consumption of fossil fuels and would lead to a lower concentration of CO_2 emissions. (Galcinpower.org,2017)

Another environmental advantage is that by decreasing transport distances, the amounts of transmission losses will be reduced, so much of the electricity presently wasted in conventional systems (and the associated environmental impacts) no longer exist. It helps the integration of renewable energy technologies and storage more effectively. Finally, a more profound and efficient regulation of the system should lead to an improvement in energy quality.(Elmubarak and Ali, 2016)(Purchala *et al.*, 2006)

2.2.2. Limitations

Although the advantages of the distributed generation model are numerous, these systems also face some inconveniences. The first drawback is the price, very often prohibitive, of the lands to locate generation centres within the community of the consumer.

The second is related to the proximity of the sources of generation with the population nuclei. These distributed generation sites would be scattered close to centres of consumption, potentially creating impacts in closer proximity to the local community.

This problem could be considered in a certain positive way, since it would reduce concentrations of high emissions in specific places. But the placement of electricity generation units close to the communities could be slowed due to poor public perception. The "NIMBY" syndrome (Public, 1991) can often lead to a rejection of the proposals of introduction of a distributed generation system. To counteract this, the ideology should perhaps be encouraged that the shift towards a distributed generation is necessary to minimize the effects of global warming. (Height, 2000)

There are some difficulties associated with installation costs, technical difficulties, lack of regulations related to this type of installation and absence of a standard model to follow.

Because the concept of distributed generation as such is relatively new, there is no legal framework to address issues of operation and installation. It is therefore crucial to establish quality systems, protocols for introduction, and participation in conventional energy markets for different types of sources. In almost all countries, there is a lack of standard legislation available to regulate their operation.

Finally, another potential disadvantage is the creation of monopolies by companies. Since in many cases the generation could be disconnected from the main grid, it will also be disconnected from the general electricity market. The companies in charge of these distribution could sell the energy generated at an excessive price and exploit what is in effect a monopoly position in that location. Therefore, a well-designed administrative structure adapted to market values is required to implement the development of these systems.(Chowdhury, Chowdhury and Crossley, 2009)

2.3. Microgrid concept

2.3.1. Definition

Microgrids are energy systems composed of distributed energy resources and end consumers of electricity, all located in a limited local area. Depending on their source, the distributed energy resources can come from distributed generation or distributed storage. We refer here to systems suited to small-scale energy-generating technologies, such as diesel generators, fuel cells and renewable energy conversion devices. The distributed storage components might be composed of batteries, flywheels, and pumped storage.(Zhang, and Gatsis and Giannakis, 2005)

Although the concept of a Microgrid has taken force in very recent years due to all the problems previously discussed, the idea is not new. The concept has simply been reformulated to a modern context from models originally designed by early electric pioneers.
There are many types of definitions for these systems, however, the specific definition of microgrids that has achieved greatest acceptance is from U.S. Department of Energy Microgrid Exchange Group (Building-microgrid.lbl.gov, 2017)

Microgrid: a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid. A microgrid can connect and disconnect from the grid to enable it to operate in both grid-connected or island-mode"(York, Key and Singhvi, 2013)

2.3.2. Types of microgrid

According to its operation and purpose, there are variations in the type of microgrid: true microgrids, where a group of generators and loads are interconnected by a wiring, having the option to work in parallel with the main network or in isolated form; systems which operate permanently isolated; and finally the private grid, which is a group of generations and loads interconnected by cables that are constantly working parallel to the main network.(Palit and Chaurey, 2011)(PwC, 2015)

2.3.3. Components of a Microgrid

As can be seen in the chart below, the components of a distributed system are the generation system such as wind, solar PV and even hydro. There is also a battery or other system for the storage of electric energy and loads. All are linked by a distribution system controlled by a central controller.

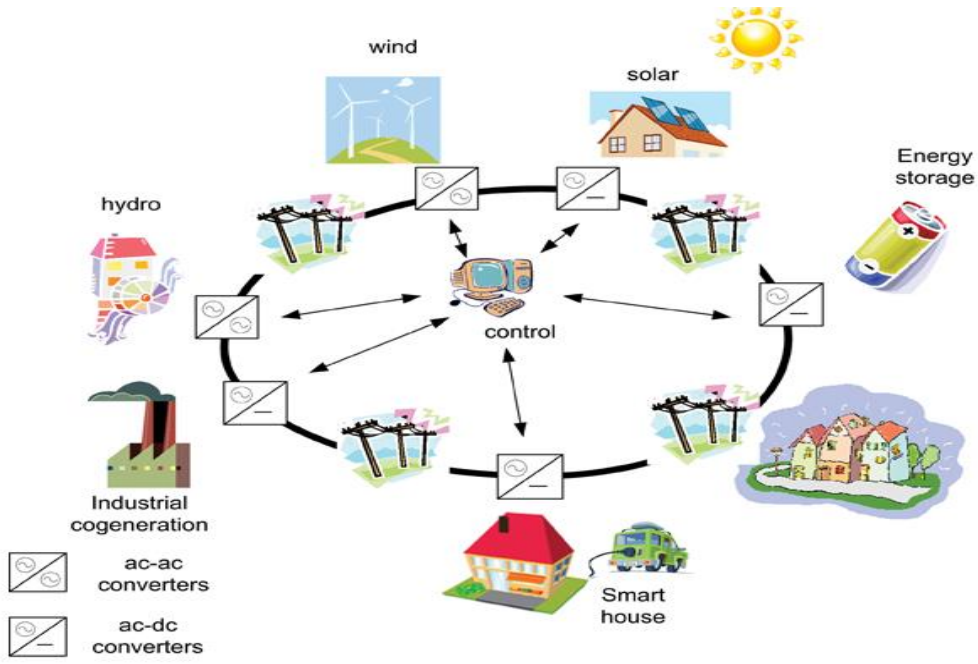

Figure 4:Scheme of a microgrid (compliance,2017)

To understand the operation of a microgrid we must understand the different components of which it is composed:

2.3.4. Generation

Compared to the general grid, both the amount of generation and demand will be significantly lower. With less generation, the integration of renewable energy sources is more difficult. Normally microgrids only have one or two generation sources, and if they fail, users who depend on this system will not have electricity until there are optimum climatic conditions for its generation.

Other problems with limited-generator systems are the difficulty of controlling frequency and voltage, which is easier on a large scale. In addition, in order to meet any demand increase at specific times, it is unlikely that the generating capacity can be increased, so demand will be limited by the availability of generation. It is this factor that brings into play the notion of energy storage.

2.3.5. Distribution

One of the advantages of a microgrid is that it does not have a transmission system, since electricity is normally produced in the same place that is consumed and electricity is usually transported at low voltages. For private and true grids, this transmission system is also used to deliver part or all of the electricity generated to the main grid.

2.3.6. Power Management System

The power management system controls the transfer of electrical power from the source of electrical generation to the devices that consume it. This management of the electric load usually requires a conversion of the electricity generated from the renewable source with an inverter that transforms the electricity to the form needed by the existing loads. This factor of the system is very important since a bad planning of this, can limit the capacity of generation or increase the price of installation and maintenance. Modern microgrid systems typically integrate intelligent counters and control systems, to manage the operation of the network in an efficient and reliable manner.

2.3.7. Electricity Consuming Devices

Group of components that consume electricity. It is important to study these devices because they will let us know the electrical demand that will be in the system, and prediction of their demand characteristics is extremely important to calculate the generation and storage capacity required by the system.

2.3.8. Storage

In order to take advantage of Renewable Energy Sources in distributed generation systems, micro-regions or distribution networks, it is necessary to study the integration of these in the most efficient way possible.
Due to the intermittent, variable and unpredictable nature of many of these energy sources, it is desirable to use storage systems to have a more robust, autonomous, reliable and competitive power generation system. As well as ensuring that there is a backup of energy, an integrated storage system allows us to supply (for a limited

time) a demand greater than that produced by renewable energy sources. In case of a possible failure of the distribution network, the microgrid can be isolated from it and can supply (again for a limited time) the loads that it has connected.
In remote microgrids, batteries are usually the only storage technology that is appropriate. The storage capacity required for the microgrid is usually not large, and alternatives such as hydro pump storage have a high initial cost and are more suitable for large-scale operations. (The Berkeley Blog, 2017) (Www2.ee.ic.ac.uk, 2017)

2.4. Planning of a microgrid

In recent years much more attention has been paid to the analysis of microgrid projects. An exhaustive study of the factors that can affect these systems in the planning phase is important: obvious factors such as electrical demand and the generation capacity of the different technologies, and also the costs of investment, social and environmental impact.(Azurza, Arranbide and Zubia, 2012)
For Microgrid projects a higher capital cost is generally required if we compare it with more conventional approaches. However, at times of high energy demand when the market price is increased, the microgrid could provide a cheaper solution than the energy purchased from the main grid. By implementing these methods, local communities could self-sustain in times of great demand by supplying local loads and gain benefit by selling excess power to the main grid. A parallel approach would be the use of storage, as it could store energy at low prices in times of excessive grid generation and be used in times of little generation when the price is expensive, thus mitigating the effects of a fluctuating price of energy from the grid.(Khodaei, Bahramirad and Shahidehpour, 2015)
For the planning of these projects it is therefore crucial to quantify the available renewable resources in the selected territory. All renewable technologies available for a microgrid depend on local climatic conditions, but their exploitation may be limited by environmental impact and costs. In many cases, the extractable amount of energy from wind is considerably greater than from other renewable sources but is likely to bring greater social and environmental impact than most alternatives.(Hafez and Bhattacharya, 2012)
The first step to carry out the study of demand is the quantification of the loads to be supplied. These loads originate from a combination of domestic, commercial and

industrial activity and in the absence of reliable measured data are notoriously difficult to quantify. Only once these loads are determined can the behaviour of the electric demand must be analysed, estimating the maximum consumption levels and the amount of energy consumed in a year. In addition, the potential growth of demand must be estimated, as any proposed installation should have be able to fulfil its purpose for many years without major modifications. .(Hafez and Bhattacharya, 2012)

After the calculation and estimation of electrical demand and the available resources, a planning strategy for the control of energy and its storage must be developed. For this, complex algorithms for control optimization are required to achieve optimum performance in the system. At present, we can observe that methods of optimization have already solved many problems coming from the integration of renewable energy systems, mainly from wind and solar sources.

Capital cost is usually of course one of the main disadvantages of the integration of renewable sources. But the continuous evolution of these technologies and the long-term rising trend in the price of fossil fuels must be considered in any long-term economic analysis. It is also necessary to introduce studies of environmental impact and potentially positive social impact of a microgrid system, such as maintenance of local jobs, generation of employment in the area, and general community welfare.(Azurza, Arranbide and Zubia, 2012)

Next, the most relevant characteristics associated with the estimation of the electrical demand and renewable potential will be studied in more depth

2.4.1. Electrical demand

The electrical demand can be classified into two different groups. The group consists of inelastic loads, which are the loads that must be supplied at all times. Examples of this may be the need to supply energy to hospitals or the demand for public lighting in residential areas. The second group consists of elastic loads, which can be adjusted and programmed depending on the moment. The priority which is given to these loads and the associated tariff structure is a complex matter, with significant social implications.(Zhang, and Gatsis and Giannakis, 2005)

For the sizing process of a distribution system or the generation technologies required for meeting demand, it is necessary to estimate energy demand in detail at all times.

To carry out this difficult task is necessary to understand how a consumer or a group of consumers behave at different times during the day, on different days of the week and over the seasons of the year. Knowledge of demand is required to define the patterns of the network, the planning of a possible new generation technology or the study of energy prices based on consumer behaviour. For this reason, anything which can improve our knowledge of demand patterns is invaluable. Unfortunately, because of data protection laws and the reluctance of commercial organisations to release sensitive information, it is almost impossible to gain access to accurate, measured demand data on the scale required for such planning operations.(Seppälä, 1996)

2.4.2. Factors affecting the electricity demand

Since there is normally no availability of direct measurements of demand in most areas, estimation is required and forecasts are made using other available information. Predictions must be made, based on the study of the various factors that can affect energy consumption. These include:

• Climate: the electrical demand depends strongly on the local climate, i.e. on temperature, solar radiation, humidity etc. The most important factor is the ambient temperature since in cold climates much of the demand comes from heating, and in very warm climates from air conditioning systems. Another example is the variation in solar radiation affecting the use of lighting equipment depending on the season of the year.

• Consumers: Characteristics of consumption depending on the scale and type of the site (domestic, commercial, industrial). Also, perhaps some sub-divisions covering type of heating, quality of building fabric, etc. Although consumption varies from one user to another, standard patterns with similar properties can be established.

• Time period: Time of day, day of the week, holidays, seasons. This factor is correlated with human behaviour considering their activities. This behaviour is usually cyclical: the demand analysis can be based on a single base day, a week or longer period.

• Historical data of demand patterns may also be followed. With knowledge of the previous demand values, it is easier to predict future demand with good precision.(Phuangpornpitak and Prommee, 2016)

2.4.3. Types of electrical demand

Depending on the type of consumption, the representation of the demand curve will have different types of forms reaching minimum and maximum levels depending on the time. It is usually represented over the course of a week since there are usually significant day-to-day variations. There are three main types of customers: industrial, commercial and residential. In the following three demand profiles are represented the electric consumption of a house, a restaurant and a factory in the period of a week.

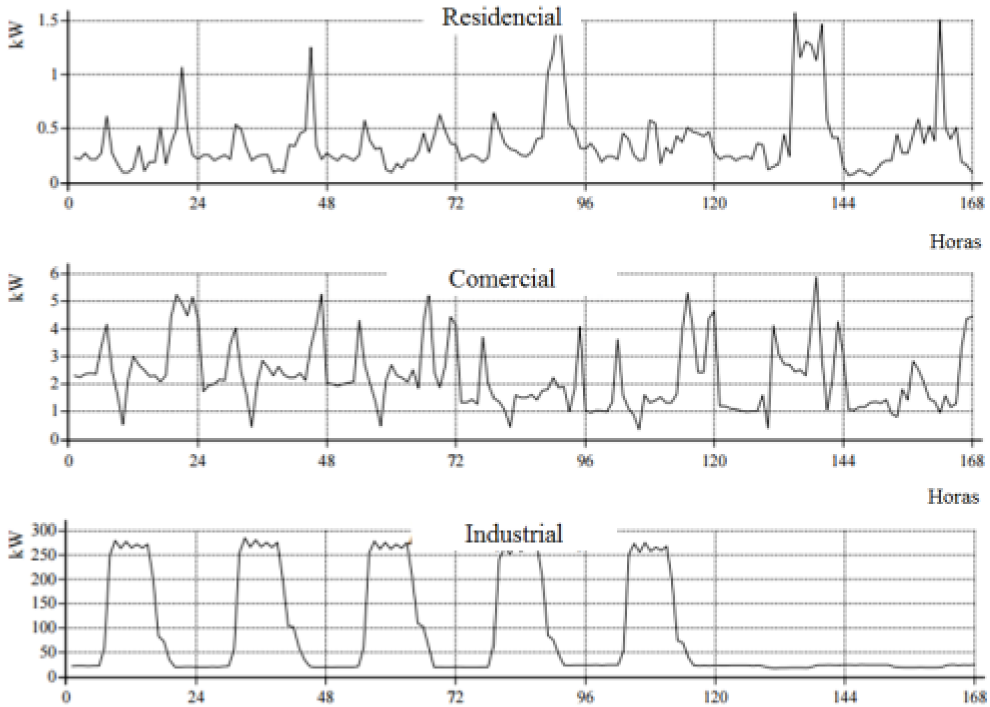

Figure 5: Representation of various types of demand profile (Seppälä, 1996)

As can be seen by comparing residential, commercial and industrial demand curves there are many differences between them.

First, residential demand: it can be observed that there is low consumption in the hours before dawn when there is no consumer activity, a rapid increase early in the morning, and the highest peak at about 6 pm when consumers reach home after the working day. In the commercial demand profile, there are peaks early in the day and again in the evening. And finally, in the industrial demand we can see a constant consumption from the first hours of the day due to the industrial activity, repeating itself the following day. In this sector as it is not working at weekends, consumption will remain at a minimum level during this period.

In rural communities, it is residential customers that are likely to have a greater relevance in the total demand.

2.4.4. Residential and commercial demand

The behaviour of residential demand is very particular, being strongly affected by socio-cultural aspects, economic activities and in certain cases, influenced greatly by the effects of seasonality, as well as the variation in the price of energy. It also depends heavily on specific aspects of consumer behaviour and lifestyle, as well as the wide diversity in the use of appliances during the day. The randomness of demand patterns depends highly on household members, patterns of presence, and the time of use of some high-consumption appliances for short periods during the day.(Sajjad, Chicco and Napoli, 2014)

In the domestic sector, demand depends not only on the number of inhabitants of a property, but also on whether the residents are in the property and whether they are active (awake); studies relate demand (electricity) profiles to the size of the dwelling and occupancy patterns, defining as an active occupant a person who is in the dwelling and who is not sleeping. On the other hand, they also indicate the relevance of having records of electrical equipment, lighting and heating systems. In a typical home, the demand base is given by basic equipment such as refrigerators, freezers, as well as microwaves and kettles.

Also in many areas due to tourism, electric demand can suffer considerable variations depending on the day of the week or season of the year, sometimes creating a real problem for rural tourism where it is normally located in remote areas. Based on the above, the need to develop models and measurement instruments has been established, allowing an approximation to the demand behaviour and its projection over time.(Richardson *et al.*, 2010) Due to these aspects, the demand curve can reach demand peaks at certain times of the day, since some hours are more propitious than others for energy consumption.

2.4.5. Demand side management (DSM)

To ensure that the system remains robust, the total electrical production capacity must be greater at all times than the maximum demand. Over the last few years, we have seen demand for electricity increasing every year and on that basis, it will be necessary to build new power plants to meet growing demand. Demand management techniques (DSM) provide a wide range of measures to reduce energy consumption. They can be implemented by a combination of variable tariffs and automated load switching. We have several DSM strategies.to soften the load peaks.

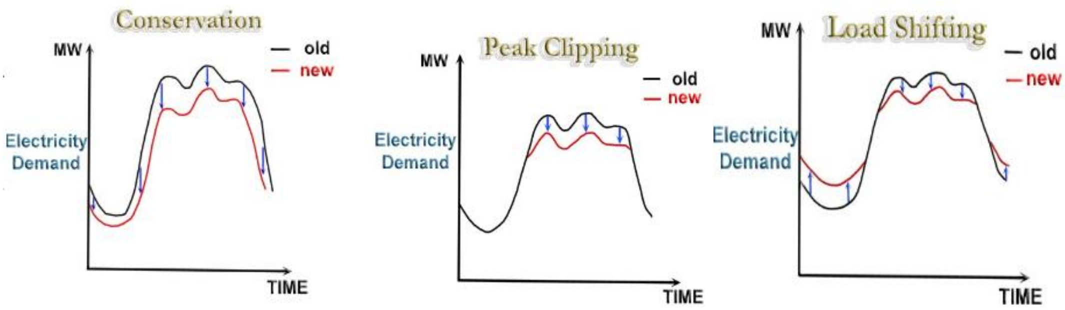

Figure 6: Representation of different measures to smooth out demand peaks (Esru.strath.ac.uk, 2017)

- ❖ Conservation Program: This program will cause consumers to reduce their electricity consumption during a full day of high energy demand.
- ❖ Peak trimming program: This program causes consumers to reduce their electricity consumption during periods of peak demand, thereby reducing the maximum.
- ❖ Load Shifting Program: This program involves both load displacement and valley filling techniques. It causes consumers to change their electricity consumption in peak periods for periods of less activity. As a result, the electric demand is reduced during peak hours, and increases in hours of less activity, thus softening the load profile. (Esru.strath.ac.uk, 2017)

2.4.6. Generation in a Microgrid. Prices trend.

A microgrid is composed of a distributed generation system, with wind and solar PV the most common renewable technologies used. In isolated areas it may require a back-up generation system (normally biomass or diesel). Using several intermittent technologies will result in a less intermittent supply (Azurza et al., 2012), but some back-up may still be necessary. The following table shows the different technologies used in microgrid, specifying if they come from a renewable source or not, the level of emissions and if they generate DC or AC.

Technology	**Source**	**Renewable (yes/no)**	**AC/DC**
Combustion	Oil	No	AC
	Gas	No	AC
	Coal	No	AC
	Biomass	Yes	AC
Solar PV	Sun	Yes	DC
Hydraulic	Mechanical energy water	Yes	AC
Wind energy	Mechanical energy wind	Yes	AC

Table 2: Summarizes technologies according to source, and type of electric power generated

Photovoltaic solar energy is the most widespread option worldwide for a small-scale energy system. The increasing size of the market and the on-going improvements in manufacturing efficiencies will make them a more attractive for the future.(Pasonen and Hoang, 2014)

Solar installations are frequently combined with wind turbines, particularly at community level. The steady development of these technologies has led to the design and implementation of control systems capable of integrating them efficiently under different climatic conditions, considering their intermittent behaviour. (Shen and Izadian, 2014)

Having a microgrid with different types of sources of generation with different characteristics, provides of an advantageous complexity. As each technology has different behaviours and different capacities of generation, they will be able to complement each other,(Electrical and Engineering, 2015) as the combination of several generation sources helps to mitigate intermittent supply, helping to reduce the need for energy storage.

PV and wind installation prices trend

The price of solar panels has fallen in recent years as its technology and production methods have matured. Seven years ago a 4kW installation cost around £15,000 - £ 16,000, but now, the price has dropped to £6,000 - £8,000. This price is for domestic facilities with low capacity. The price currently for larger, say 100kW solar installations will be £1,500 - £2000 for each installed kW. For larger capacities, this can be reduced further as shown below.

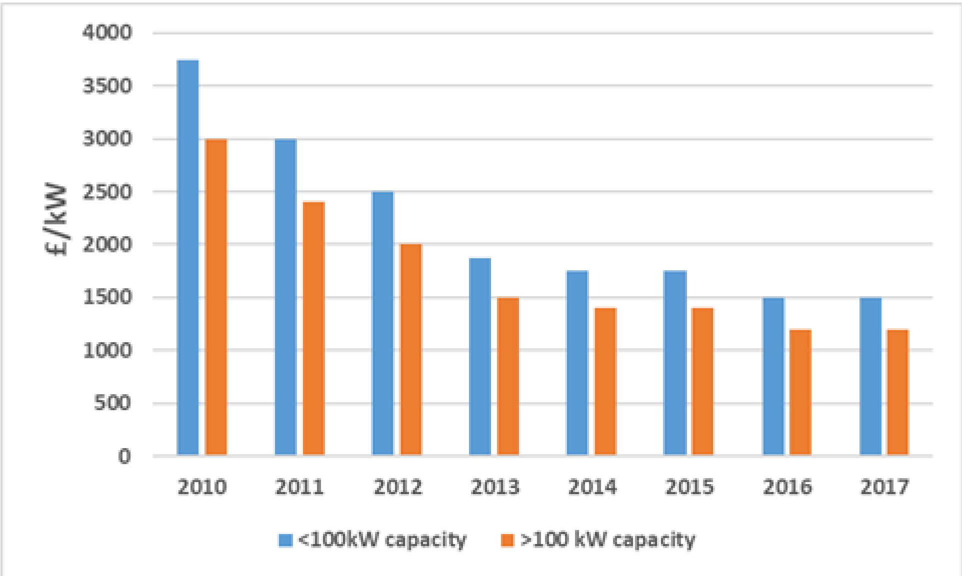

Figure 7: Price trend of photovoltaic energy per kW of installed capacity (Theecoexperts.co.uk, 2017)

The price of PV per installed kW is still descending, and the potential remains for significant further reductions. (Theecoexperts.co.uk, 2017)

The final price of a wind turbine depends on factors such as turbine capacity, maintenance, project location, contracts and warranty issues. The price of a 2 MW wind turbine is approximately £2.1 million, but for a 10kW capacity machine is approximately £22,000, so price per kW installed is greatly affected by scale. In addition to this initial price, there are other costs that can significantly increase the final price, such as network connection costs, transport to the place of installation, and the foundation of the structure. Costs have fallen steadily in the last 30 years, but are levelling out. (Conserve Energy Future, 2017)

2.5. Storage technologies

The promotion of increased energy storage capacity in a microgrid system will enable a greater integration of renewables, avoiding undesirable wastage of clean energy in low demand periods, and at the same time will provide more security to the electrical system. As a tool for the operation of the system, the most widespread technology today is Hydro pumped storage, although we increasingly in the future, will tend to use small-scale storage in the shape of the batteries of electric and hybrid vehicles. Batteries are likely to find increasing usage to complement solar PV installations.(Isabel and Molina, no date)

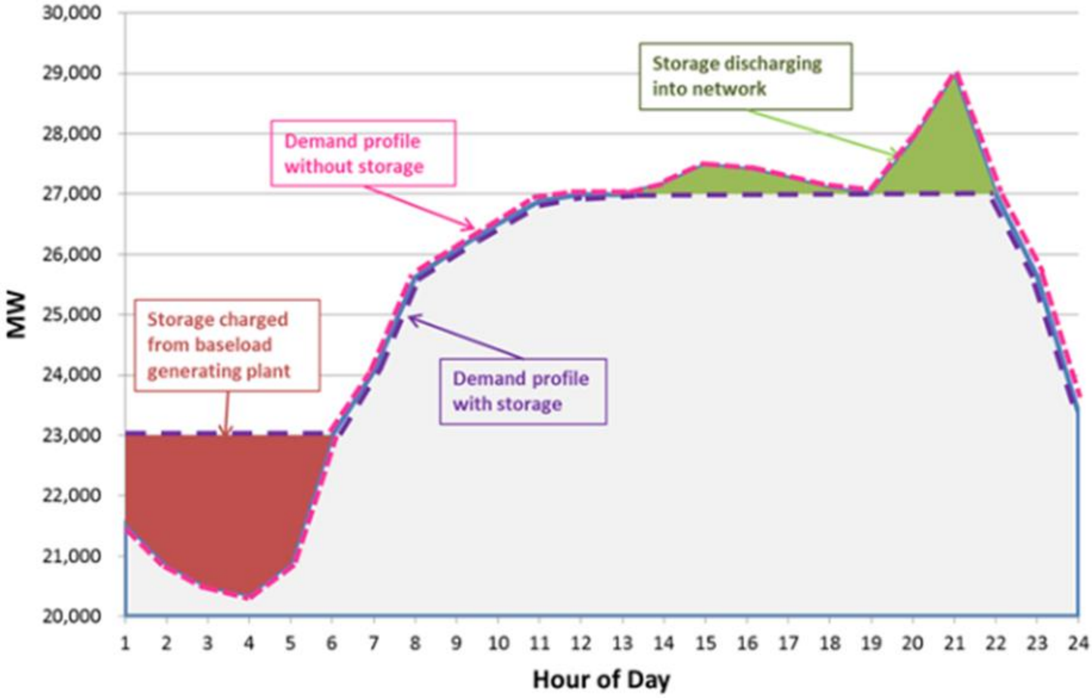

Figure 8: Representation of the change of the demand profile using storage over a day

On a large scale, if you have large energy storage systems that can absorb the energy produced by wind and wind farms, they can be used to store the energy produced by renewable technologies in times of low electrical demand (red area) and deliver at times where the energy demand is greater (green area).

Below are briefly described the different storage technology groups that are currently available. For the present project, a fuller description will be made of electrochemical storage technologies studying the yield, energy density, cycle and life expectancy, capital cost, maturity, and environmental impact. The remaining groups of storage technologies are not so relevant for the present project due to the technical difficulty of their implementation, but they have been presented in order to show the context.

2.5.1. Mechanical storage

Flywheels

These devices consist of a flywheel that rotates at very high speed and an integrated electrical device that can carry out motor functions to turn the wheel and thus store energy, or as a generator using the kinetic energy stored in the wheel.

Its efficiency is of course reduced by friction during its operation. Therefore, the challenge of increasing efficiency in this system is to reduce this friction. Two mediations are performed to achieve this: the first will be to let the wheel turn in a vacuum, as this will avoid the friction of air; and secondly the rotor is carried on electromagnetic bearings. The typical rotational speed of a modern flywheel can be up to 16,000 rpm and can store up to 25 kWh, which can be created and consumed almost instantly.(Joseph and Shahidehpour, 2006)

Figure 9: Representation of the components of a Flywheel (Oberhofer, 2012)

Compressed Air Energy Storage (CAES)

This technology has the ability to store energy in the form of a compressed gas (normally air), pumping it into large storage tanks or into natural underground formations. This stored energy is released during periods of high demand, passing the compressed gas through a turbine. This is currently receiving special attention as a solution to address the intermittent problems of renewable technologies.(Gardner, no date) (Sc.ehu.es, 2017)

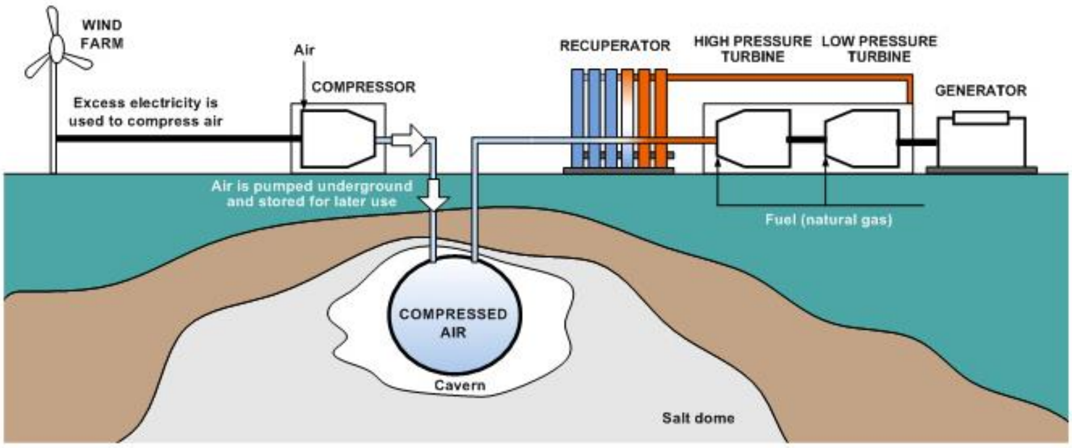

Figure 10: Possible configuration of a CAES system (Sc.ehu.es, 2017)

Pumped Hydro Storage

Pumped hydroelectric storage (PHS) is the most widely used model for large-scale storage. Energy is stored as potential energy by pumping water from a lower reservoir (1) to an upper reservoir (2). It is activated when there is an excess of energetic generation coming from renewable energies. The energy is released by running the water back down through a turbine in times of high electrical demand.

For these installations a significant change of elevation between the two reservoirs (head of water) and the ability to store a large volume of water is required, limiting the potential for widespread replication.(American Society of Civil Engineers, 1996)

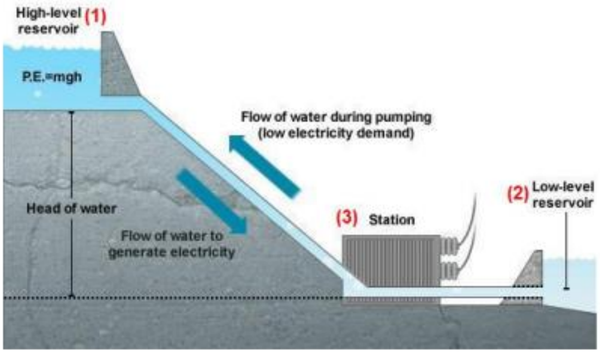

Figure 11: Hydro Pump Storage Operating System (American Society of Civil Engineers, 1996)

2.5.2. Electrochemical storage

The last group of technologies is electrochemical storage. These will be studied in more depth since there is a special interest for microgrid applications and therefore for the present project. The devices may be divided into two groups: solid state batteries, and flow batteries.

Solid State Batteries

Conventional batteries are still the most commonly used tool in small-scale storage today. These batteries consist of parallel or series connected electrochemical cells that create electricity from chemical reactions. In these, there are three clearly differentiated parts: the electrodes, negative (anode) and positive (cathode); the separator; and the electrolyte. In an external circuit of the battery, in the process of discharge the electrons circulate from the anode to the cathode, and in the opposite direction during the charging process. The two types of batteries most used in this group are lithium (Li-Ion). And lead-acid (Pb-acid).

The major problem facing these batteries is that they are quite sensitive to charging and discharging cycles and environmental conditions. So far, the most widely used generators have been lead-acid batteries since they are technologically mature, inexpensive and do not require very complex maintenance. Their disadvantages are limited life expectancy, and performance.(Jones *et al.*, 2012)

Lead acid batteries are the most common rechargeable batteries; they are very widely used because of their low cost. Until recently they have been the automatic choice for

small-scale applications. They are composed of several individual cells containing lead alloy plates submerged in an electrolytic solution. (Art, 2012)
In these batteries, the active components are lead (Pb) in the negative plate, and in the positive plate lead dioxide (PbO2); a solution of sulphuric acid (H2SO4) in water as electrolyte is used. Here we can see the reactions during discharge and charge.

$$PbO_2 + Pb + 2H_2SO_4 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftarrows}} 2PbSO_4 + 2H_20$$

Equation 1:Chemical reactions within a lead-acid cell (Dietel, 2011)

As the main advantages of this type of battery we can emphasize its maturity, the low cost in both installation and maintenance, and is able to supply high currents. However this technology is environmentally unfriendly as these batteries are composed of highly toxic materials for the environment. In terms of performance, their energy density per unit volume or weight has been surpassed by more recent battery types.(Browner, 2013)

Lithium (Li-Ion) batteries.

In recent years their use has been boosted due to the explosion in market demand for portable electronic devices, especially the laptop and cell phone. These batteries have seen rapid improvements in their manufacturing processes and the introduction of new materials to separate the cathode and the anode, giving a higher energy density and reduced costs.
Their applications are broad, with an increasingly important (in fact dominant) role in hybrid and fully electric cars. It is this application which in recent years has been attracting the attention of research and development teams, and further driving down costs.(Brodd, 1990)

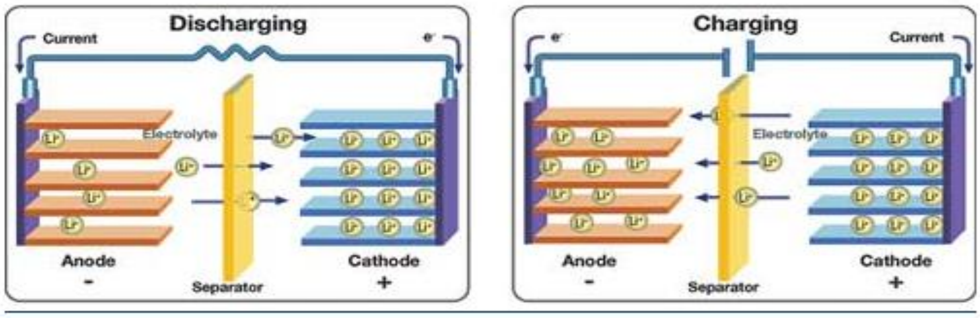

Figure 12: Representation of the operation of a Lithium-ion battery (Research & Development, 2017)

As before, these batteries are composed of one or more generating cells. Each is composed of three components: a positive electrode, a negative electrode and a chemical electrolyte. The positive electrode is composed of cobalt lithium oxide ($LiCoO2$) or lithium iron phosphate ($LiFePO4$). The negative electrode is composed of carbon (graphite) and the electrolyte varies from one type of battery to another.

During the charge of the battery, the positive electrode gives the electrolyte part of its lithium ions, which move through the electrolyte to the negative electrode and remain there. In the process of discharge the reverse operation occurs.(Oswal, Paul and Zhao, 2010)

2.5.3. Flow batteries

Flow batteries are batteries which have an electrolyte, which contains one or more electroactive species, and flows through the electrochemical cell that converts chemical energy into electricity. Additional electrolyte from external tanks can be added by pumping them into the cell stacks.

These batteries have the capacity to recharge in a small interval of time by reversing the redox reaction or replacing the electrolyte. Therefore, the energy capacity of the battery depends on the volume of the tanks. The type of commercial flow battery most used is vanadium(Corporation, Municipal and District, no date)

Vanadium batteries use vanadium redox pairs dissolved in sulphuric acid-diluted mixtures, eliminating contamination in the diffusion of ions from one part of the membrane to the other, rendering the electrolyte life uninterrupted.

In the negative electrode is located the pair V2 + / V3 + and in the positive the pair VO2 + / VO2 +. Advantages of these batteries are the high speed of charging and discharging, and the ability to provide high power (more than double their rated power) for short periods of time. Their handling is very safe and efficiency is of the order of 85%.

The disadvantages of these batteries are the complexity of their system when compared to other technologies, and low energy density by volume. This low density leads to the need for more cells to obtain the same power as other batteries. Due to the need for circulation of large quantities of electrolyte with pumps its application to the transport sector would be problematic.

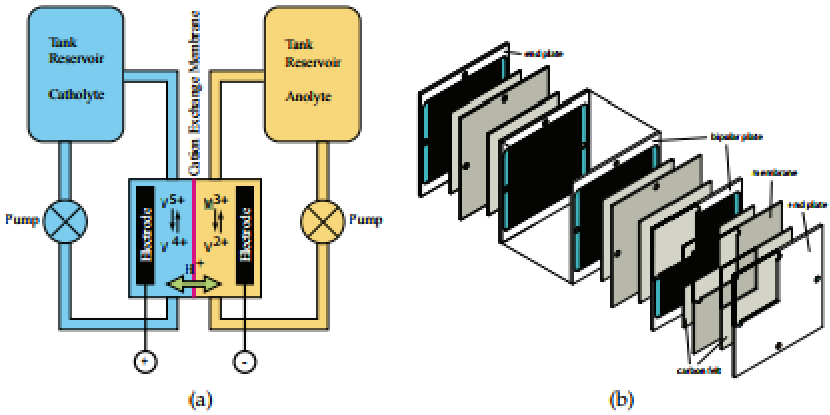

Figure 13: Representation of the performance of a vanadium flow battery (Blanc and Rufer, 2010)

The surfaces in contact with the catholyte are coloured in blue and in orange for the anolyte. (Blanc and Rufer, 2010)

2.5.4. Price trends in batteries

In recent years the characteristics of the batteries are improving technically, and also economically. This is evident as the price per kWh has been falling drastically in recent years. The decline in price is linked with increased competition among manufacturers to increase their market share. Figure 14 shows predicted price trends for a range of electrochemical battery technologies.

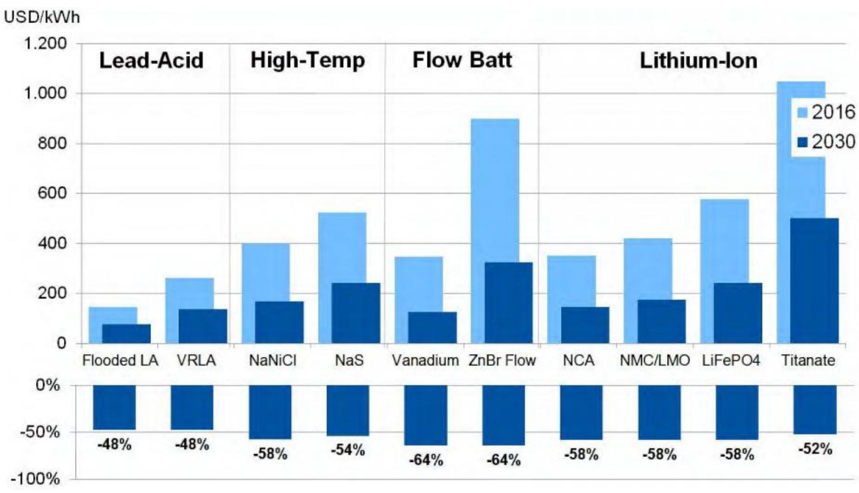

Figure 14: Price Trends for Different Battery Types (Renewable, Agency and Kairies, 2017)

It is noted that lead-acid batteries remain the cheapest, with LA's flooded batteries at only $180/kWh. These are followed by flow batteries, with vanadium batteries priced at $340/kWh in 2016 and predicted to fall in the price by 2030 by 64%. Slightly more expensive are lithium-ion batteries, but again prices are predicted to fall by 2030 by more than 50%.

2.6. Legislative and economic framework of self-consumption in Spain

There are two economic aspects to be considered when talking about self-consumption:

2.6.1 The remuneration of the surplus generated by the self-consumption.

Depending on the amount of energy that is paid, and the way to compensate the energy generated with the energy consumed, the following schemes are distinguished:

- Sale of surplus: the energy generated is paid through a regulated tariff (feed-in-tariff)
- Spill of surplus: there is no remuneration for the energy discharged to the network on consumption

- Net balance: all the energy generated is added up and all the energy consumed is subtracted over a period of time. If the figure is positive, the surplus can be remunerated at a set price

2.6.2. The contribution of the self-consumer to the costs of the system.

As specified in Law 24/2013 of the Electricity Sector, in Spain there are two categories of self-consumption: in the first category, there will only be one subject destined to own consumption, and this subject will not be in the register of production facilities; in the second category, there will be two subjects, the consumer and the producer, and the installation should be properly inscribed in the production registry.

The first category of self-consumers will have a contracted power limit of 100 kW and will not be able to receive economic compensation for the energy generated and not consumed. For the second category, there is no power limit and they will receive an economic consideration for the discharge schedule of energy to the network, according to the current regulations, although they must pay any generation toll corresponding to said energy.

When a consumer wants to become a self-consumer, they must consider the amount of energy consumed and surplus energy generated by the installation, since for each self-consumed kWh the variable costs of electricity will be saved (tolls and charges, energy cost and associated taxes), whereas for each kWh of surplus, the income received will be inferior since it will reflect only the price of the energy in the market. Since the necessary investment is proportional to the installed power, there will be an incentive to maximize self-consumption and minimize the excess. (PwC, 2015)

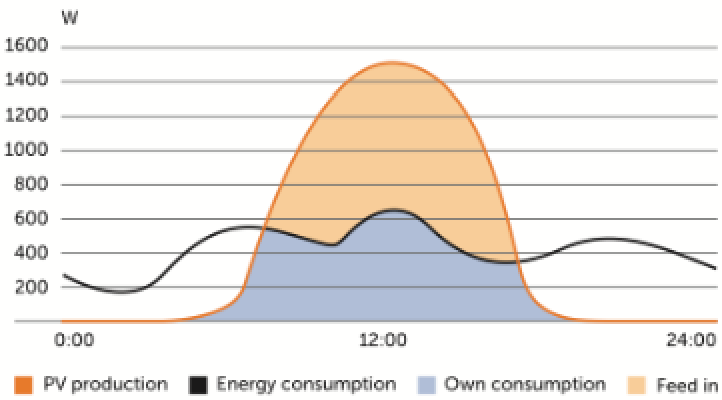

Figure 15: Representation of demand, generation and surplus on any given day (PwC, 2015)

3. Location chosen for the case study

3.1. Climate in Spain

Spain is located in a centre of atmospheric circulation with different conditions in the North and South. It is in a temperate zone, not being a zone of mixture between volumes of hot and cold air, therefore the climate is not homogeneous, and is very varied depending on the latitude or the orography. Therefore, we will have places with mild temperatures, not exceeding 15 ° C, and also others that exceed 40 ° C, usually in summer (increasing from north to south), sites with a humid oceanic climate with annual rainfall exceeding 2500mm, and sites with a Mediterranean desert climate with rainfall that does not exceed 200mm annually, as in Cabo de Gata, with 150mm annually. However, there are a number of general features that can be summarized in the following points:

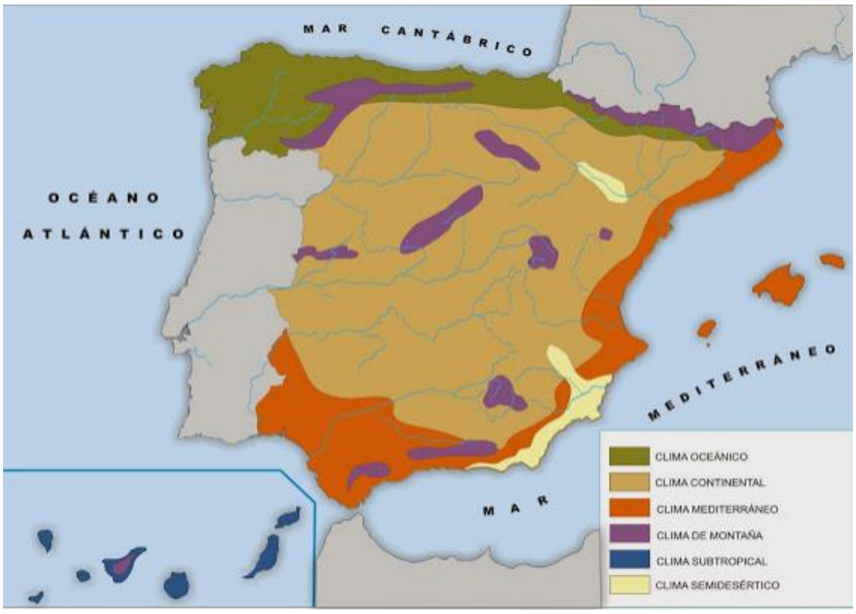

Figure 16 Representation of the different climates in the Spanish geography (Francisco, 2017)

The map above shows the six different climates found in Spain. The predominant ocean climate is found in Galicia, the Cantabrian coast and the western part of the Pyrenees with characteristic temperate temperatures and frequent rainfall throughout the year.

The continental climate covers a large part of the country with large temperature differences between winter and summer: summers are hot and winters are very cold. There is always frost in winter (to reach temperatures below 0 ° C) and usually few rainy periods.

The Mediterranean climate in the eastern part of the country on the shores of the Mediterranean Sea is characterized by dry and hot summers, with average temperatures above 22 ° C and wet and rainy winters with mild temperatures.

And finally, there are the mountainous climates that predominate in areas located more than 1,200 meters above sea level, as in the Pyrenees, Sierra Nevada, and Picos de Europa. Their general characteristic is very low temperatures in winter and mild conditions in summer, with strong precipitation that increases with altitude generally in the form of snow. (Francisco, 2017)

The mountain climate is marked by a variety that is highly influenced by altitude, which causes two clear effects on the climate corresponding to the area in which the mountain is located. The altitude causes a drop in temperatures: for each 1000 meters of ascent, the temperature will be 6º reduced, so at 2000 meters altitude there will be 12 ° less than at sea level. This climate is explained below in more detail since it is the area where our project will be located.

3.1.1. Climate of Sierra Nevada

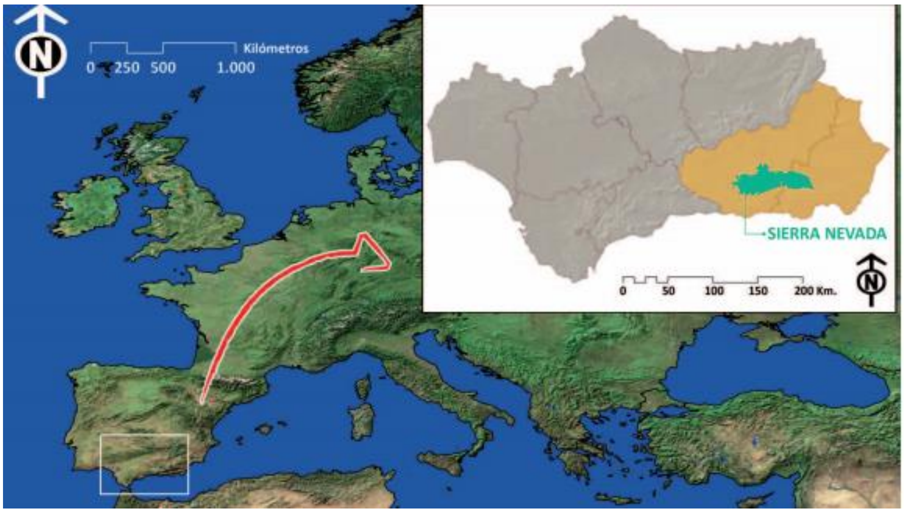

Figure 17: Location of Sierra Nevada

Sierra Nevada is a mountainous group belonging to the Betics system, specifically the penibetic system. This is located mainly in the province of Granada. It is the second highest mountainous massif in Western Europe, following the Alps. Its maximum altitude is reached in the peak of Mulhacén, at 3.482 meters above the level of the sea. Our specific location for this project is in a lower area near this peak)

Sierra Nevada is a clear example of Mediterranean ecosystems with high mountains. In summer the rainfall is minimal, while in winter rainfall is almost exclusively in the form of snow from 1600m above sea level. It receives the strong insolation characteristic of the Mediterranean zone in which it is. The factors that determine its enormous climatic diversity are its altitude, latitude and the topography of the landscape.

The altitude tends to produce an increase of the insolation as it rises and causes thermal fluctuations of great importance: below Capileira (1496 m altitude), the annual average temperature oscillates between 16 and 12 ° C, and above 3,000 m is less than 0 ° C. The northern slope is colder than the southern slope due to its lower insolation and greater exposure to the north winds. The winds are maximum in autumn on the south slope with southwestern winds. Another maximum is in spring on the northern slope, which has a strong influence from the North Atlantic with north and northeast winds

In summary, the altitude of Sierra Nevada presents unusual characteristics; in the middle-high parts (where the project is centred) the air cities is clean and transparent, so the radiation is more intense, and the air temperature is lower; it therefore presents optimum characteristics for photovoltaic energy.

It will also be favourable for the installation of wind energy due to the frequency and intensity of the winds, increasing with altitude and reaching maxima of 200 to 250 km/h in the high summit.(Nevada, no date)

3.1.2. Project Location

Capileira is a Spanish village located in the southern part of the province of Granada in Andalusia. Its municipal region occupies the surface area of 56.9 km².

Much of its municipal region belongs to the National Park of Sierra Nevada, reaching up to the peaks of the Veleta and the Mulhacén, roof of the Iberian peninsula. This village sits as the second highest town above the level of the sea on the peninsula. All of the municipality is also part of the Historic Set of the Barranco del Poqueira.

The slope in the terrain sometimes reaches gradients of 40%. For a long time the main sources of income came from livestock and agriculture taking advantage of a peculiar system of cultivation called terraces, necessary due to these extreme slopes of the landscape. Its population passed from being 3000 inahabitants in the 1950's to about 500 that currently live permanently in this village. The main factor that caused this fall in population was the general rural exodus in the 1970's towards cities; today its population is stable.

This village is situated in the upper part of the Poqueira valley, on the southern slope of the Sierra Nevada. During recent decades tourism has begun to emerge in the local rural economy, and today it gives the main economic source. Many tourists come to be able to rest away from the hustle and bustle of urban centers to enjoy activities such as hiking. Therefore, despite having very little population, the village can duplicate and even triple its population at the time of vacation periods and weekends. (Citypopulation.de, 2017)

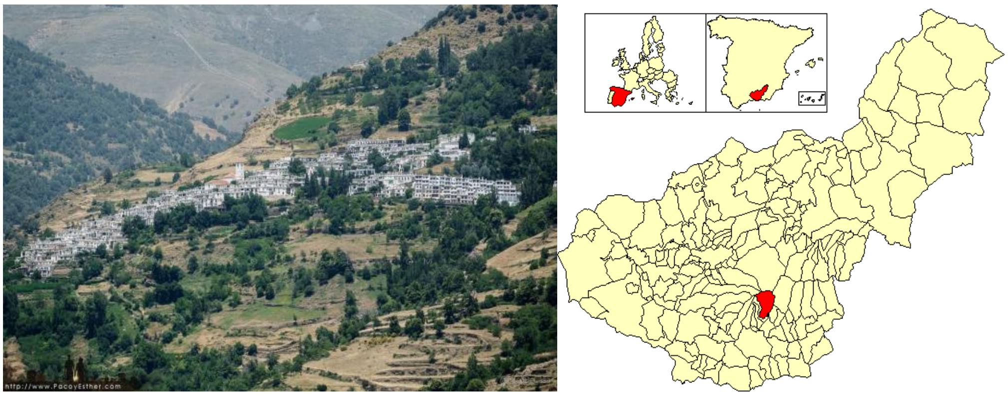

Figure 18: Picture and Location of the village of Capileira

In recent years this village has gained a reputation for sustainable tourism: the inhabitants have promoted measures such as the maintenance of architectural aesthetics. These measures have led to Capileira being declared a Historic Artistic Set, in addition to being mentioned by the Council of Europe as a model of popular architecture. Now this town would be willing to take a step towards an efficient system of electric self-consumption, as long as it does not damage the overall status of the village.

4. Electrical demand prediction of the village of Capileira

For an optimal analysis of a distributed system, a study of system loading is an essential first step since it will influence the capacity of the system as a whole.

In Spain, there are in many cases (mainly for large cities) published data of electrical demand. But often for remote locations, as is the case for the town of Capileira, the demand data are restricted to the public, leading to the need for their estimation. The most widely used methods in these cases are surveys. For the study of electrical demand, three steps were taken:

- Differentiation and quantification of loads.
- Study of the monthly, weekly and daily average demand of each load
- Survey the population on trends in consumption.

4.1. Differentiation and quantification of loads.

Taking the information from the council of Capileira, at the town there are registered 196 habitable houses which are inhabited permanently by almost 3 people on average. 15 restaurants and 6 hotels of 40 rooms on average. All the loads able to consume in the village are summarized in this list:

- 196 Habitable houses
- 15 Restaurants
- 6 hotels
- City Hall together with the school
- Street lighting

A survey (appendix I) was carried out to determine how the people were settled in the town, this survey was aimed at homeowners, homes, restaurants and hotels. It was performed with the clear objective to estimate at any moment what was the electrical demand of the town.

The survey began asking all homeowners whether they have electric heating in their homes or other types of heating such as gas or biomass, as this would drastically change the electric demand in the winter months. The answer was that in 126 homes electrical heating is used, while the remaining 70 used other type of technology being usually biomass. In the case of the owners of restaurants, hotels school and council, all responded that they used gas heating.

4.2. Consumption from each load

The next step was to ask homeowners with electrical heating the average consumption for each month (they were asked for bills from the supply company); the same process was followed with homeowners without electrical heating; also for owners of restaurants and hotels. In order to obtain this data for public lighting, the school and the city council buildings, information was obtained from city council workers. Taking the data of the average electric demand in kWh in each month of each load base were all compiled in Table 3.

KWh	**Public Lighting**	**House with Heating**	**House without Heating**	**Hotel**	**Restaurant**	**School and council**
Jan-2016	2500	205	158	8750	2080	3650
Feb-2016	2300	190	148	8600	1900	3550
Mar-2016	2150	160	148	8340	1700	3430
Apr-2016	1700	157	147	7300	1650	3390
May-2016	1400	150	147	6300	1400	3300
Jun-2016	1100	145	145	4500	1450	1500
Jul-2016	1100	143	143	4200	1346	250
Aug-2016	1150	142	142	4350	1299	220
Sep_2016	1200	146	146	5250	1458	1890
Oct-2016	1250	148	148	5995	1512	1910
Nov-2016	1700	151	151	6750	1876	2105
Dec-2016	2350	155	155	8100	1899	2750

Table 3: Monthly electric consumption (bill from the company supplier)

The highest load is for the hotel reaching a peak of 8750 in January 2015, following by school and the council, lighting, restaurant, house with electrical heating and without electrical heating. Although the houses per unit are the loads that consume the least, the whole is the second load of the village after the group of hotels.

4.3. Study of the monthly, weekly and daily average demand of each load

4.3.1. Load of the Houses

Having the average consumption based on kWh of a base house makes the assumption that all the houses with electrical heating due to their similarity will consume the same amount. Therefore, knowing that there are 70 homes registered in the village we multiply the demand for this base home for the 70 homes. The same speculation is made for the 126 homes without electrical heating obtaining the data represented in Figure 19.

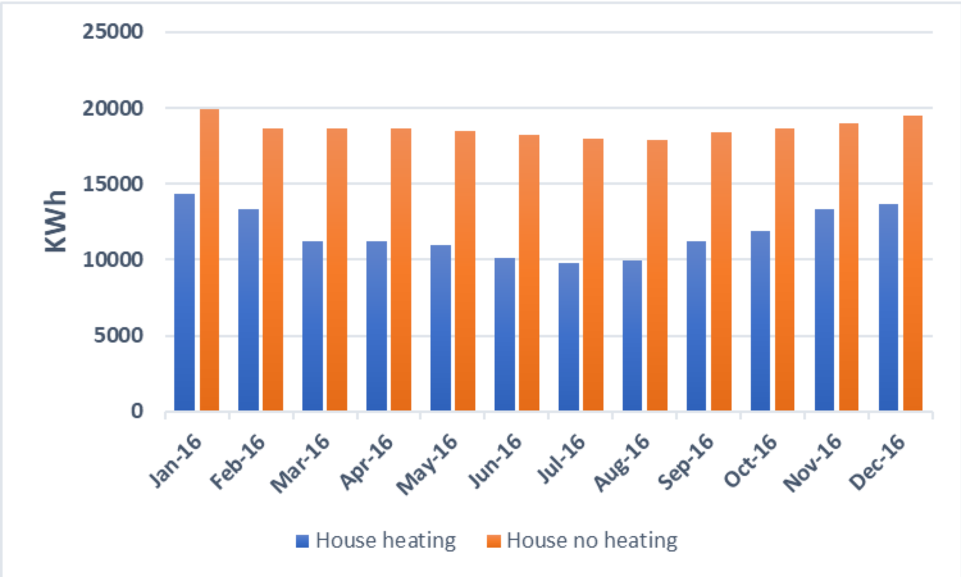

Figure 19: Electricity consumption Houses

It is observed that in spite of the fact that the houses with electrical heating consume more electricity than the ones that do not have, in the global computation, the group with electrical heating consume more electricity because there are more of them. The peak demand from the group of houses with electrical heating exceeds 14.000 kWh in January, however this figure is surpassed by the demand of the group of houses without electrical heating that almost reaches 20.000 kWh, also in January.

4.3.2. Load of hotels and restaurants

The same steps were taken to estimate the demand of the group of restaurants and hotels in the village. Therefore, we estimate the total demand of each month multiplying the average demand of each month of the base hotel by the number of hotels existing in the village. The same procedure is applied for the demand of the 15 restaurants obtaining the data represented in Figure 20.

Figure 20:Electricity consumption hotels and restaurants

As already mentioned, the load with the most demand is the group of 6 hotels which exceeded 50,000 kWh during December, January and February, with only half that demand in the summer months because tourists choose other places like the beach. The same effect can be seen in the total demand of the 15 restaurants that reach peak demand again in the month of January of more than 30.000 kWh.

4.3.3. Electrical demand School, Council and public lighting

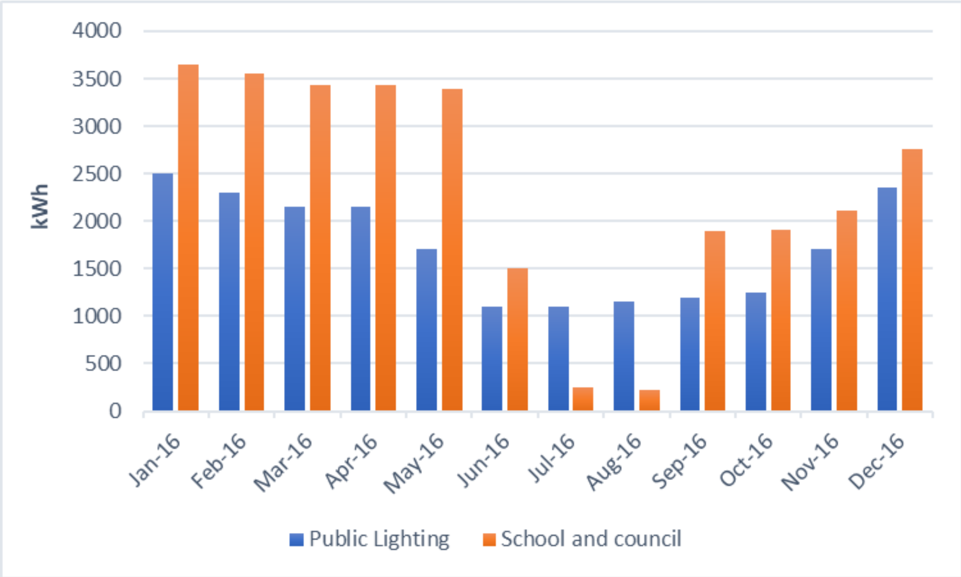

Figure 21: Electricity consumption Public Lighting, School and council

In the demand of the school and the town hall, there is a significant fall in the month of June reaching minima of 200 kWh, because during the summer months the school closes completely and the activity schedule of the town hall is reduced to only 3 hours per day instead of 8 hours.

The demand of the electric lighting shows the expected great difference between the summer months and the winter ones.

4.4. Total electrical demand

Having finished this step and having estimated all the total loads we proceed to calculate the average total demand for each month obtaining the following data represented in Figure 22.

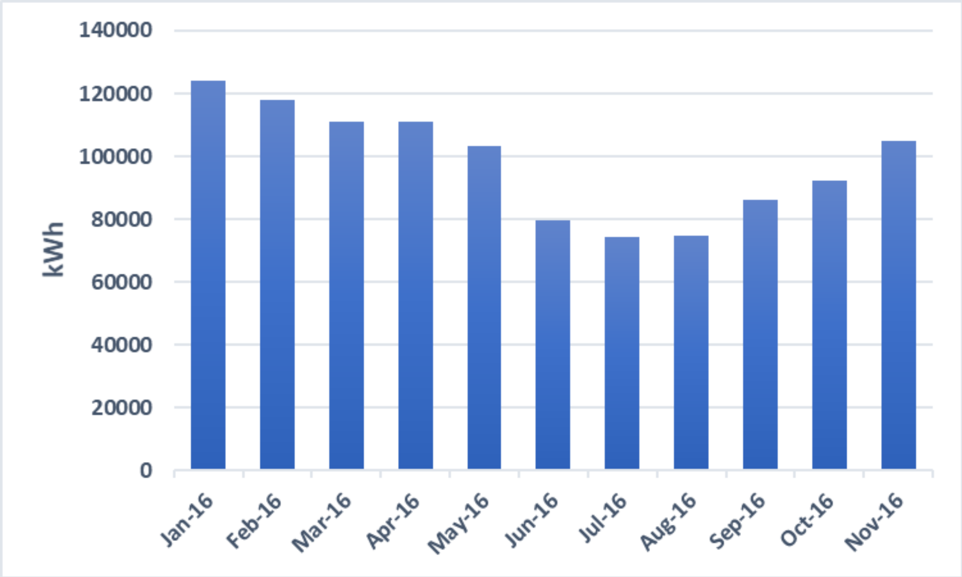

Figure 22: Total monthly electricity consumption in the village

As expected, a peak demand was in January, this exceeds 120000 kWh. It is evident that the demand curve of this village is absolutely dependent on two factors.

- ❖ The first is tourism, since this village depends absolutely on this economically, and in times of high season occupancy in the town increases more than double, evidently increasing electricity demand.
- ❖ The second is simply the mountain climate difference between summer and winter. In winter demand will be increased for heating systems, while in summer there is no requirement for heating or air conditioning. In addition, lighting systems will be operating for more hours, due to the fewer hours of daylight.

4.5. Electrical Average demand per day

In order to be able to run HOMER it is necessary to obtain the demand curve on a base day hourly basis. Having estimated the amount of kWh spent in each month, we proceed to estimate how many kWh is consumed on average on one day of each month. The electric demand of each month will be divided by the number of days of each one. This data is represented in Figure 23

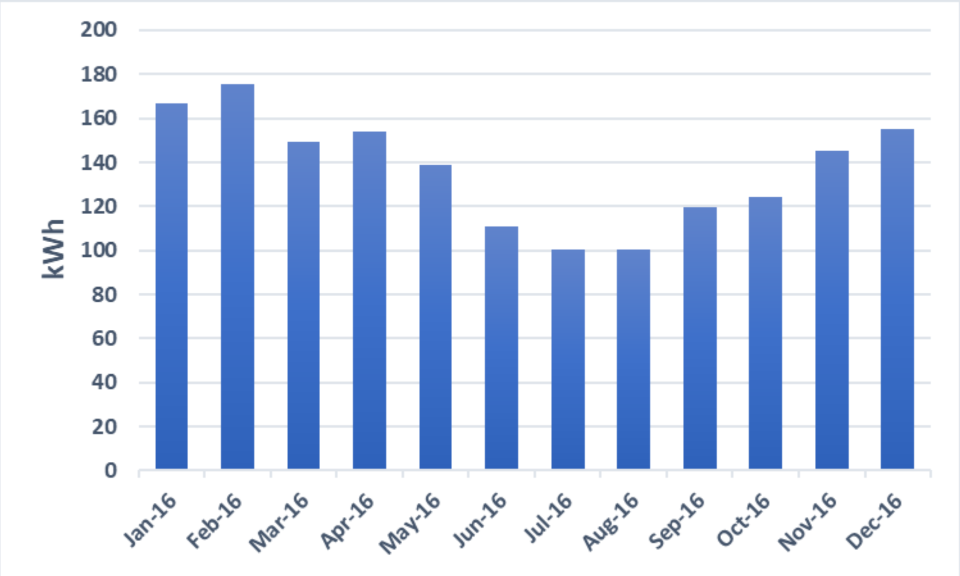

Figure 23: Daily average electric consumption of the village

Note that the month with more kW per hour spent average is now February, the reason being that February has only 28 days, three less than January.

4.6. Population survey on trends in consumption.

Getting the kWh consumed on average in a day, might suggest that demand would be constant throughout the month. However, this is not real, because the demand depends on the activities in the village. It can vary depending on the day of the week (if it is weekend hotels and restaurants are busier) and depending on the time of day.

Therefore, we proceeded to make another survey:

- ❖ For homeowners asking when are the most active moments of the week. The answer was that almost all the activity in the housing was carried out at the beginning of the day, at noon for lunch, and especially at the end of the day until approximately midnight. They also concluded that they consumed more on weekends because they spent more time at home.

- For the owners of restaurants and hotels, certainly the most active moments were in the early hours of the morning and at night, increasing activity twice as much on weekends.
- The school and the town hall had a more or less constant demand from 9 to 2 in the afternoon.
- And the lighting was constant in the night hours.

In general, it was concluded that considering all loads, Saturday was the day with the most consumption throughout the year obtaining the percentage of 20% of the total demand of the week, followed by Friday and Sunday with the same consumption approximately of 15%. It was also observed that the day with less consumption throughout the year was Monday with a steady rise until Thursday. Figure 24 shows the percentage of consumption day by day throughout the year.

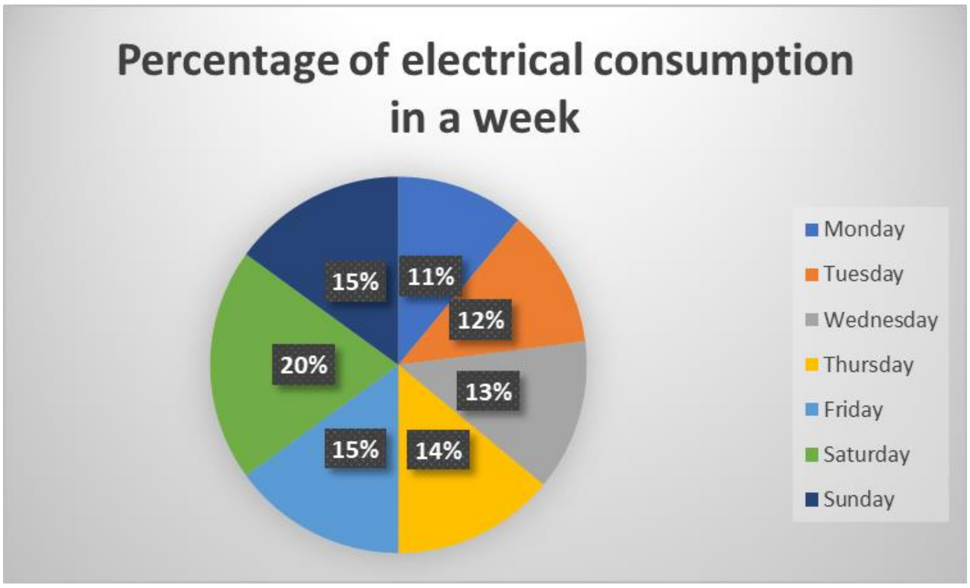

Figure 24:Percentage of electricity consumption on different days of the week

4.7. Electrical demand profile of Capileira

Knowing that the month that is consumed the most is February, and the one that is least July, and making assumptions following the survey, proceeded to estimate the curve of the demand for all the months of year in three different situations:

- ❖ On a Saturday when the capacity of hotels and restaurants is complete and therefore the consumption is the maximum in the village reaching 20% of the weekly consumption
- ❖ On a Monday when the consumption is the minimum in the village, since the hotels and restaurants are operating to their minimum capacity, reaching only 11% of the general consumption.
- ❖ On an average day assuming that the same amount of electricity was consumed every day of the week.

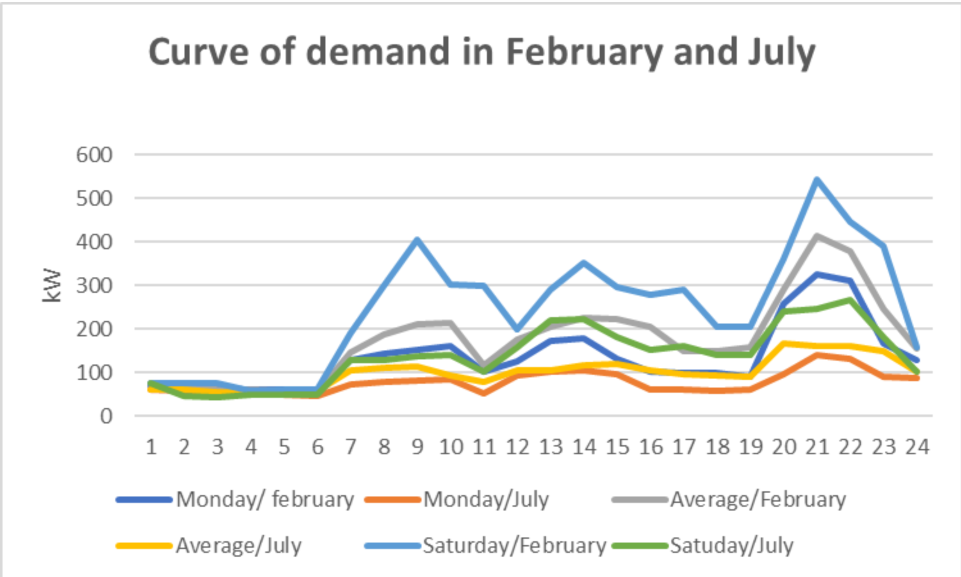

Figure 25: Demand curve depending of the day

As expected from the survey consumption in the early morning is minimal since there is no activity (public lighting plays an important role here), but at 7 am due to the activity of people in hotels, houses and restaurants the curve shows an increase, until 10 am when it descends again, climbing again at noon with activity in restaurants. But the most significant peak in consumption occurs at 9 pm on a Saturday in February, reaching the highest consumption of the year of 543 kW (light blue demand). The curve with lowest demand occurs on a Monday in July when hotels and restaurants do little trade, and the village does not require much electricity due to the good weather.

5. Selection of HOMER Pro Software

After a review of all the software currently available to model hybrid energy systems and their capabilities, it has been decided to carry out the simulation exercise with the HOMER software.

5.1. Homer definition

HOMER (Hybrid Multi-Resource Resource Optimization)(Hafez and Bhattacharya, 2012) analyses the operation of a system calculating the energy balance of 8,760 hours in a year. For each hour, HOMER is able to measure the electrical and thermal demand with the generated energy coming from the chosen set of components, calculating the flow of energy existing between them all. In the event that batteries are used in the system, HOMER details the times of charge or discharge. HOMER analyses the energy balance for each combination of the system being planned. (Homer Energy, 2015)

To carry out system modelling, the user selects a group of components with their technical and financial information. Once this step is done, HOMER simulates the operation of the system by calculating the energy balance for each hour of the year, comparing the demand with the energy generated in the system. Finally, HOMER performs sensitivity analysis on different factors such as wind speed, solar radiation, or the life of the system components.

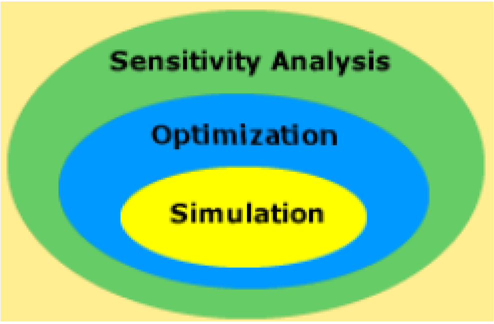

Figure 26: Function of HOMER (Homerenergy.com, 2017)

HOMER Simulation algorithm

HOMER simulates, optimizes, and performs a sensitivity analysis on micropower systems as follows:

5.1.1. Simulation

In this phase, the combination of the system is proposed. It is planned to configure the loads, the different components, the natural resources on which they depend and the limitations of the system. Once all the components are combined, the electrical and thermal demand for each hour is compared with the generated energy for the system.

5.1.2. Optimization

In the optimization phase, HOMER identifies the best possible combinations of the system, taking into account the economic feasibility, and calculating the net present cost (NPC). The NPC is calculated by summing all costs and revenues over the entire useful life of the system taking into account the cost of capital, replacement cost and the cost of operation and maintenance of system components, using the discount rate for the calculation of future flows. Time simulations are done, for each possible combination of the system, finding the solution with the lowest NPC since that will be the most optimal.

Optimization also calculates a list of combinations ordered by Cost of Electricity. The COE contains the average price per kWh of electrical energy generated by the system. (Suamir, 2016)

5.1.3. Sensitivity Analysis

For the sensitivity analysis, an optimization is carried out to discover values of sensitivity variables. The essential factors in modelling a micro-system are often uncertain.

To reduce this uncertainty problem, HOMER performs a sensitivity analysis of factors and time data. In this step, HOMER makes many optimizations in input factors. For all the values of the sensitivity variable, the technical characteristics and costs are represented, finding the optimal solution in which the system supplies all the load. In summary, HOMER calculates the optimal size of all components of the system and the energy flows between. HOMER is one of the most demanded tools in the sizing of hybrid systems, and in the analysis of rural and small scale systems connected in parallel with the network or isolated from it.(Modeling, no date)

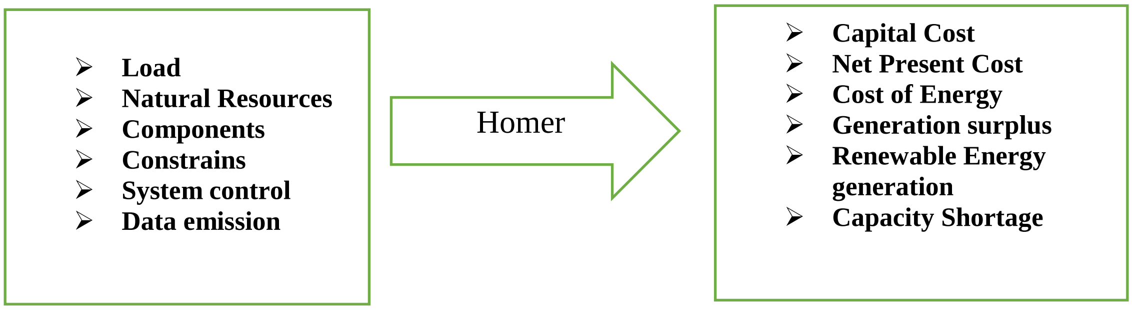

Figure 27: Schematic representation of the functions of HOMER (Sinha and Chandel, 2014)

6. Model description of Capileira electrical system

6.1. Load profile of the studied area

The electrical demand profile of a system shows the sum of the loads at the study location. In this case it will be the electric demand of the Villa de Capileira, which is composed of loads such as housing, restaurants, hotels, a town hall, school and public lighting. For the simulation, HOMER needs an example of electricity consumption over a weekend day and a weekday for each month of the year.

6.1.1. Primary electrical load

All electrical loads in the system require an AC supply. The average primary electric load in our system is 411587.69 kWh/month for hotels, 30,676 kWh/month for housing, 25,2298.85 kWh/month for restaurants, 2383,154 kWh/month for the city and city council, and 1773,077 kWh/month for the street lighting. This results in an average total demand over a year of 101,2198.9 kWh/month . The load profile shown in Figure 28 is imported into HOMER. The corresponding average annual electric load is 3,110 kWh/day with a maximum load of 550 kW in the month of February on a Saturday at 9 pm. HOMER assumes a daily random variability of 8%.

6.1.2. Seasonal Profile

In Figure 28 HOMER represents five demand data for each month of the year.

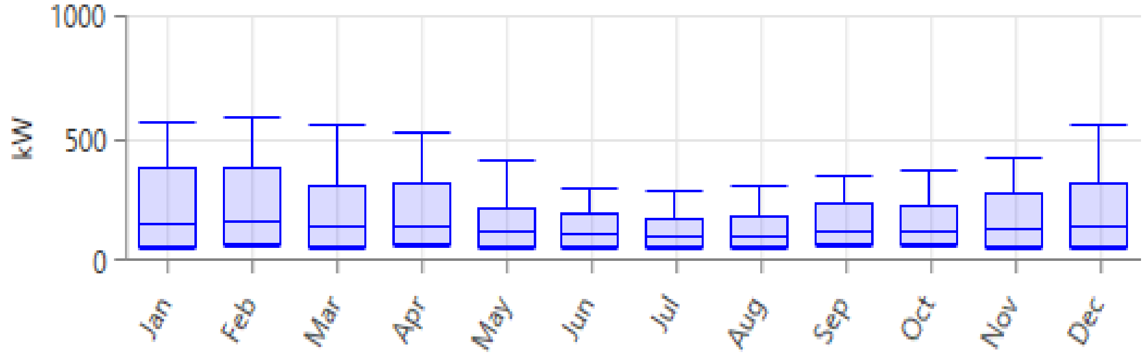

Figure 28: Monthly average electricity demand given by HOMER

For the month of February where the highest demand for maximum primary load is 550kW, the average daily maximum is 384.55, the daily average is 155.52, the average daily minimum is 51 and the minimum is 51kW

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6.1.3. Daily Profile

The graphic represents the demand profile of an average day

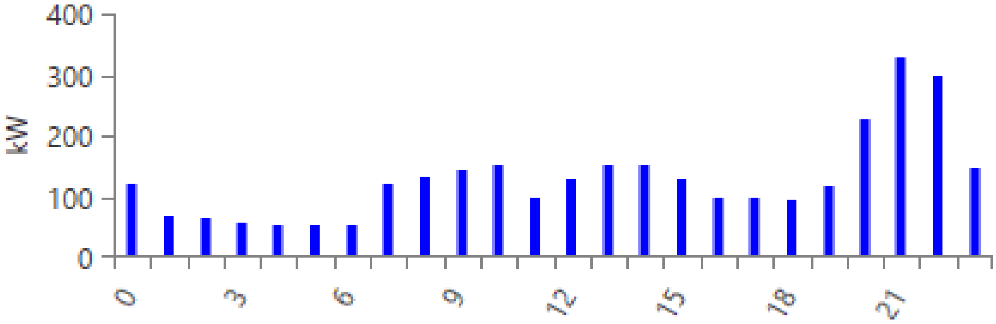
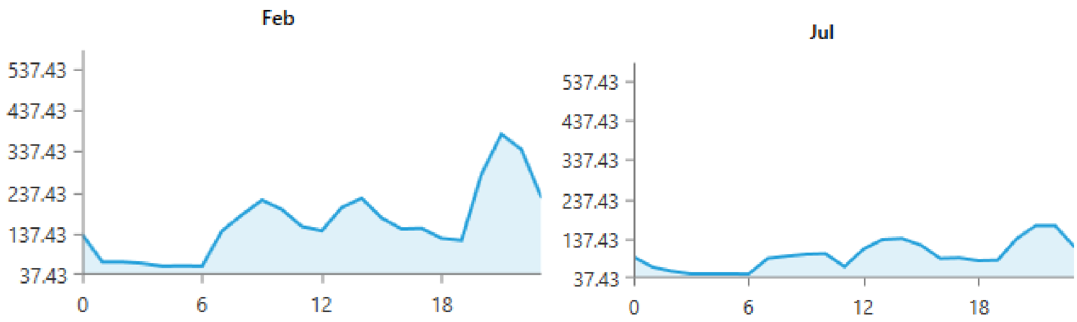


Figure 29: Daily Average electricity consumption given by HOMER

There are three peaks throughout the average day in the village, the first at 10 a.m. with a demand of 152kW, the second at 2p.m., also with a demand of 152kW, and the last and most significant is at 9pm with a demand of 327kW.

6.1.4. Differences of demand between winter and summer



As expected from the demand assessment study, there are clear differences in demand between winter and summer. On an average winter day, peak demand at 9 p.m. may be at 340kW while in summer it may only reach 140kW.

6.2. Resource data of the studied area

Meteorological data are a fundamental part in the analysis of any system that uses renewable energies as a source of generation. For the study of these climatological factors the location of the project site has to be defined. The village of Capileira is located at latitude 36.962 ° N and longitude -3.359 ° W.

6.2.1. Solar resources

To simulate a system containing photovoltaic energy, HOMER must be given solar resource data for the project location. The global horizontal solar irradiance must be specified. Radiation data is provided by NASA surface meteorology in kWh/m2/day. However, the data provided by NASA for the location of Capileira is at an altitude of 360 meters above the sea. This is not accurate, since our true location is at 1496 meters.

The higher the altitude of the place, the lower the attenuation of the sun's rays through the atmosphere, so that the UV radiation will be higher than at sea level. Due to the lack of data in this location and at this altitude, it is assumed that solar radiation will be 10-12% higher every 1000 meters. The radiation was therefore estimated to be

11% higher than given in the data provided by NASA.. (Cornelius, 2013). The obtained is represented in Figure 30.

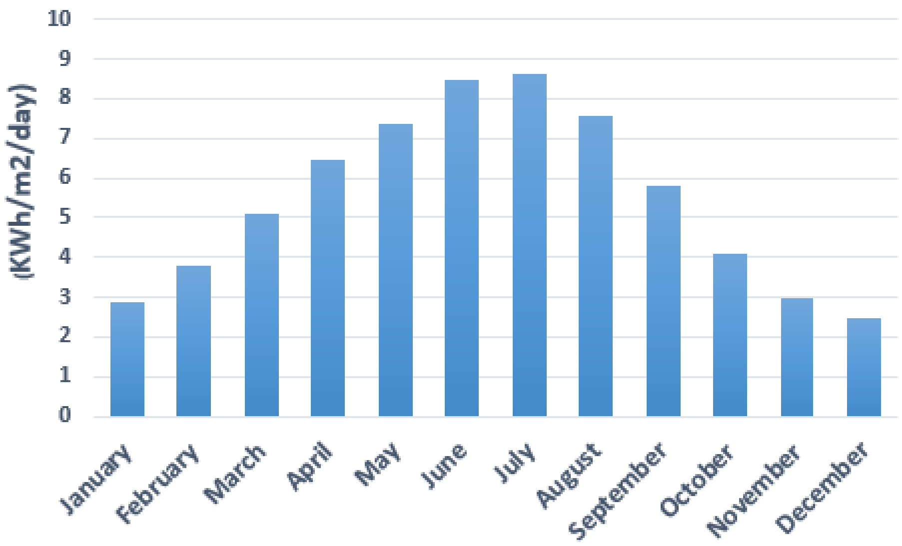


Figure 30: Monthly average radiation

Minimum and maximum monthly average solar radiation values are in December and July, with 2.45 kWh/m2/day and 8.65 kWh/m2/day respectively. At the location of the village, the annual average daily solar radiation is assessed at 5.474 kWh/m2/day.
The data provided by NASA in relation to the temperature and average wind speed in Capileira do not seem to be correct due to the aforementioned factor of altitude. As you ascend, you anticipate a lower temperature and a higher wind speed. Therefore, other sources of data seem to be required.

6.2.2. Temperature Resource

The temperature data provided by Meteoblue takes into account the altitude above sea level. These temperature data are significantly lower than those provided by NASA and appear to be closer to reality .(7-días et al., 2017). The temperature profile is shown in Figure 31.

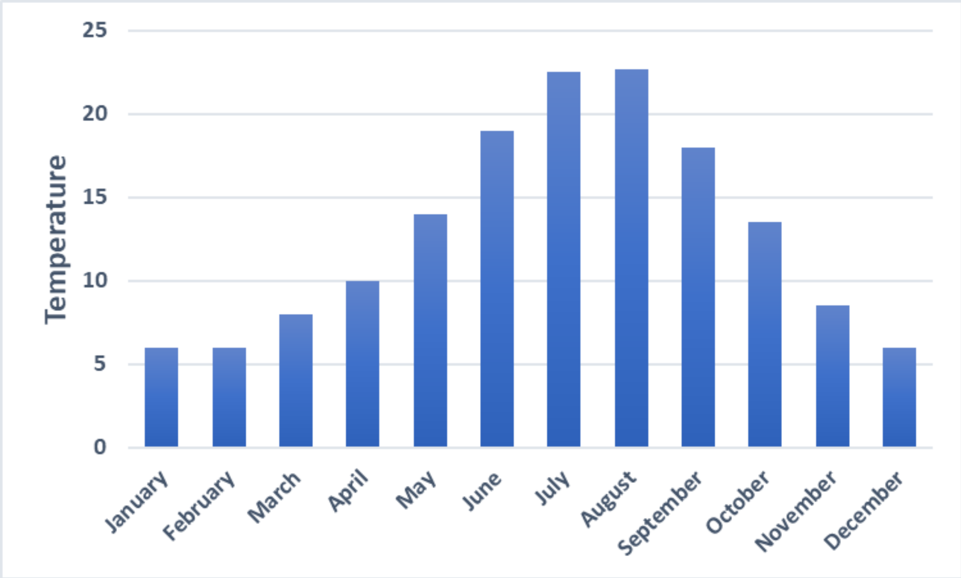


Figure 31: Monthly average temperature

Minimum and maximum monthly average temperature values are observed in January and August, with 6°C and 22.7°C respectively. The scaled annual average temperature is 12.85°C. It is possible to reach a minimum temperature of -5°C in January, and in August a maximum temperature of 33°C.

6.2.3. Wind resources

In order to simulate a system with wind turbines, wind resource data must be provided to HOMER indicating the average monthly wind speed profile at the location. This profile must be as realistic as possible since the output from wind turbines relates to the cube of the wind velocity. The introduction of erroneous data could lead to a system output very different from reality.

Looking again at the data provided by NASA's meteorological database, it seems that the average wind speed data is undervalued, perhaps again due to discrepancies in altitude. (7-días et al., 2017). Therefore, the data provided by Meteoblue are taken. In Figure 32 is represented the monthly average wind speed in a year.

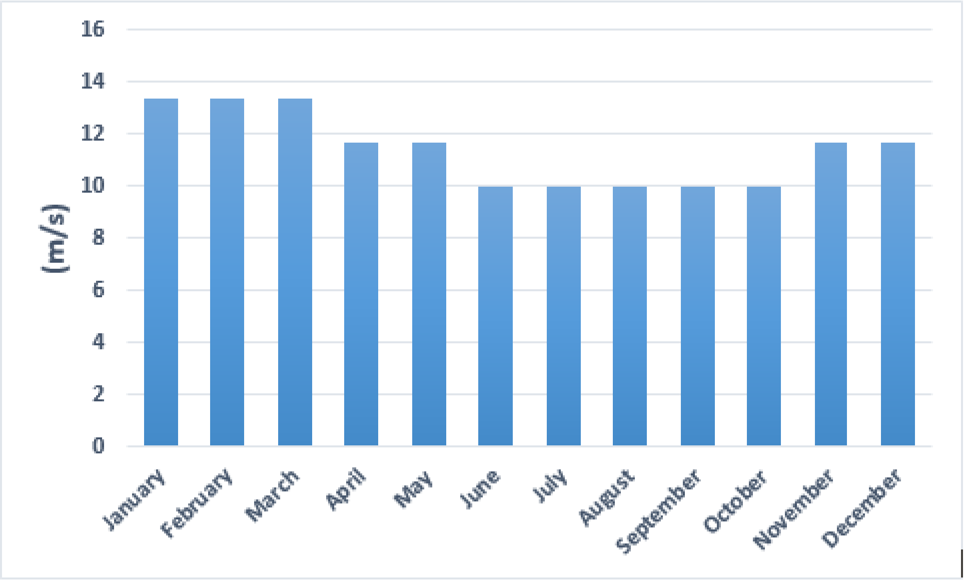


Figure 32: Monthly average wind Speed

7. Introduction of the system in Capileira and Procedures

7.1. Process of introduction of technologies for self-consumption in the village

In order to understand the behaviour of our proposed system, we take the demand profile of the village, and study the introduction of renewable technologies. This process will be done as follows:

- The introduction of solar energy will be examined in isolation; different generation capacities will be studied to see which is the most favourable choice.
- To add to the solar capacity, generation from wind turbines will be considered. Several combinations will be studied in order to discover again which is the best economic and technical option.

- Methods to soften the electricity demand curve will be examined, to reduce demand at peak hours, and see how they might influence our system.
- The idea to install a storage system will be investigated. This would store the generation surplus to take advantage of it in a time of high demand. With our system connected to the grid, it will be established if a storage system can confer any benefits.
- Finally, the feasibility of a hypothetical isolated microgrid system will be studied.

7.2. Case 1: System of PV configuration

For the configuration of the Capileira system in HOMER it is necessary to use the parameters represented in the following figure

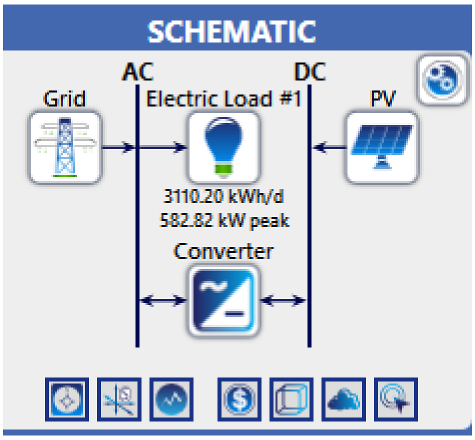


Figure 33: Configuration of the Capileira power system PV capacity

This system consists of our profile demand described above, the main grid, PV panels, and the converter. The main grid is connected to the AC bus and can directly supply the AC electrical demand. However, PV panels connected to the DC bus require a converter in order to use the electricity produced.

For the simulation, it is necessary to introduce the price of the technologies used. HOMER requires the specification of the initial cost, replacement cost and costs for operation and maintenance. The initial cost for small PV installations less than 100kW at present is around £1500 per kW, however for installations larger than

100kW the price is reduced by approximately 20%. Therefore, for installations larger than 100kW, the initial cost of installed capacity will be £1200 per kW with a replacement cost of £1000, while O&M is set at £20/kW/year. The initial and replacement costs of the converter will be £240/kW and £220/kW while the O&M will be £9/kW/year.

	Capacity (KW)	Initial cost (£)	Replacement cost (£)	O&M cost (£)	Lifetime (year)
PV	100	120,000	100,000	4,000	25
Converter	79.7	240/KW	220/KW	9/KW/year	15

Figure 34: Initial cost of technologies with PV

The cost of replacement is lower than the initial cost since there is a downward trend in the prices of renewable technologies due to the likely increase of its penetration in the future

7.2.1. Power prices

According with section 2.2.2, two types of tariff for purchase from main grid were taken: a fixed price, which is £0.145/kWh and the hourly tariff which will be differentiating between peak hours (1 pm-10pm) at £0.155/kWh and valley hours (11 pm-12am) at £0.0650. These rates at present have no built-in fees or system maintenance charges, so will be increased by 20% to be more similar to reality.

For the sale of electricity from generation produced the rates in Spain fluctuate greatly, so the calculation of an average value is not an easy task. The net sales price is set at £0.0520/kWh according to the recent average price for the purchase of electricity from renewable energies in Spain. An exception is electric power sold every day from 1pm to 5pm in the months of June, July and August that will be set at a price of £0.085/kWh. The reason is that due to the high temperatures throughout Spanish regions at this time, many users require the use of air conditioning, leading to an increase in electrical demand. This logically should lead to an increase in sell back rate in distributed generation systems. With a sell back rate for these hours of the year of £0.085/kW, the rate for the rest of the year will be set at £0.045/kW to maintain an average of £0.0520. The following table summarizes the purchase and sale prices to the main grid

£/KWh	Valley Hours	Peak Hours	Sell back rate	Sell back rate in peak demands
Fixed annual tariff	0,15	0,15	£0.0520	£0.0520
Hourly rate with Peak demands in summer	0,085	0,175	£0,0520	£0,0850

Table 4: Price of kWh adjusted in HOMER for each tariff according to purchase and sale to main grid

For the fixed annual rate will be adjusted using the option of simple rates, and for the option of hourly rate will adjust the prices in the option of scheduled rate in HOMER

7.2.2. Results analysis

In this section, we present the results obtained from the simulation in HOMER, for the Capileira region. Several alternative systems have been designed with different amounts of electrical generation coming from PV only. The HOMER output includes a financial analysis of all system options. It therefore conducts a study of the economic performance and economic impact of each combination of distributed generation technologies. Increasingly the generation capacity leads to higher costs, and therefore a balance must be struck in generation and consumption.

Simulation results

The following table considers generation capacities from 50 kW to 900 kW, taking into account that no storage will be used.

Capacity PV (KW)	Ren. Frac (%)	Production(kWh)	Import(kWh)	Export (kWh)
0	0	0	1,135,224	0
50	7.58	90,922	1,049,136	0
100	15.1	181,844	964,500	1,005
200	29.2	363,689	827,791	34,629
300	40.4	54,5533	753,379	127,782
400	48.9	727,378	706,847	248,166
500	55.4	909,222	678,065	386,093
600	60.6	1,091,066	658,921	536,099
700	64.7	1,272,911	644,736	691,061
800	68	1,454,755	633,865	848,095
900	70.9	1,636,599	624,946	1,009,556

Table 5: Renewable fraction, production, Import and Export depending of capacity of PV installed

As can be seen by adding extra generation capacities from PV, there will be a directly proportional increase of the generation in the useful life of the installation. It will also increase the percentage of generation from renewables, but this will increase at a lower rate. Although generation increases with the capacity of installed PV, without the use of storage in moments of no solar activity (at night) we will continue to require electrical import from the main grid. Therefore, as the generating capacity increases, the imports of the grid will decrease, but at a much lower level, which in turn increases the exports.

To show these factors more clearly, the percentage of energy used and the load met per generation capacity have been calculated.

a) **Percentage of energy used:** This shows the percentage of use of onsite generation; the remaining percentage being exports that are sold to the main grid**.**

% Energy used onsite = (Load (kWh)-import (kWh))/renewable generation (kWh) *100

Equation 2: % Energy used onsite

b) **Load met by the PV system**: This figure shows the percentage of the electric demand that comes from the PV generation. The remaining percentage will be supplied from the main grid.

% Load met by solar = (load (kWh)-import (kWh))/ Load (kWh)*100

Equation 3: Percentage of Load met by generation

The figure 35 shows the trend of these two parameters, as a function of the capacity of PV, without using storage:

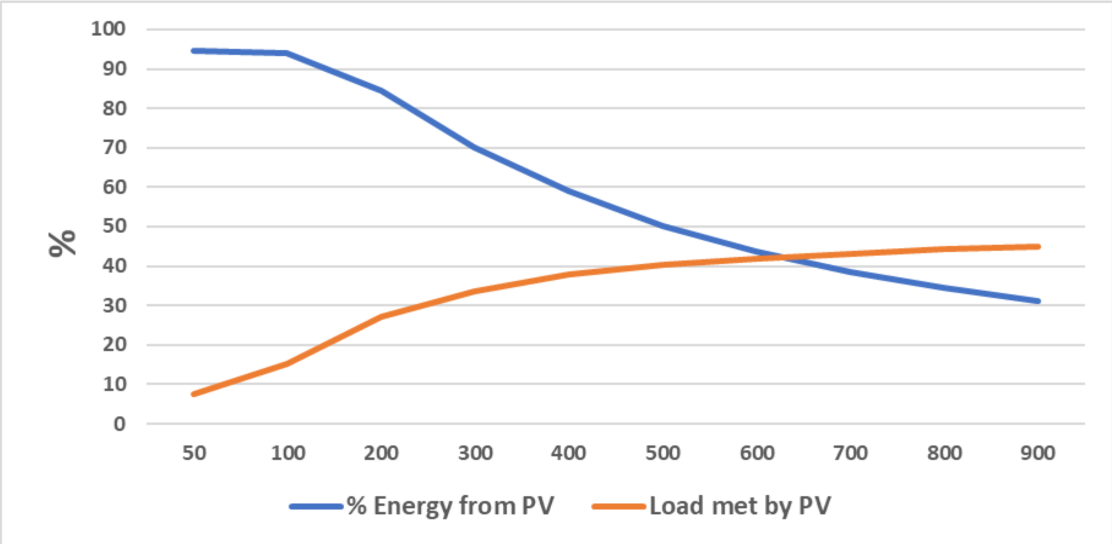


Figure 35: Variation of percentage of energy used onsite and load met by generation depending on PV capacity

It is observed that the percentage of electric energy used from the PV generation decreases steadily as we increase the generation capacity. However, as the generation capacity increases, the percentage of load met by generation increases as well, but each time to a lower level. It evidently increases the energy supplied to the load by reducing imports, but at night we will require the same import as before.

To further illustrate these effects, we can calculate the percentage of the PV energy consumed locally with each increase of the capacity.

Capacity (KW)	Fraction energy generation locally (%)
0	0
50	94.68
100	93.08
200	75.17
300	40.92
400	25.58
500	15.82
600	10.52
700	7.8
800	5.97
900	4.9

Table 6: Increase in percentage of energy consumed onsite with the different transition

Additional energy generation consumed locally = (Energy consume onsite (kWh)-previous energy system (kWh))/ additional generation (kWh)

Equation 4: Additional Energy Generation consumed locally

The largest percentage of energy consumed locally occurs in the transition from 0 to 50kW, being 94.68%. This decreases exponentially with further increases in PV capacity, so that with 900kW in which there is only 4.9% of the energy consumed locally; exports to the main grid form the remainder.

Economic Analysis

A study of the economic analysis for each capacity taking into account the hourly and fixed tariff has been carried out in order to show the reduction of COE and NPC. Table 7 shows all this information.

	COE (£) Hourly tariff	NPC (Millions £) Hourly tariff	COE (£) fixed tariff	NPC fixed (million £)
0	0.13	1.90	0.15	2.20
50	0.126	1.85	0.146	2.14
100	0.12	1.77	0.14	2.05
200	0.11	1.66	0.128	1.94
300	0.0999	1.63	0.117	1.91
400	0.0913	1.63	0.107	1.91
500	0.0841	1.65	0.0989	1.94
600	0.0781	1.69	0.0918	1.98
700	0.073	1.72	0.086	2.03
800	0.0689	1.77	0.0812	2.08
900	0.0653	1.81	0.077	2.13

Table 7: COE and NPC with different tariff depending of PV capacity

The COE in the hourly tariff descends in a greater rate than in the fixed tariff. In both cases COE decreases because the exports increase at a greater rate than the initial cost of the installation.

For the NPC with hourly tariff, it is observed that the highest value is for the capacity of 0 kW since despite having a higher capital cost as generation capacity is added, the savings produced by the reduction of imports from the main grid will be even greater. This decreases in the capacities of 0-400 kW. Above the capacity of 500kW the NPC increases because having a higher initial cost with respect to lower capacities, savings are no longer sufficient.

For the fixed tariff the NPC falls from the capacity of 0 kW to 400 kW, but from 500 kW it rises as for the hourly tariff. However, it reaches a greater COE and NPC than the hourly tariff. This is due to the fact that in this case there is no distinction between peak and valley hours, with kWh coming from the grid being generally more expensive.

In summary, this analysis demonstrates how important is the buying and selling price to the main grid per kWh, since this will lead to determining whether a system of self-consumption is economically viable or not

7.2.3. Selection and study of PV capacity chosen

After observing the characteristics according to the capacity used, a capacity of 100kW was selected for the next study, for two reasons

- Despite not meeting the load in most of year and having a higher NPC and COE than some other generation options, a high percentage of generated energy is used to supply the load. It must be remembered that the generation system is created with the exclusive task of supplying the local demand, and not to sell electricity to the main grid.
- The second and most important reason to choose this capacity is due to a local urban law that protects the aesthetics of the village. It is not permitted to install solar collector plates on the roofs of the houses of the village, and the only possibility for a PV installation is an 800m2 site owned by the council. To estimate the suitable area that can occupy a capacity such as 100kW, we consider that a typical 250W PV panel measures around 1.7 m2 (Theecoexperts.co.uk, 2017). To obtain the capacity of 100kW an area of 680m2 will be needed. Therefore, the capacity of the site is sufficient.
- Choosing equal or higher capacities to 100 kW, the price of a PV system would fall from £1500/kW to £1200/kW.

7.2.4. Simulation results of chosen capacity

Technical results

Having chosen the 100kW simulation as the one that most suits the system, the illustration below represents the PV power output according to the hours of each day (y axis) during each day of the year (x axis).

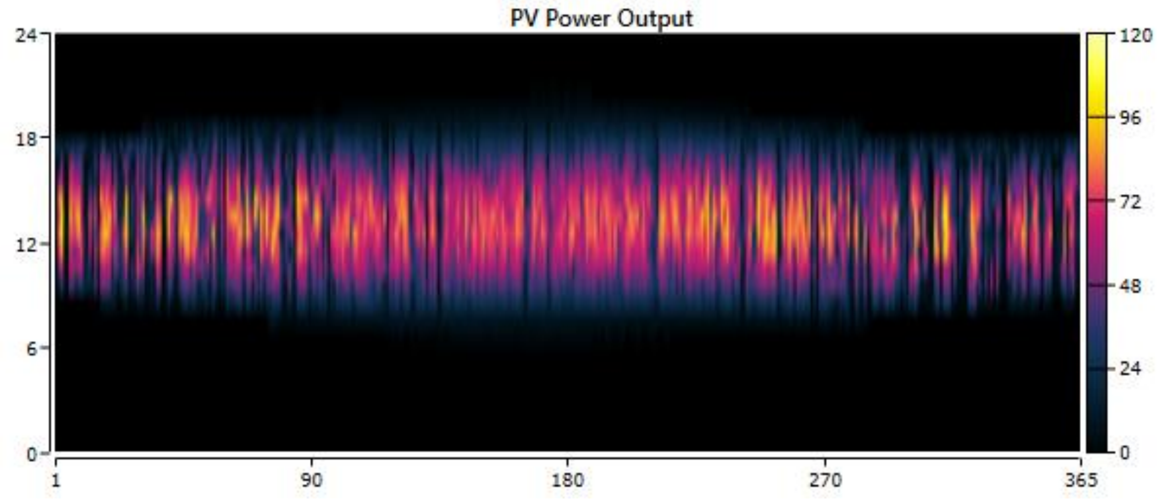


Figure 36: Power output of 100 kW capacity in Capileira

The hours of activity of the panels occur between 9 in the morning until 6 in the afternoon in winter, while in the summer months they operate between 8a.m. and 8p.m. The PV output is estimated as 181 844 kWh/year with 4387 hours of operation per year, and the mean output is 498 kWh/day.

Comparison of the PV energy outputs in a winter and summer week

The following chart represents the generation of PV panels in one week of winter and another week in summer.

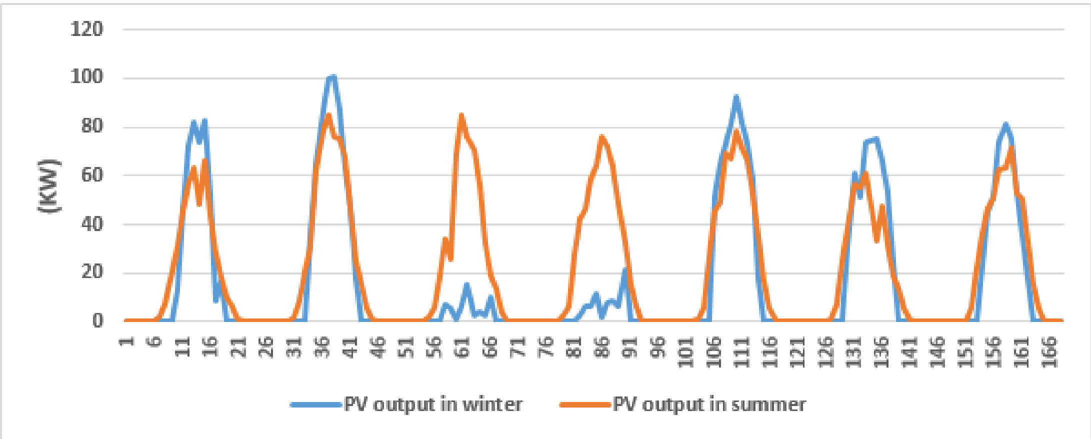


Figure 37: PV power output in a winter and summer week

Even in the winter week there is generation during every day, but it has different values depending on the nature of the day. In the example here, for the third and fourth day there is hardly any generation due to cloudy sky. In the summer week the values of generation are more stable on all days of the week.

Despite the number of hours of activity, with the same sky conditions in winter and in summer, the PV output at noon reaches higher values than in winter. This is because the temperature of the panels is lower than in summer thus having a larger output.

Monthly power generation

The graph shows the monthly generation amount for one year. The orange colour symbolizes the PV generation and the green area the energy bought from the main grid.

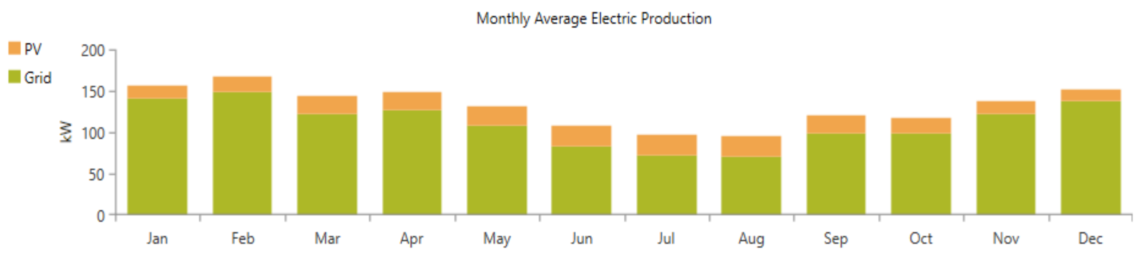


Figure 38: Monthly Average Production

The load depends heavily on imports from the grid, especially in the winter months when the electrical demand is maximum and the electric generation coming from PV panels is low. However, in the summer months of we will require approximately half of the imports required in winter since the electrical demand is minimal and the generation is at a maximum.

Comparison of Primary Load with PV power output over a year

Figure 39 represents the electric demand for the whole year hour by hour in blue, while the generation of 100kW of PV capacity is represented in red.

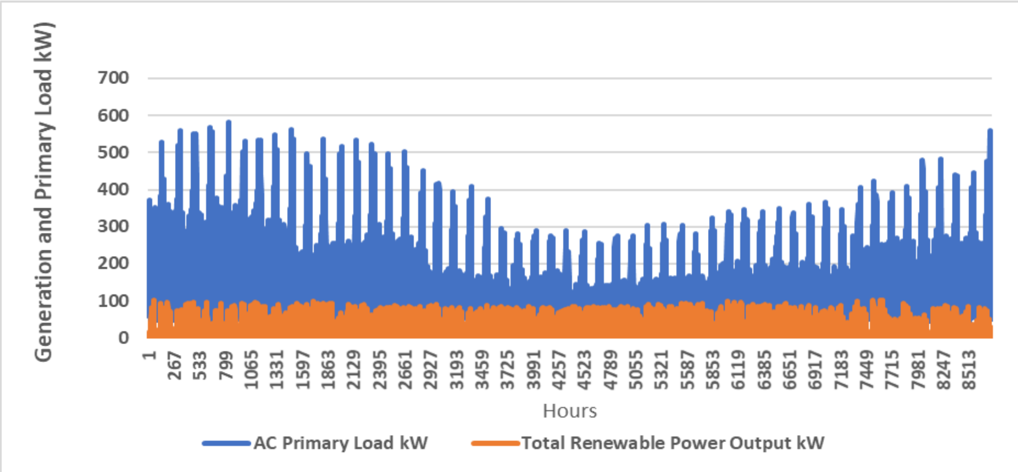


Figure 39: Generation and Primary Load in a year (kW)

This demand reaches maximum values at weekends in the winter months (when the occupation of the village is at a maximum). The generation from PV is in the range 50-100kW on average, and almost never supplies the full demand.

Comparison of Primary Load with PV power output over a winter week

Figure 40 shows the electric generation and electric demand in a winter week.

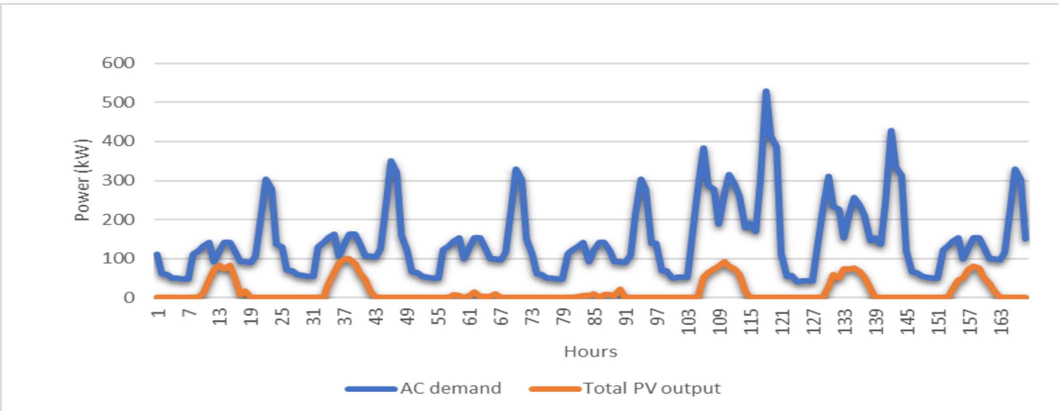


Figure 40: AC Primary Load and generation in a winter week

It is observed with more clarity here that the PV generation does not reach the demand of the village at any time of the week. Therefore, it will be necessary to import from the main grid constantly.

Import and export from the main grid in a winter week

Figure 41 shows the amounts of import required hour by hour during that winter week.

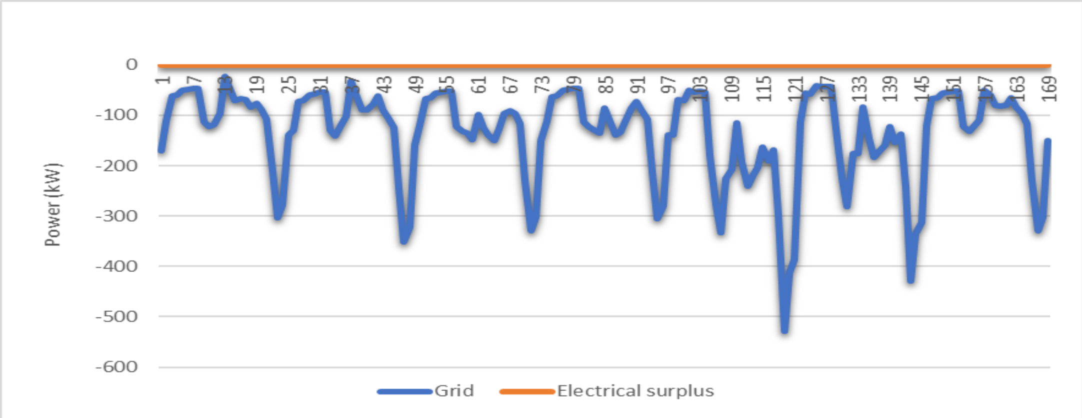


Figure 41: Electrical surplus and import in a week of winter for 100 KW PV capacity

The import is represented with the blue line, and has negative values since it is electricity to be purchased from the grid and carries a cost. It reaches a maximum value of -530kW, and at times falls very close to zero. However, the value of export in this week is always zero since there is at no time any generation surplus to be sold to the main grid.

Monthly amount of import and export from the main grid

This table represents the amount of import and export in each month of the year

Figure 42: Monthly quantity of Electrical import and export

Exports only occur from June to October but at very low values. In general there are only 1003 kWh throughout the whole year, while the import quantity is 964,586kWh. Compared to the demand of 1135223 kWh/year, the total generation of the PV panels is 181,844 kWh/year, so the 100kW system will be able to supply only 16.01% of the energy requirements of the town of Capileira.

Sensitivity analysis Impact of the converter size

In an installation with batteries, a converter is necessary to convert DC electric power into AC. This process is called inversion while the reverse process is called rectification. The converter size is an input variable in Homer and refers to the inverter capacity which is the maximum amount of AC electric power that the device can produce by the inversion process. The user specifies the rectifier capacity, which is the maximum amount of DC power that the device can produce by rectification, and is taken as a percentage of the inverter capacity. Therefore, the rectifier capacity is coupled to the inverter capacity and is not an independent variable.

It is necessary to specify the capacity of the converter that converts the DC electricity generated by the PV panels into AC electricity consumed by the village. HOMER selects the optimum system of converter for the capacity of 100kW using the optimizer as shown in the table 8.

PV (kW)	Grid (kW)	Inverter (kW)	Rectifier (kW)	Dispatch
100	999.999	79.7	76	CC

Table 8: Converter size for 100 kW of PV Capacity

The best result is obtained with an inverter conversion capacity of 79.7 kW, since the maximum power of the inverter is 80 kW. The mean output for the inverter will be 79.8, while for the rectifier it will be zero because the converter will only be used to transform DC electrical power from the panels into AC to be consumed by the load.

If the capacity of the converter is oversized, there will be no loss of effect on the system but it would increase costs. But if it were of less capacity that would increase the amount of import from the main grid and decrease the export, since all the generation of the panels passes through this limited conversion which reduces the renewable penetration in the load.

Table 9 shows the effects on the system of bad dimensioning of the converter.

	PV production (kWh)	Import (kWh)	Export (kWh)	COE (£)	NPC(Million£)
50 kW converter	181844	992058	0	0.123	1.81
79.7 KW converter	181844	964500	1005	0.12	1.77
100 kW converter	181844	963495	1023	0.121	1.77

Table 9: Comparison according to different converter sizes

Having the same energy production from the panels, for an under-sized converter (50kW), the initial cost of the investment will be lower, but there will be a greater amount of import from the main grid since the generation is limited when converting. For an oversized converter (100kW), the decrease in imports will be very low, but there will be an increase of the initial cost, so increasing the COE and NPC .

Economic Analysis

The following table shows the COE and NPC for the hourly and fixed tariffs, for the current system in which there is no PV generation and for the scenario in which there is 100kW.

Capacity (KW)	COE (£) Hourly tariff	NPC hourly tariff (million £)	COE (£) fixed tariff	NPC fixed (million £)
0	0.13	1.90	0.175	2.57
100	0.12	1.77	0.14	2.05

Table 10: Comparison of COE and NPC with different tariffs for 100 kW and KW installed PV

For both types of tariff, the installation of 100 kW PV capacity has decreased COE and NPC, being a profitable business for both cases, having a COE and NPC reduction of £0.01 and £0.13 million for the hourly tariff, while for the fixed tariff the COE and NPC reduction was £0.035 and £0.52 million. For this last tariff, the reduction of COE and NPC is higher because the imports are valued at a higher price.

Cash Flow by component

Figure 43 shows the cash flow of the different components of the system with fixed tariff.

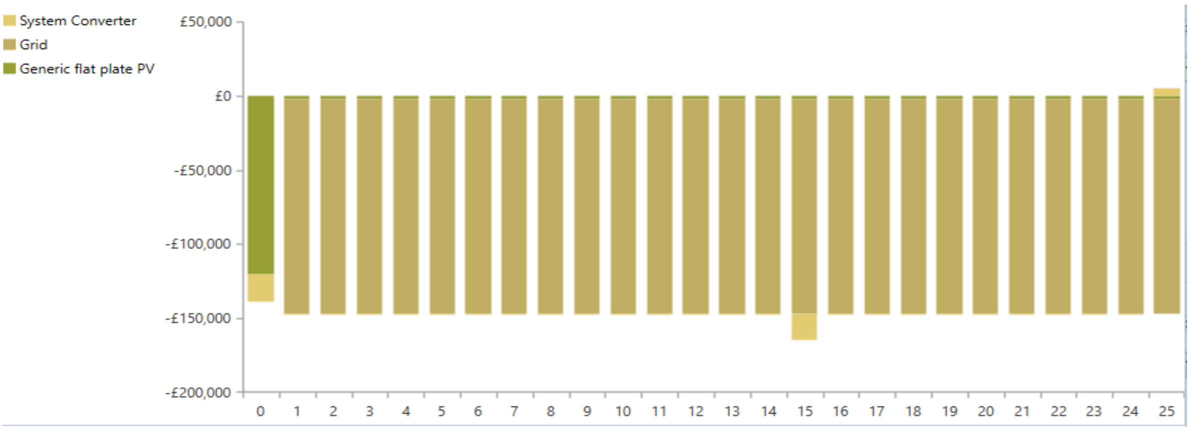


Figure 43: Cash Flow of different technologies in the system

There is the initial cost of the 100kW PV installation of £120,000 plus the initial cost of the converter system, totalling something more than £19,000. There will be an annual purchase cost for electricity from the main grid of about £145,000, added to which are the maintenance cost of the conversion and PV systems, up to year 15. At which point, in addition to these regular costs, the replacement cost of the converter is added.

7.2.5. Conclusion

In general, this installation of 100kW will contribute only 16% of the requirements of the village, a very low percentage if the aim is to be 100% renewable. With a maximum generation of 100kW and a peak demand of 550kW, another technology with perhaps different generation characteristics is required to complement the existing one. Energy storage may then have to be considered, to make full use of resources when energy supply exceeds the demand.

7.3. Case 2: PV plus Wind turbines system configuration

In an attempt to increase the generation from renewables the site, wind energy is chosen. In the area available for the use of renewable technologies only space for three or four turbines is available. Because the location of the project is in Sierra Nevada National Park and this village is considered a heritage site, it would not be allowed to install turbines with a hub height greater than 25 meters due to the visual impact. This limits turbine selection to capacities of up to 100kW.

Several types of such turbines were investigated in order to check their output in our system. Two models of turbines, from VESTAS and WES, each with 100kW capacity were selected in our study. The following graph shows the generation curves of the Vestas V20 and WES 100 turbines.

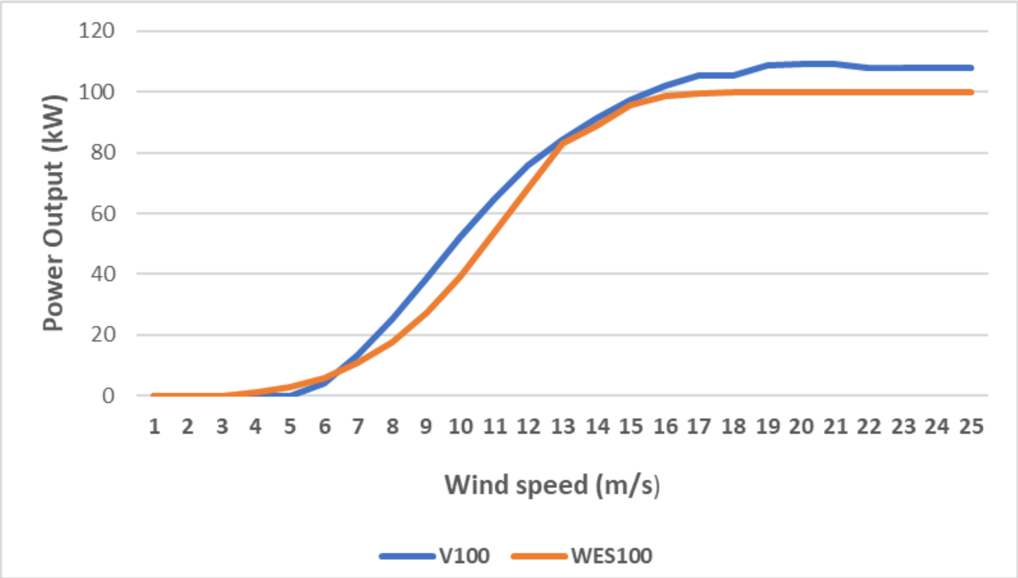


Figure 44: Curve generation of Vestas 20 and WES 100

The Vestas 20 achieves generation levels of up to 108 kW from 18 to 24 m/s while the WES100 reaches only 100kW. The WES generation starts at 3 m/s while the Vestas V20 cuts in at a wind speed of 5 m/s.

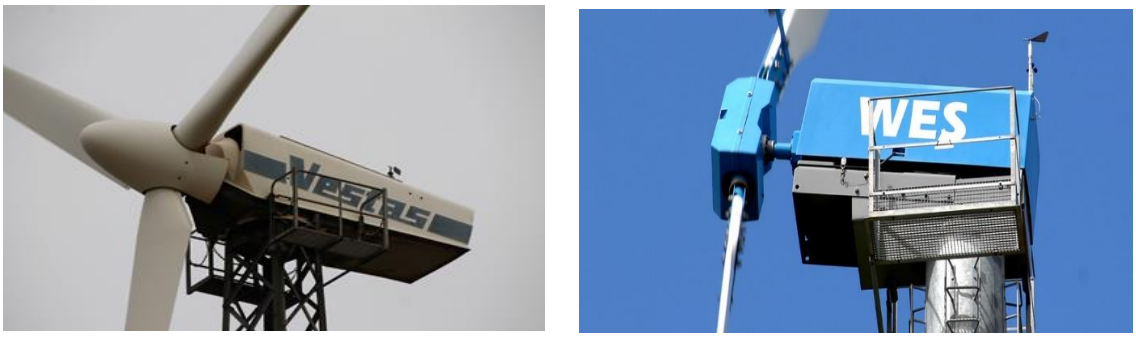


Figure 45: Pictures of VESTAS 20 and WES100

Several simulations were made with different combinations of wind turbines, always taking into account the complementary capacity of 100 kW of PV. The table on the next page shows the different combinations.

7.3.1 Turbine Price

According to section 2.2.6. After having added the initial cost, the cost of installation, connection to the grid and transport it is estimated that the initial cost of the Vestas V20 is £125 000 and the replacement cost is £118 000. The corresponding initial and replacement costs of the WES100 are £126,000 and £119,000 respectively. It is estimated that O & M for turbines is 1.2p/kWh over the total turbine lifetime, so it is set for the V100 and WES at £5549.48 and £5509.46 respectively.
Simulations were made for a fixed rate and an hourly rate of purchase of electricity from the network as was done previously

7.3.2. Simulation results

Table 11 considers the different combinations of PV and wind turbine, noting that no energy storage systems will be used.

Combination	Ren. Frac (%)	Total production(kWh)	Import (kWh)	Export (kWh)
PV+3xV20	83.8	1,695.281	315,320	864,341
PV+3xWES100	85.2	1,683,074	289,898	826,467
PV+4xV20	88.7	2,199,760	278,426	133,3925
PV+4xWES100	89.9	2,183,484	244,634	128,1613
PV+2xWES100+ 2xV20	90.5	2,191,622	230,192	1,275,309
PV+1xWES100+ 3xV20	90.2	2,195,691	237,897	1,287,083
PV+3xWES100+ 1xV20	90.2	2,187,553	235,096	1,275,591

Table 11: Different combinations of turbine with 100 kW of PV capacity

Combinations of three turbines were quickly discarded since they do not provide the required generation. In the combinations of 4 turbines it is observed that the choice with the highest generation is the four V20 turbines, producing 2,199,760 kWh. However, this is not the one that has the greater percentage usage of renewables (it produces more exports and imports than other combinations). The choice with the greatest usage of renewables has is with two V20 and two WES turbines, with 90.5%.

To show these factors more clearly, we have calculated the percentages of green energy used and load met, for each generation combination. The results are presented in Figure 46.

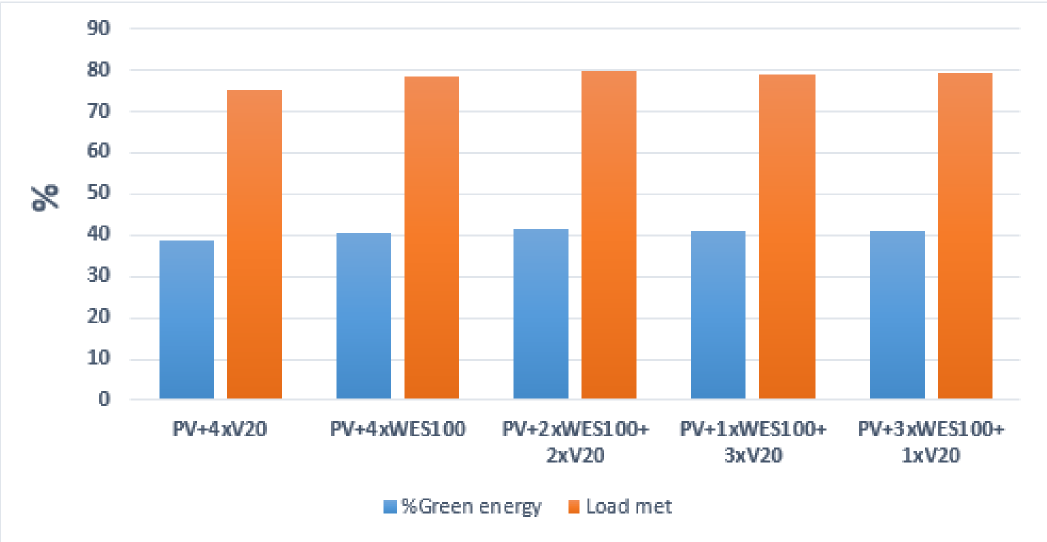


Figure 46: Percentage of energy consumed onsite and load met by generation according with different combinations of turbines plus 100 kW of PV capacity

All combinations reach between 75 and 79% of load met by the system and between 38 and 41% of the energy consumed onsite, so there is no great difference between them. The most successful combination is with the two V20 and 2 WES turbines, that reaches 79.72% of load met by the generation and a percentage of green energy used of 41.29%.

However, it is perhaps more sensible to use only one manufacturer of turbines. Therefore, the best performer is the combination of PV and 4 WES100 turbines, with 78.45% of load met and 41.2% of green energy produced onsite.

In general, with the process of installing the four turbines have led to a significant increase in the load met by renewable energy generation. But it has also led to a decrease in the amount of the renewable energy produced which can be used onsite, from 89% in the initial system to only 40.05%. This is because with such a large renewable energy capacity, exports will at times increase significantly.

7.3.3. Simulation results of chosen combination

Technical results

For the configuration of the Capileira system in HOMER it is necessary to use the parameters represented in figure 47.

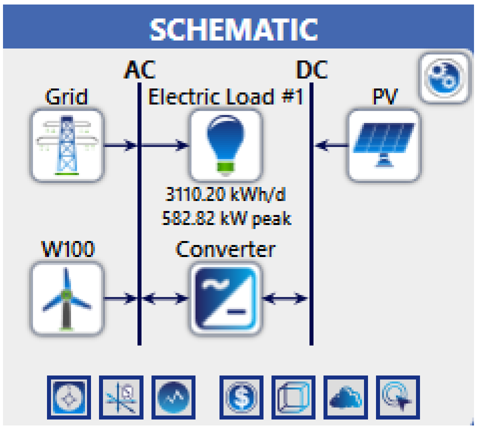


Figure 47: Configuration of the energy system of Capileira with 100 kW of PV capacity plus four turbines WES100

This system consists of our profile demand quoted above, the main grid, PV panels, converter and wind turbine. The power system is mains connected to the grid and can use electricity from both wind turbines and PV to supply the electric load. The 4 WES turbines are connected to the AC electric bus. They are connected directly to the load while the PV panels require a feed through the converter.

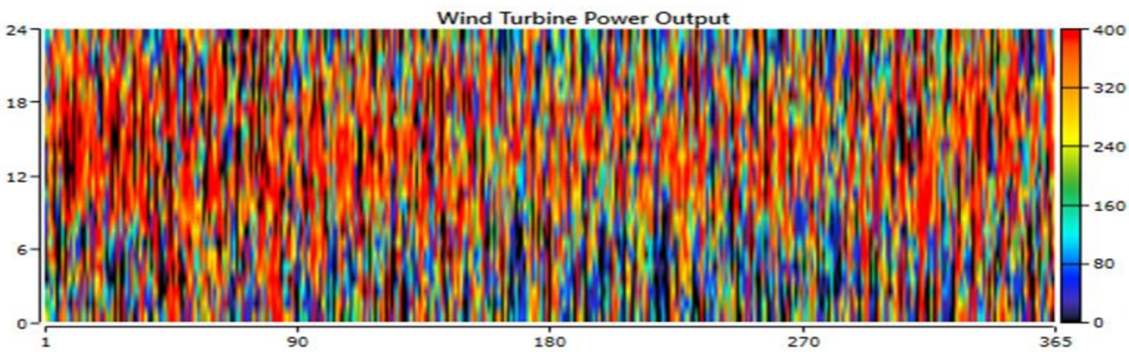


Figure 48: Configuration of the energy system of Capileira with 100 kW of PV capacity plus four turbines WES100

The 4 WES 100 output is 2,001,640kWh/year with 8341 hours of operation per year, and the mean output is 228 kWh/day. The PV system provides 7.49% of the energy consumed on the grid, the four WES100 82.4% and 10.1% are imports from the main grid.

Comparison of the renewable energy outputs in a winter and summer week

Figure 39 illustrates the electricity generation from wind energy and solar energy during a winter week.

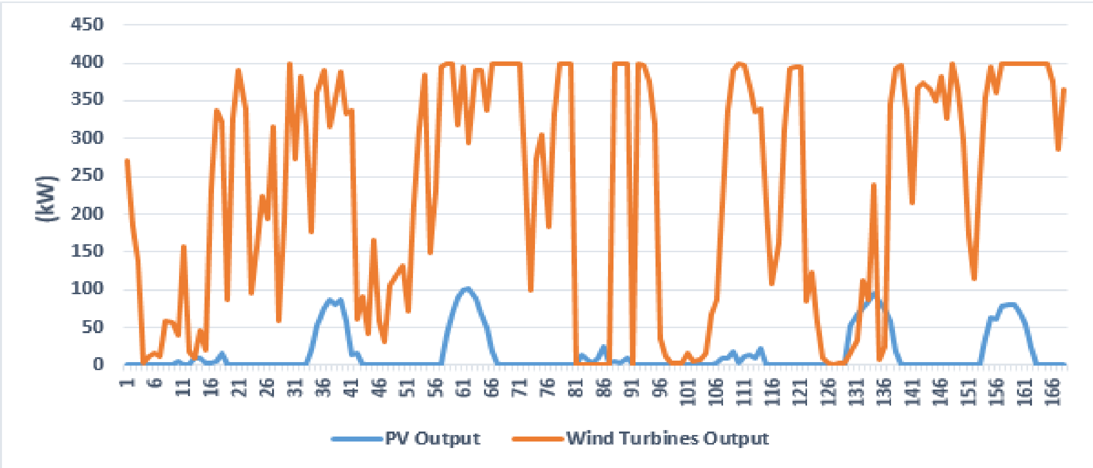


Figure 49: 100 KW and four turbines power output in a winter week

As expected, the wind power output fluctuates greatly throughout the week, reaching in many cases the maximum possible generation of 400kW, and at times producing nothing. At times of maximum generation of both technologies the output can reach 500 kW, slightly lower than the peak demand of the village. The season with more wind energy output is winter, making the turbines an excellent complement to solar energy with its low values of energy output in the winter months.

Monthly power generation

The Figure 50 shows the total supply from each source in every month throughout the year, including imports from the grid.

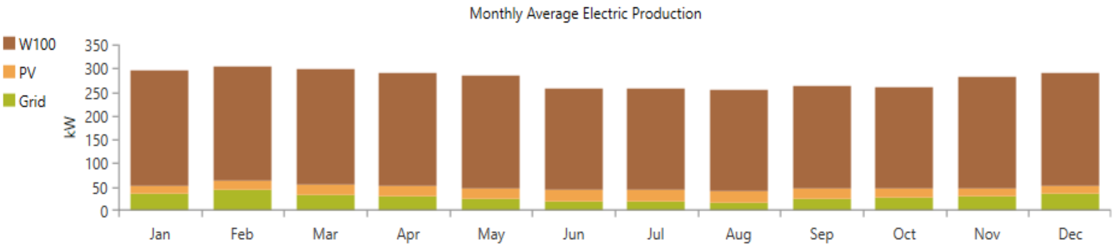


Figure 50: Monthly average Electrical Production with 100 kW and four turbines

In every month, the main source of supply is wind energy. In the summer months despite having a lower wind power output, the imports from the grid are much smaller since the solar power output has higher values and the demand in the village is lowe

Comparison of Primary Load and total generation output over a year

Figure 51 shows the total power output from renewable sources and the AC primary load.

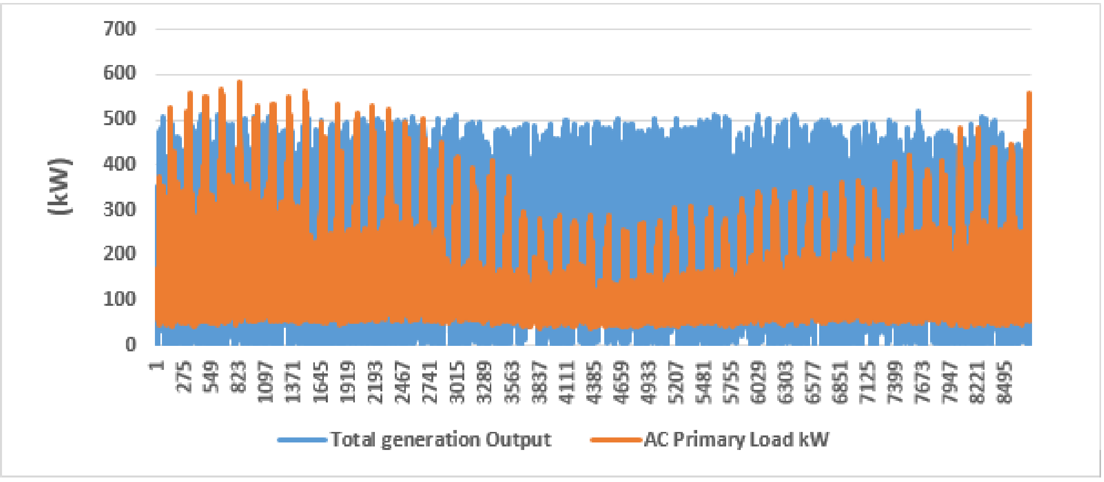


Figure 51: AC Primary Load and system generation in a year

With the addition of 400kW of capacity from the wind turbines, the combined output of the two technologies will have values almost always higher than the electric demand of the village, except in winter months at the weekends when the load can reach values around 550kW. In these cases it will be necessary to import from the grid.

Comparison of Primary Load and total generation output in a week of summer and winter

It can be seen in Figure 42 that harnessing the renewable output has the potential to fully meet demand throughout the year. The next graph illustrates load and renewable generation for a typical winter and summer periods.

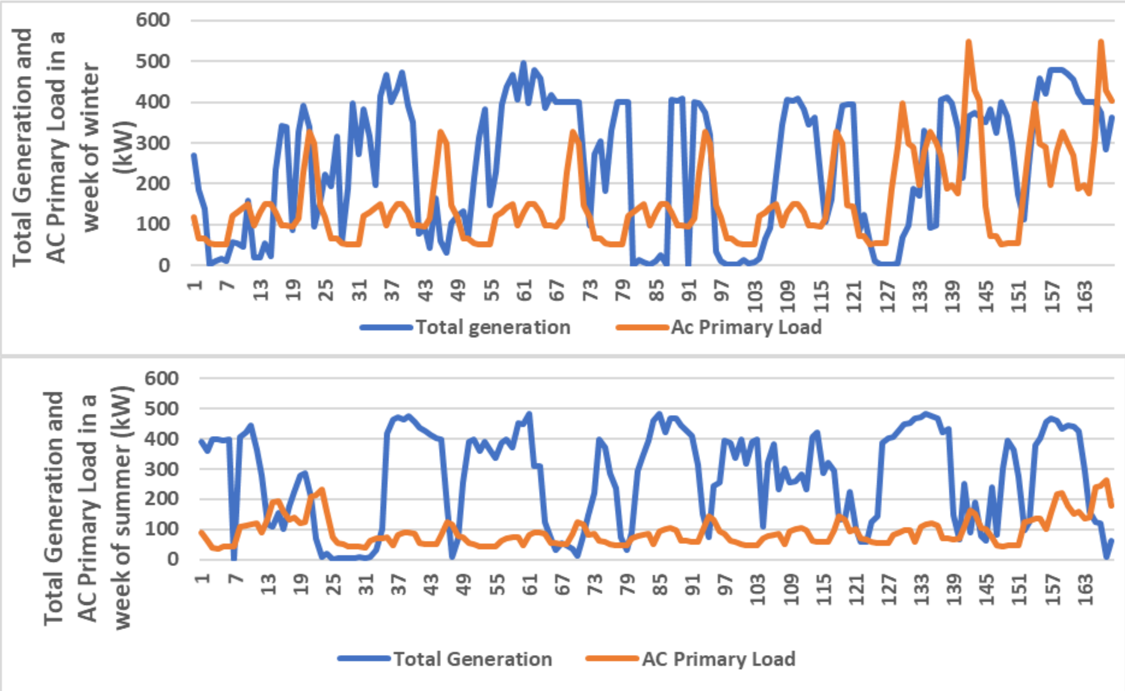


Figure 52: AC Primary Load and and generation from the system in a winter and summer week.

In general there is no great difference in generation between summer and winter. What is evident is the change in the value of the load, being in winter much higher than in summer. This will make imports higher in winter, and exports higher in summer.

Import and export from the main grid in a week of summer and winter

In the two graphs below the values of import and export are represented for a typical week of winter and summer.

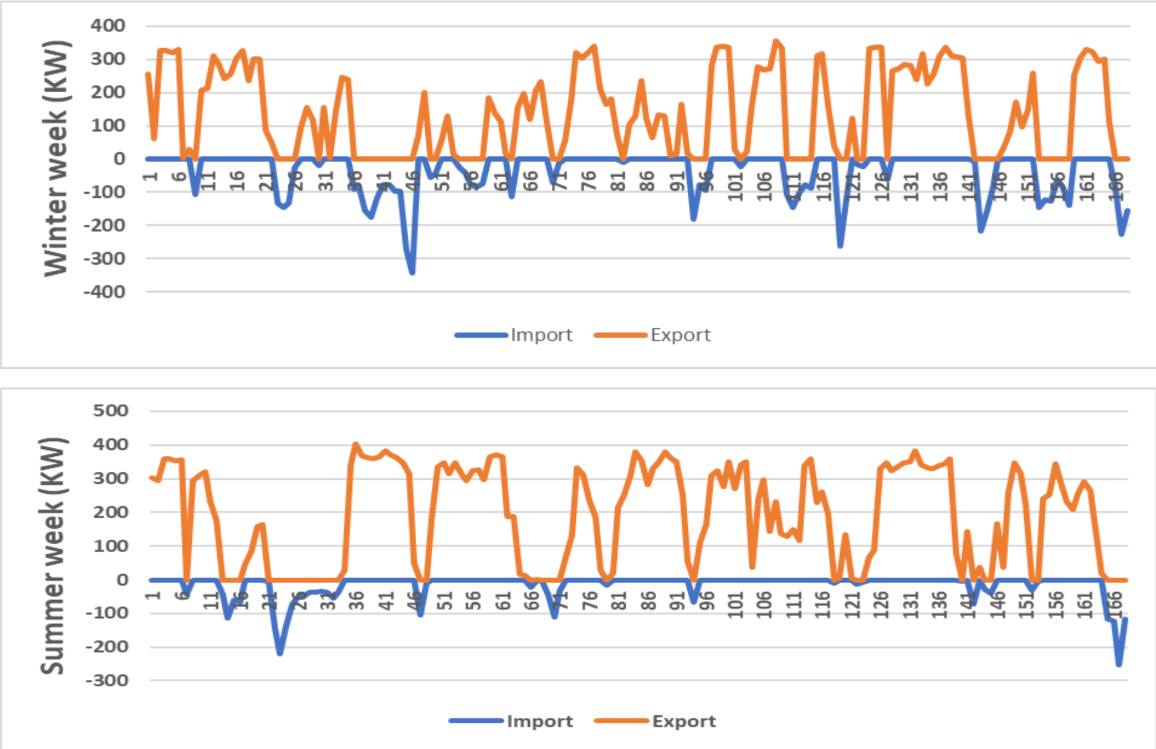


Figure 53: Electrical Import and export in a winter and summer week

Since there are higher values of load in the winter months than in the summer months, there is more import from the main grid than in summer. Even in summer, although generation values are generally well above those of the load, there will at times still be a deficit: periods of high electric demand do not always coincide with those of high generation and vice versa.

Monthly amount of import and export from the main grid

The figure 54 shows the amount of import and export for each month

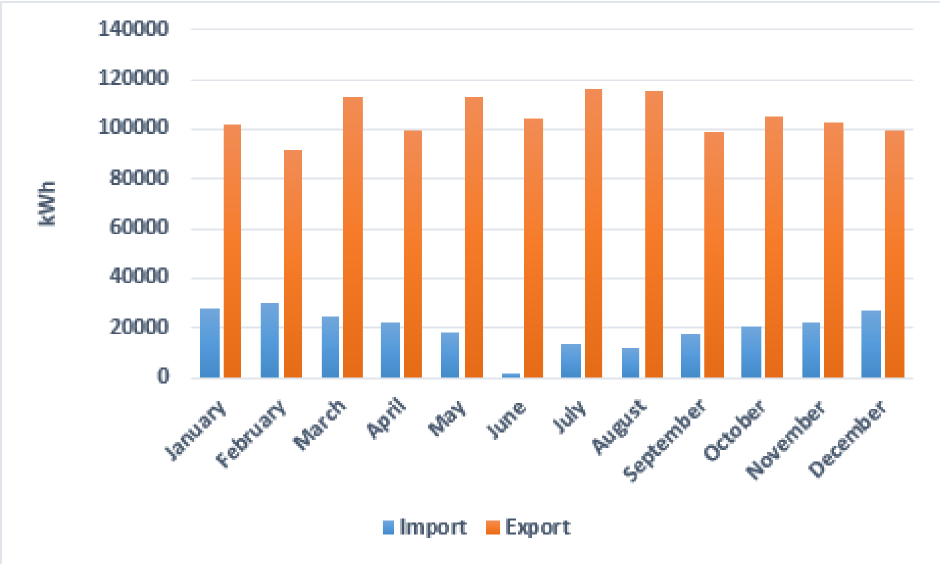


Figure 54: Monthly electrical Import and Export in a year

The values of the exports fluctuate according to the month between the values of 120000 and 90000 kW in the month of February. With regard to imports the highest levels are seen in winter months due to the load.

Economic Results

Given the prices per kW of each component of the system, and price of turbines, the cost for the installed PV capacity of 100kW and four WES100 turbines is summarized in the following table.

	Capacity (KW)	Initial cost (£)	Replacement cost (£)	O&M cost (£)	Lifetime (year)
PV	100	120,000	100,000	2,000/year	25
Coverter	76.1	240	220	9/KW/year	15
4WES100	400	504,000	476,000	22,036/year	20

Table 12: Initial cost of PV plus turbines system

In order to understand the impact of electricity sale and purchase prices on the system, investigations were carried out for each capacity for both fixed and hourly rates. The following table summarizes the different NPC and COE for each situation

.

Capacity (KW)	COE (£) Hourly tariff	NPC (£) Hourly tariff	COE (£) fixed tariff	NPC (£) fixed tariff
0 KW	0.13	1.9 Million	0.15	2.20 Million
100KW	0.12	1.77 Million	0.14	2.05 Million
100KW+ 4xWES100	0.0168	525,463	0.0207	646,663

Table 13: COE and NPC with different tariffs depending of different capacities of generation

For the current system of the village with no type of generation, both NPC and COE have highest values, despite there being no initial cost of installation. The price of imports from the grid reaches the NPC of £2.2 M for fixed tariff, however for the hourly tariff we find lower values, since much of the electricity consumed by the village is in valley hours at a reduced price. Adding up to 100kW PV generation capacity, lower NPC and COE values are found. In spite of having an initial cost for installation, it reduces the imports from the main grid thus reducing these costs. For the hourly tariff the values are lower than for the fixed tariff, for the same reason as before.

And in the last scenario of 100kW of PV plus four WES turbines there will be found the highest initial cost, however there are also the lowest values of NPC and COE as it has substantially reduced imports from the grid. Again, use of the hourly tariff produces lower values than the fixed tariff.

Cash Flow by component

Figure 55 shows the cash flow of the different components of the system

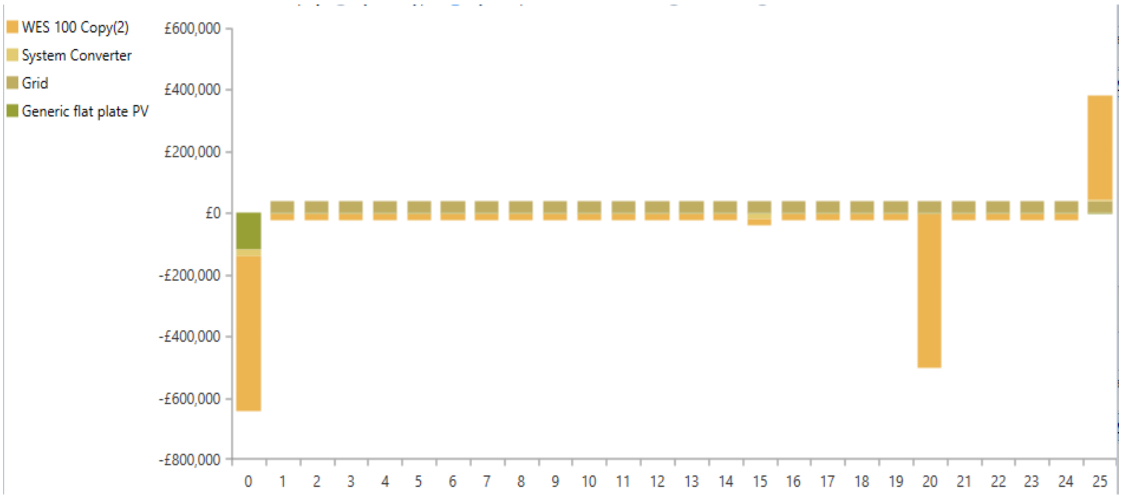


Figure 55: Cash flow for different technologies and electricity prices in the project

For year 0, the 100kW of PV, the converter system and the four WES100 turbines demand a capital cost of £120,000, £18,275 and £504,000 respectively. In the following years of operation there will be the cost of maintenance of the turbines, PV panels and converter and a steady income calculated by subtracting the sales of electricity to the main grid from the purchase. For the year 15 there will be a replacement cost of the converter and for the year 20 the replacement cost of turbines.

7.3.4. Conclusion

In this second scenario, by adding the four wind turbines WES100 to the 'existing' 100 kW of PV it was found that 89.9% of the needs of the village could be covered. The vast majority of this (over 90%) comes from the wind turbines. The intermittency of the wind supply will inevitably cause problems with matching supply to demand, but with a grid connection this is not a serious issue. It would be worth examining the potential role for energy storage even on this site, given the possibility of variable tariffs both now and in the future.

The variations in the NPC, COE and the percentage of energy generated and load met by generation after and before adding the four turbines are represented in the table below. A further entry is made, intended to show whether the 100 kW of PV system with four turbines is better economically and technically speaking than generation from a hypothetical system using 500 kW of PV alone.

	COE Fixed tariff(£)	NPC Fixed tariff(£)	COE Hourly tariff (£)	NPC Hourly tariff (£)	Energy consumed onsite (%)	Load met by generation(%)
100KW	0.14	2.05 Million	0.12	1.77 Million	93.88	15.03
100 KW PV +4x WES100	0.0207	646,663	0.0168	525,463	40.78	78.45
500KW	0.0989	1.94 Million	0.0841	1.65 Million	50.28	40.27

Table 14: Variation of COE, NPC, Energy consumed onsite and load met by generation adding solar Capacity or wind capacity

In the transition from single PV capacity of 100kW to that of 100kW of PV plus the four turbines is observed that despite having a higher initial cost, the NPC has fallen by more than £1,000,000, since imports from the grid have declined. The percentage of renewable energy consumed onsite has fallen from 93.88 to 40.78% since exports are greatly increased, and the percentage of load met by renewable generation has increased to a figure of 78.54%.

Is it better economically and technically speaking to use two technologies with different characteristics than a single technology?

From figures in the table the answer would seem to be yes. Economically the combination of PV and wind turbines obtains a much lower NPC compared to 500kW of PV alone. Technically it is also more advantageous as it achieves a percentage of load met by generation of 78.45% compared to only 40.27% from PV. It is reasonable to say that the combination of two or more technologies will always be more beneficial and economical since different sources can frequently complement each other, generating energy over a greater part of the year

The biggest imports of electricity are made in winter and at weekends, when the village is at maximum capacity. The demand peak usually occurs at around 9 p.m. Without the use of storage, any increase of generation capacity will probably decrease these imports, but at other times, exports will be increased to a higher level. Of course the sale of electricity to the grid is not the purpose of the project, which is simply to satisfy the demand of the village.But another method that might be used for the purpose of meeting the demand and reducing energy deficits in this type of system is demand-side management, in which users are encouraged to avoid consuming electricity at times of potentially high consumption.

7.4. Load-side Management

7.4.1. Concept introduction

Observing the demand curve of the village, we can conclude that there are three daily demand peaks: the first occurs during the early hours of the day, the second at around noon, and the third reaching the highest levels from about 8p.m. These peaks will be even higher at weekends.

Measures can be carried out to modify the energy demand of consumers, using methods such as financial incentives. The aim is to encourage the consumer to use less energy during peak hours and to shift consumption to a time when it is low. Effective demand management may decrease total energy consumption, and will certainly reduce peak demands.

Theoretical demand-side measures were simulated: these had the purpose of reducing electric demand from 8pm to 12pm every day by 10%, except at 9pm which is the time with the highest demand peak, when it was reduced by 20%. The energy saved at peak times was instead used between the hours of 4 p.m. and 7 p.m., thus smoothing the demand curve. Figure 56 shows how the demand profile evolved over the following winter day.

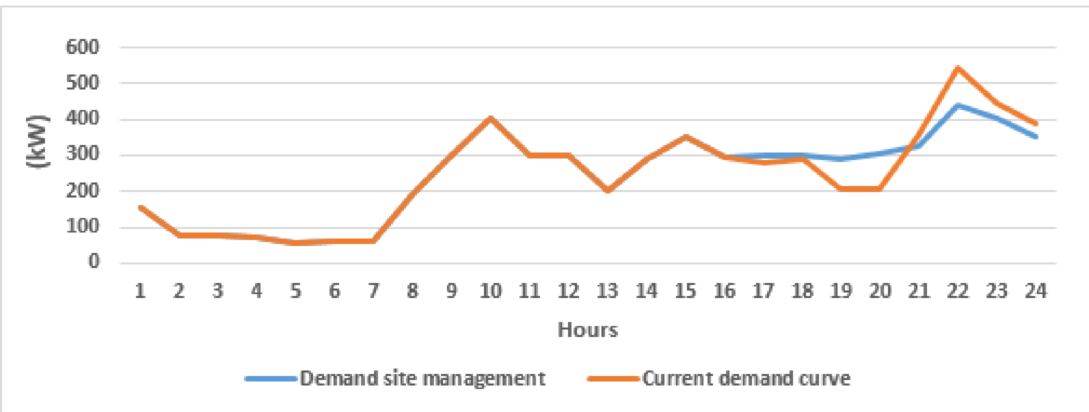


Figure 56: Smoothing the demand curve after the measurement in a day of winter

These measures do not change the electric demand curve in the village until 4 p.m. Users might be encouraged to operate electric heating from 4 in the houses and switch it off after 8 p.m. This measure would reduce the annual consumption and import of the village, and result in a higher percentage of load met by generation.

Comparison of both current demand and demand after measurement with Primary Load throughout the year

Figure 57 shows how the annual demand curve would be modified by the measures described above.

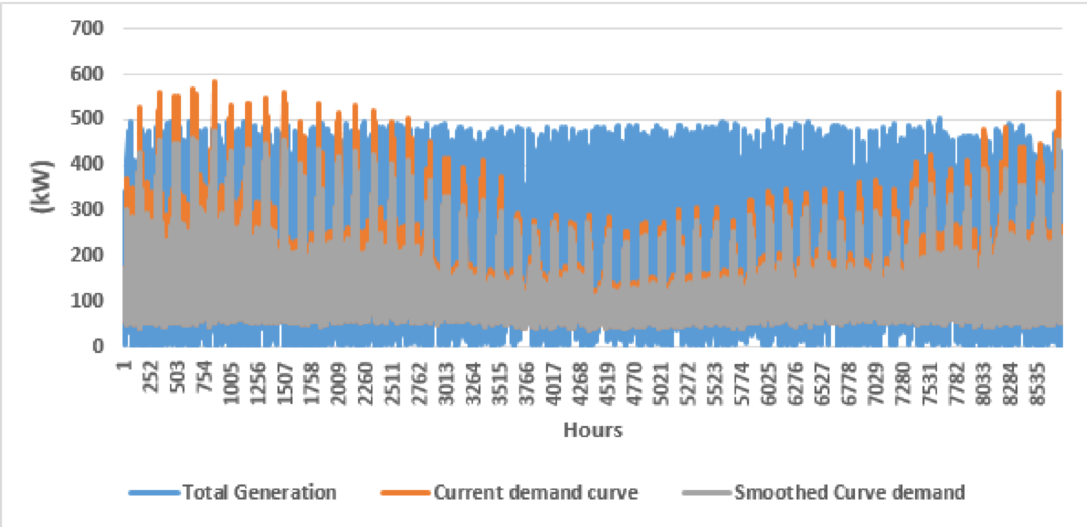


Figure 57: Total generation from the system and AC Primary Load before and after of demand side management in a year

During summer, these measures are not very effective since electricity generation in almost all cases is above consumption. However, in winter they reduce the peaks in demand that previously reached 580kW, well above the maximum renewable generation capacity of 500 kW. These are now reduced to below 500kW, lowering imports and increasing the percentage of load met by renewable generation.

Effects on imports and exports in a typical winter week

The following graph shows the import and export values before and after the demand-side measures

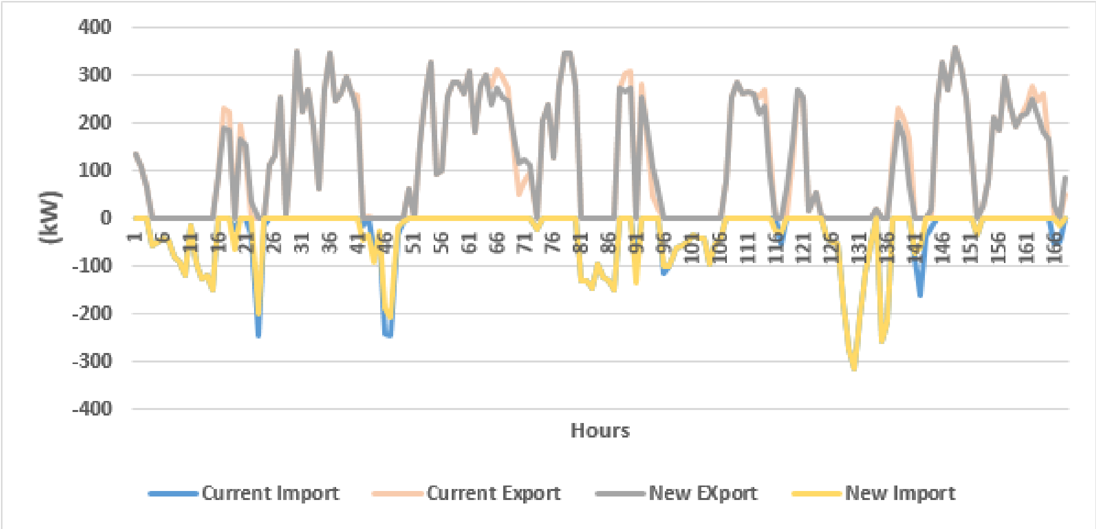


Figure 58: Difference of Electrical import and export in a week of winter after and before the measure

The original import and exports are represented blue and red, while the new import and export values are represented in yellow and grey. As can be observed, there are reductions in some cases with high import values (hours of peak demand) and also the exports (during valley hours). This leads to an increase in the percentage of energy consumed on site and load met by renewable generation. But the overall effect is relatively small.

Table 16 summarizes the main differences between the system before and after the measures of demand-side management, for an hourly tariff.

	Current Demand	Demand-side Management demand
Import (kWh)	247,175	235,708
Export (kWh)	1,265,745	1,247,089
Energy consumed onsite (%)	41.01	41.54
Load met (%)	78.22	79.23

Table 15: Difference of Import, export percentage of energy consumed onsite and load met before and after de measure:

After these measures, the imports and exports were reduced by 11,467 and 18,656 kWh respectively, thus increasing (slightly) the percentage of energy consumed onsite and load met by system. This measure will also have an economic benefit for both tariffs since there are less imports, and with no change in initial cost will reduce the NPC and COE.

7.5. Case 3 : Adding Storage to the system

It is clearly an option to add storage to the system, in order to reduce imports from the grid at times of low generation and high demand, and to reduce exports when the situation is reversed. In this way we may approach the use of 100% of the available renewable energy. The study will be confined to the use of the main types of electrochemical batteries currently available, namely lithium-ion, vanadium flow batteries and finally lead-acid.

In the simulation with HOMER, the batteries are considered as a device capable of absorbing DC electricity, to be stored until the moment of discharging. The amount of energy that any battery can store, and the number of times it can be charged within its useful life depends on different factors such as:

- **Nominal capacity**: The capacity of a battery is the amount of electricity it can provide to a load. It basically depends on three parameters: discharge rate (or speed at which we discharge it), temperature and final voltage.
- **Round trip efficiency:** It measures the efficiency of the battery or bank of batteries over the charge/discharge cycle. Typically, it is around 80%.
- **Minimum and maximum state of charge:** This data specifies the level to which the battery may be charged and discharged. This factor is also linked to the efficiency and life of the battery.

Homer applies two different methods for specifying battery life. These are presented below.

- **Battery cycle life** specifies the life expectancy that a battery has, to the time that it must be replaced.
- **Lifetime throughput** estimates the number of cycles until the battery fails, and is a function of discharge level. In other words, a battery that is routinely fully discharged will give less cycles than one that is discharged at 40%.

With the use of battery, the associated converter carries out two processes:

- Inversion: converts DC electricity from solar panels and batteries into AC to be consumed by the load.
- Rectification: the reverse process, in which AC energy generated for example by wind turbines is transformed to DC to be stored in the battery.

In control system of HOMER, there are two methods of electrical delivery. One is the cycle charging method (CC), in which electricity used to charge the batteries comes from the main grid. Here, the use of batteries would not lead to our main objective of reducing imports and increasing the fraction of renewables supplied to the system. Therefore, the implementation of CC would only lead to an increase of COE and NPC, since meeting the demands of the load would require the same amount of imports, and there would be a higher initial cost. The other method of sending electricity is load-following (LF), that only charges the batteries from the surplus generation of our renewable system. This method would lead to an increase of renewable fraction, since any surplus could be used in moments that are required, thus reducing the amount of import and export to the main grid.

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HOMER limitation

HOMER in normal conditions will sell any electrical surplus to the grid, and any deficit is imported. However, with the use of batteries, the software automatically uses the method CC, which charges the batteries with energy from the main grid, and does not increase the renewable fraction. This limitation of HOMER makes it difficult to reach our goal. The sellback rate influences the system since HOMER prioritizes the sale of the surplus over battery charging. To prioritize the battery charge it is necessary to prohibit sales to the grid by adjusting the sale rate to 0 kW and the sell back rate to negative values. It will also be necessary to adjust the purchase rate to a value slightly above the peak demand of the village of Capileira (560 kW), to avoid collapse of the system in cases that require imports from the main grid. This limitation of HOMER will inevitably lead to a COE and NPC greater than the starting value since despite reducing imports, the money generated by exports no longer exists, and in addition of course there will be a higher initial cost due to the batteries. (De bartolo,2015)

	COE	NPC
Sellback condition	£0.0207	£525,463
No sellback condition	£0.0973	£1,430,000

Table 16: COE and NPC before and after prohibiting sale of surplus to the main grid

This prohibition of sellback will make the system economically to require a smaller inverter and rectifier, leading to an increase of imports from 244,263 kWh that existed in the original system with sellback to the grid, to 246,703 kWh

7.5.1. Storage Opportunities in the system

In this section, a study of the different systems as storage opportunities in the village of Capileira is carried out. No lead-acid battery will be analysed in the study because, despite their low cost, they are highly polluting, have a low energy density, have an excessive weight, do not support deep charges and discharges and most of the models in the market do not exceed the capacity of 10 kWh.

Lithium-ion NMC Batteries

Some of the most successful Li-ion batteries are those with a nickel-manganese-cobalt cathode (NMC). Two types of batteries have been selected.

- **Tesla 50 KW Powerpack 2**

This has a capacity of 210 kWh and a power of 50 kW with a dimension per unit of 555 cm × 209 cm × 332 cm. This model is the newest from Tesla, designed to store energy for off-grid and parallel power systems.

The Powerpack 2 is composed of 16 individual battery capsules, built together with a cooling and heating system adapted from the Model S automobile. It incorporates a new inverter specifically designed for the installation.

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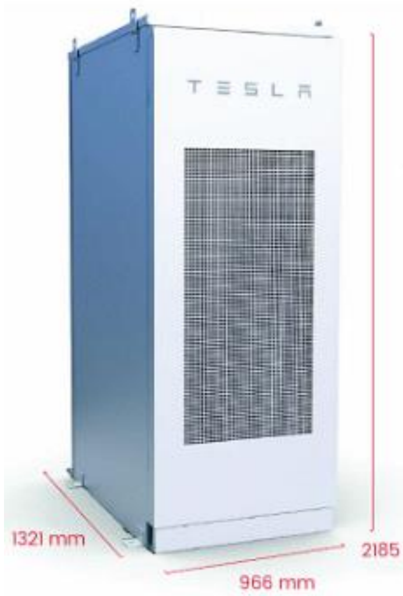

Figure 59: Tesla 50 Powerpack batteries (Klip and Klip, 2017)

There are several recent examples of successful installations of this model such as:
The supplementing of 15,000 solar panels with 30 Powerpacks at the Ash Mountain Solar Farm in Connecticut, USA.
Ta'u, an island of 17 square miles and 787 inhabitants, located in the Pacific ocean more than 4,000 miles off the west coast of the United States, which previously had been supplied by diesel generators. Ta'u now owns a solar farm with 5,328 photovoltaic panels and a system of storage of 60 Tesla Powerpack batteries that can store up to 600 kWh of electricity, sufficient to supply for up to three days without sunlight.

Nominal Capacity (kWh)	210
Nominal Capacity (Ah)	553
Nominal Voltage (V)	380
Float life (years)	10
Roundtrip efficiency (%)	88
Maximal charge current (A)	131
Maximal discharge current (A)	131

Table 17: Tesla 50 Powerpack properties

The minimum state of discharge is stipulated at 10% giving a useable capacity of 0.9 x 210 = 189 kWh so the useable capacity is lower the nominal capacity. The chemistry of the Tesla 50 kW Powerpack is Lithium-ion NMC. According to a report on the development of different storage technologies by IRENA in the year 2016, this type of battery will cost £390/kWh whereas by 2025 (the time of replacement) the price is expected to fall to £220. Therefore, the initial cost of a 210 kWh unit will be adjusted in HOMER to £81,900, the replacement cost to £46,200 and O&M to £1050/year.

- **NEC DSS 170kWh 369kW**

The DSS distributed storage devices have variable rated capacity (85 kWh to 510 kWh) and power (30 kW to 650 kW), and are packaged in cabinets, containing environmental control and safety technology.

Figure 60: NEC DSS 170kWh 369kW **(NEC Energy Solutions, 2016)**

This battery type is present in HOMER, and the properties of it are summarized in table 19.

Nominal Capacity (kWh)	170
Nominal Capacity (Ah)	236
Nominal Voltage (V)	720
Float life (years)	15
Roundtrip efficiency (%)	96
Maximal charge current (A)	628
Maximal discharge current (A)	628
Throughput (kWh)	849,996

Table 18: NEC DSS 170kWh 369kW properties

The minimum state of discharge is stipulated at 10% giving a useable capacity of 0.9 x 170 = 153 kWh so the useable capacity is lower than nominal capacity. The chemistry of the NEC DSS 170kWh 369kW is Lithium-ion NMC. Using information from IRENA in the year 2016, the initial cost of a 170-kWh unit is adjusted in HOMER to £66,300, the replacement cost to £27,200 and O&M to £850/year.

RedT vanadium redox technology

After many years of development, companies such as RedT have marketed a new technology that stores electrical energy efficiently in liquid form using a vanadium redox electrolyte. The useful life of these batteries is over 25 years. Due to its low maintenance cost and its standardized modular design that allows easier transportation and dismantling, it has one of the lowest storage costs in the industry. With the passage of time they have been reduced in size, giving more functionality and usability.

Unlike lead and lithium batteries, this type of energy storage system has no risk of thermal leakage and is non-explosive. Its depth of loading and discharging is 0 to 100% without significant degradation, unlike for example lead-acid batteries that suffer degradation by discharging them below 40%.

It would be fair to say that these systems are still at a fairly early stage of development. RedT has successfully installed a demonstration system in Evora, Portugal which has a 5kW rated power with 12 hours (60kWh) storage capacity. This will be used to maximise the efficiency of a 6.6 kW PV array that has been installed on the roof of the hospital and, in the process, help to reduce energy costs. The system is capable of delivering a high-quality domestic 2kW load for 2 to 3 days during periods of low solar output.

There are several sizes of these batteries with rated power hovering between 5 and 120 kW, and nominal capacities between 20 and 300 kWh. For our study of the village of Capileira we have chosen two different models, to examine their performance

- **RedT 5-20**

The smallest machine in the RedT energy product range has a rated power of 5 kW, at a nominal voltage of 48V and rated current of 125 A. The usable depth of discharge is 100%, with a DC/DC efficiency of 70-80% and a life of more than 25 years. Its dimensions are 1830 x 1830 x 1830 mm and its dry weight is 1597 kg.

Figure 61: RedT 5-20 appearance (Description and Applications, 2001)

- **RedT 15-75**

The RedT 15-75 has a rated power of 15 kW, at a nominal voltage of 48V and a rated current of 375A. Again, the usable depth of discharge is 100%, the DC / DC efficiency is 70-80% and the life is more than 25 years. Its dimensions are 3005 x 2240 x 2890 mm and its dry weight is 5500 kg.

Figure 62: RedT 15-75 appearance(Description and Applications, 2001)

These battery types are present in HOMER, and the properties are summarized in the Table 20.

	RedT 5-20	RedT 15-75
Nominal Capacity (kWh)	20	75
Nominal Capacity (Ah)	417	1560
Nominal Voltage (V)	48	48
Float life (years)	25	25
Roundtrip (%)	75	75
Life throughput	876,000	876,000
Maximal charge current (A)	105	313
Maximal discharge current (A)	105	313

Table 19: RedT 15-75 properties

The maximum and minimum state of charge is stipulated at 100% and 0%, with the ability to load and download in full for all models. The chemistry RedT is redox-flow batteries of vanadium. This type of battery will cost between £340/kWh for small capacity batteries and £330/kWh for big capacity batteries whereas by 2035 (the time of replacement) the price is expected to fall to between £145 and £135/kWh.

	Initial cost (£)	Replacement cost (£)	O&M (£)
RedT 5-20	**6,800**	**2,900**	**100/year**
RedT 15-75	**24,750**	**10,125**	**375/year**

Table 20: Prices of RedT 5-50 and RedT 15-75

7.5.2. Simulation Results

For this case only the hourly tariff method of purchase would be used since it was the most economically profitable in the previous case. In order to find out which is the most favourable combination that can complement the generation system composed of 100 kW and four WES100 wind turbines, an economic and technical study was carried out. It was performed with the clear guideline of obtaining a generation and storage system more economically viable than the existing one, that is with a NPC higher than £1.90 million (obtained with the load fully connected to the main grid). The initial cost depends on the nominal capacity and the kWh price of each technology. Therefore, to analyse the feasibility study, several simulations were carried out with each technology, adding a nominal capacity for each battery. For the

Tesla 50 kW Powerpack simulations were performed from 1 to 10 batteries; for the RedT 5-20 and RedT 20-75, 10 to 100 and 3 to 30 units were used; and finally, for the NEC DSS model 170 kWh, 2 to 20 units were simulated. The purpose of this process was to obtain similar nominal total capacities for each battery. The following table summarizes the most technically advantageous simulations (with the highest percentage of load met by generation) and with the COE and NPC not exceeding £0.13 and £1.90 million respectively.

	Quantity	Usable nominal capacity (kWh)	COE (£)	NPC (Million£)	Import (kWh)	Load met (%)
RedT 15-75	**24**	**1800**	**0.126**	**1.85**	**35857**	**96.84**
RedT 5-20	**90**	**1800**	**0.127**	**1.87**	**35844**	**96.84**
NEC DSS 170kWh	**8**	**1360**	**0.126**	**1.84**	**38428**	**96.14**
Tesla 50 PowerPack	**5**	**1050**	**0.124**	**1.82**	**54292**	**94.66**

Table 21: Difference of Load met by generation of technologies with a NPC lower than £1.9 million

It is observed that the two combinations with the smallest imports and therefore the greatest percentage of load met by renewable generation are the cases with 24 batteries RedT 15-75 and 90 RedT 5-20 with 96.84%. The difference between these two vanadium redox batteries is the cost, since the RedT 15-75 has a lower COE and NPC. The lithium-ion batteries give inferior performance as their initial cost is higher, they have a shorter life time and they do not take full advantage of their nominal capacity. Marginally, the best option to complement the generation system is that of 24 RedT 15-20 summing 1800 kWh of nominal capacity.

With the use of 8 batteries of Tesla 50 Powerpack would have a nominal capacity of 1680 kWh and would obtain a greater percentage of load met by generation (96.8%) than obtained by RedT 15-75. However, the NPC would be well above the limit of £1.9 million. Lithium-ion batteries are basically rejected for having a higher price than vanadium.

7.5.3. Simulation results of chosen combination

Technical results

For the configuration of the Capileira system in HOMER it is necessary to use the parameters represented in Figure 63

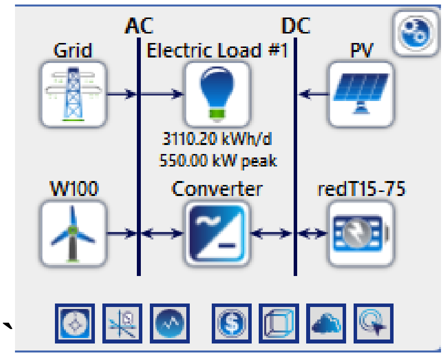

Figure 63: Configuration of the energy system of Capileira with the use of storage

The system consists of our profile demand, the main grid, photovoltaic panels, converter, wind turbines and batteries. The electrical system is connected to the grid and the electricity from both turbines and PV can be used to supply the electric load. The 4 WES turbines are connected to the AC electric bus and to the load, whereas the solar panels and batteries require a converter.

Load met as a function of the combination of components

Figure 64 shows the percentage of load met by renewable generation, depending on the number of RedT 15-75 units used.

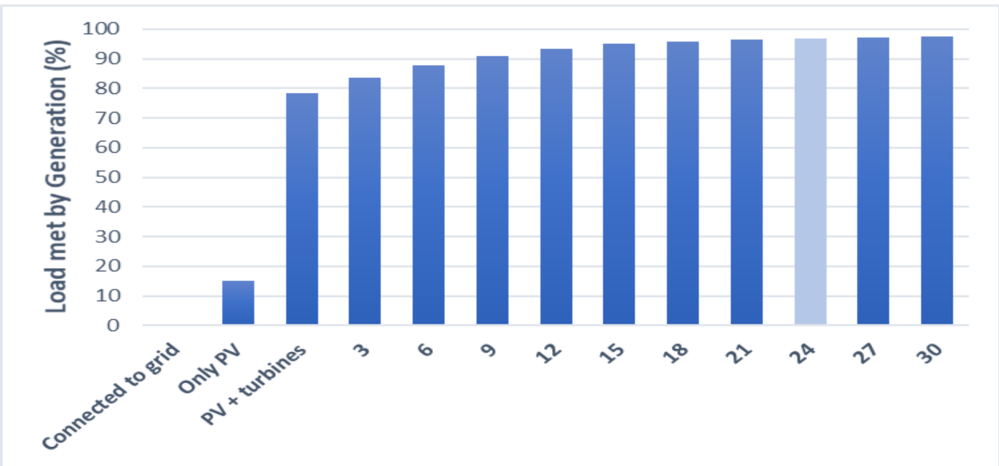

Figure 64: Variation of load met by generation depending of capacity of generation and numbers of RedT 15-75

As previously stated, the percentage of load met by generation met by combining the PV system with the four wind turbines reaches 78%. With the use of the batteries there is an increase in this percentage, with steadily diminishing impact as we increase the nominal storage capacity, by adding batteries in multiples of three up to the nominal capacity of 1800 kWh with 24 batteries.

Reduction both import and export in a winter week

The following graph shows the import and excess values before and after adding 1800 kWh of storage nominal capacity with 24 RedT 15-75 in a typical week of winter.

Figure 65: Difference of electrical excess and import before and after the use of forty RedT 15-75 batteries

As we are prohibiting sales, there will be no exports to the grid so if energy cannot be stored by the batteries it will be wasted. There is a clear reduction of excess and of imports from the grid with the use of 24 batteries. The values of the electrical excess are lower because some of this is used to charge the batteries up to their maximum capacity. The values of imports from the main grid are reduced since the energy stored in the batteries is used at times of little generation or much electrical demand.

Import reduction by month

Figure 66 shows the values of imports before and after installation of the batteries.

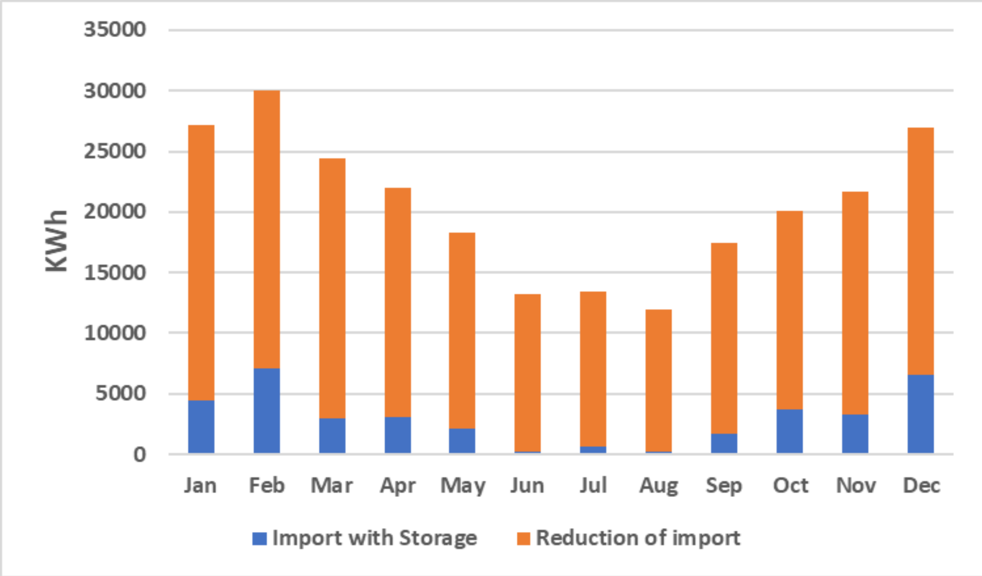

Figure 66: Monthly Electrical Import and reduction of import with the use of storage

There is import reduction during all the months of the year, with the greatest in February with a fall of 23,018 kWh (this is the month with highest demand values). The month with the smallest import reduction is July (12,885 kWh), which is one of the months with the smallest demand. In general, the addition of the 24 RedT units will reduce imports with respect to the initial system (no storage) by 82.99%.

Sensitivity analysis impact of the converter size

It is necessary to calculate the capacity of the converter that changes the DC electricity generated by the PV panels into AC to be consumed by the village (inverter); also the capacity used to convert AC from the wind turbines into DC for storage in batteries (rectifier). HOMER specifies the optimum capacities, as shown in Table 23.

PV (kW)	Grid (kW)	Inverter (kW)	Rectifier (kW)	Dispatch
100	0	61	58	LF

Table 22: Optimal Inverter and rectifier size in the system

The best result is obtained with an inverter conversion capacity of 61 kW, since the maximum power of the inverter is 70.3 kW, while for the rectifier it is 58 kW

Financial Results

The cost of components for the new system are summarized in the following table.

	Capacity (KW)	Initial cost (£)	Replacement cost (£)	O&M cost (£)	Lifetime (year)
PV	100	120000	10000	2000/year	25
Coverter	76.1	240	220	9/kW/year	15
4WES100	400	504000	476000	22036/year	20
24 RedT	1800 KWh	594.000	243,000	9,000/year	25

Table 23: Initial cost and lifetime by technology

The value of the initial cost with the addition of batteries will increase considerably. The storage is the component with the greatest initial cost, surpassing the 4 wind turbines. However, for replacement costs it is estimated that the price of redox batteries will fall considerably in the next few years while the price of wind turbines will not.

Cash flow

Figure 67 shows the cash flow of the different components of the system

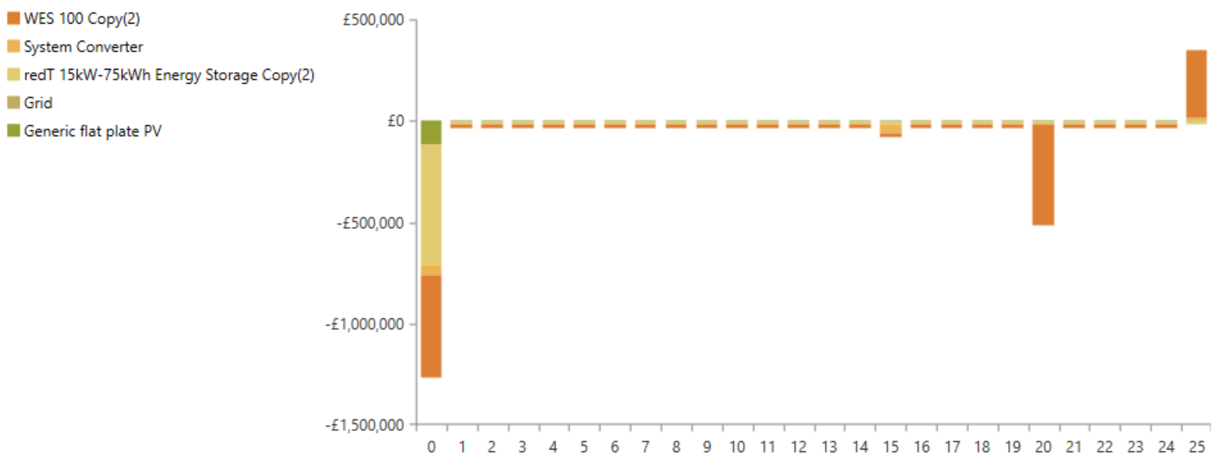

Figure 67: Cash flow by technology of the system

For year 0, the 100kW of PV, converter system, four WES100 wind turbines and 24 RedT batteries there is a capital cost of £120,000, £18,275, £504,000 and £594.000

respectively. For the following years of operation there will be the cost of maintenance of the turbines, PV system and converter, and a calculated income obtained by subtracting the sales to the main grid from the purchase. For year 15 there will be a replacement cost of the converter, and for year 20 the replacement cost of turbines. And finally, in the last year there will be a cash return for the salvage

Conclusion: generation versus storage

From the analysis of the system consisting of 100 kW of PV capacity, four WES100 turbines and the 24 RedT batteries, it was found that 96.84% of load met by renewable generation will be achieved. This leads us to the question of what would happen if we reduced the storage capacity to add more generation? What would be the optimum extra solar or wind capacity? The table below summarizes possible results after a decrease of 3 or 6 batteries and adding generation.

	NPC (Million £)	**Import (kWh)**	**Load met by generation (%)**
4 turbines + 100 kW + 24 batteries	1.85	35857	96.84
5 turbines + 100 kW + 21 batteries	1.97	33379	97.05
4 turbines + 200 kW + 21 batteries	1.81	37976	96.65
6 turbines + 100 kW + 18 batteries	2.18	29581	97.39
4 turbines + 300 kW + 18 batteries	1.96	33862	97.01

Table 24: Generation versus Storage

Some combinations are found that exceed the original percentage load met by generation. Two of these result from applying three or six less batteries and one or two more wind turbines; a third uses an extra 200 kW of PV capacity; however, these would each exceed the NPC limit of £1.90 million. And in addition, there would be a substantial increase in surplus energy wasted since sale to the grid is prohibited.

The only combination that would not exceed the NPC limit would involve adding 100 kW of PV capacity and subtracting three batteries from the system, but then the resulting load met by generation would be less than the original. Therefore, the most advantageous combination technically and economically appears be the one first selected.

7.5.4. Conclusion

An increase in the percentage of load met by renewable generation of 18.54% was achieved by the addition of 24 vanadium redox batteries. This brings us very close to the initial goal of achieving a 100% of load met by generation, however to reach this goal is a utopian since the total life cost of an offgrid system would be approximately 3 times more than being connected to the main grid. This is due to several economic factors:

- ❖ By prohibiting any sellback to the main grid the system stops perceiving a benefit for the energetic surplus generated.
- ❖ The price to buy electricity from the main grid: for the last case investigated we have used only the hourly tariff system since it has been proven to be the cheapest rate for the village. The present system without renewable generation consumes all its electricity from the main grid, having a NPC of £1.90 millions, therefore any system that exceeds that price is not economically viable. However, if we look at conditions using the fixed tariff, an NPC value of £2.20 million would be obtained resulting in more potential for battery installation, thus increasing the load met by generation.
- ❖ The last factor is the price of the technologies for generation and especially for storage, since often the implantation of storage in distributed systems of self consumption does not deliver a good economic result. Maybe in the near future this will change, if prices continue to follow present trends.

To demonstrate this, an analysis of the system of the village with purchase from the main grid by means of the system of fixed tariff has been completed (fixed price of £0.15/kWh), that supposes a NPC greater than £2,2 million. In addition, the initial cost of the batteries was adjusted to a value equal to the current replacement cost, thus simulating a project carried out in the future. Hence the capital and replacement costs were £10,125 with an O&M cost of £375/year. Table 26 summarizes the results.

	Number of batteries	No generation NPC (million £)	NPC given by system (£)	Load met (%)
Hourly tariff Current Price	24	1.9	1.85	96.84
Fixed tariff Future price	69	2.2	2.16	98.49

Table 25: Difference of load met by generation achieved with different tariffs and their NPC

As expected when applying the fixed tariff of purchase to the main grid, the limiting NPC that can be achieved for the project to be viable was £2.2 million, higher than the hourly rate with £1.9 million. Therefore, a larger margin is available. Also adjusting the price of the battery to a lower value, permits the installation of 69 batteries RedT 15-75 obtaining a NPC of £2.16 million and reaching a percentage of load met by generation of 98.49%. The goal of getting 100% of load met would be even closer.

Nevertheless, another important problem is the fact that beyond certain levels, increasing the nominal capacity of the batteries does not bring a great increase of the load met by generation, due to the existence of high peaks of demand in the village that are difficult to supply. Therefore, it would be necessary to consider the technique of demand side management described in section 7.4.

Demand side management

The current demand and the demand after this measure have the same NPC limit of £1.9 million in the hourly tariff of purchase from the main grid. However, by smoothing the demand curve and reducing demand peaks, we reduce the necessary imports from the main grid. The results obtained before and after the measurement are summarized in the following table.

	Batteries	NPC (Million £)	Import (kWh)	Load met by generation (%)
Current demand	24	1.85	35857	96.84
Demand site management	27	1.9	13065	98.72

Table 26: Difference of load met by generation achieved after and before of measure

By decreasing imports with the same initial installation cost the NPC will be lower, and therefore another three batteries could be added without exceeding the limit of £1.9 million to make the project economically viable. With this process, the percentage of load met by generation of 98.72% will be reached. It is interesting to note that this load met by generation using and only 27 batteries is larger than previously obtained using 69 batteries.

8. Discussion of work

The work reported here followed the development of a methodology to achieve an unconventional electrical generation system with storage connected to the network in a village in southern Spain. The village presented an electrical load with very large variations, due to factors such as the difference in climate between winter and summer and the strong influence of tourism. Careful analysis allowed the elaboration of an electrical supply system that can approach energetic autonomy for this village, and has the ability to inject surplus electricity into the grid.

The correct sizing and configuration of the renewable energy supply system is of course critically dependent on patterns of energy demand. The usual difficulties were encountered in arriving at an accurate estimate of demand in this case. From the information obtained, a number of supply and storage options have been investigated to obtain the preferred solution from a technical and economic point of view. Cases were also considered using a modified demand, associated with a more efficient control of consumption (demand-side management).

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8.1. Effects of adding solar capacity to the Capileira energy system

With solar energy as the only renewable source of generation in our system, it was found that imports from the grid could be eliminated at certain times, but the system remained highly dependent on imports for the most part. Increases in solar generation capacity from 50 to 900 kW were considered: larger capacities brought greater potential for exports, but struggled to make an economic case. Imports from the grid were reduced to a much smaller extent than exports were increased.

From an economic point of view, it might be hoped that any introduction of a generation system in the village would be a profitable business, considering the high taxes presently imposed in the village. There is also the prospect of exporting electricity to areas peripheral to the project (in this case, the southern coast) during the central hours of the day, particularly in summer months. Demand for air conditioning in these regions is already high and is increasing, and has a strong correlation with the availability of energy from PV systems. The electricity could probably be sold back at a higher price than normal, acquiring more benefits. In mountain sites such as the village considered here the effectiveness of PV systems is particularly good, because of the high radiation levels and low ambient temperatures. There may be very significant future opportunities here.

The economic factors for the village site were measured considering the NPC, which takes into account the initial cost of the project and the purchase and sale costs and benefits of the network. It was observed that for any low capacity the installation was profitable since the NPC decreased for each extra unit of capacity added. However, the NPC began to increase beyond 500 kW of generating capacity, due to declining reductions in imports from the grid.

It is obvious that a single PV installation alone without storage, could never achieve 100% of load met by renewable generation. An extreme example is that with a capacity of 900 kW, 144% of the load was generated in total values, but only 47% of the actual load in the village was met by renewable generation.

Even though the optimum capacity in economic terms was 500 kW, there were other practical considerations in the village of Capileira. Planning and conservation laws prevent the installation of PV systems on the roofs of buildings, and the only feasible alternative site is a small space enabled by the municipality, where a capacity of approximately 100 kW might be installed, contributing only 15% of the needs of the village in total energy terms. With this maximum generation capacity of 100kW and a maximum demand of 550kW, it would require another technology with perhaps different generation characteristics to complement the existing one.

8.2. Effect of adding wind capacity to the Capileira energy system

Adding a second energy source to complement the existing one produced a remarkable technical and economic evolution. Wind turbines rated at 100 kW each were specified, limited by a specific law of Sierra Nevada National Park which prohibits any turbine installation with hub height higher than 25 meters. The wind resource in the region is very good, partly because of the high altitude. Winds are driven to some extent by thermal effects, generated by the proximity of the coast and arid regions further inland.

Technically the most favourable combination was the one that exploited the slightly different power delivery characteristics of the WES100 and Vestas machines. But finally, it was decided to select four WES100 units, on the grounds that it makes more sense to have a single supplier. In any case, the differences in performance were quite small.

In this second case, adding the four turbines to the existing 100 kW of PV resulted in 78.45% of load being met by renewable generation, a great improvement on the 15% met with only the PV capacity. Economically, with the installation of these four turbines, in spite of having a higher initial cost, there is a drastic decrease in the NPC for both electricity tariffs: a reduction from £1.77M to £525,463 is observed. The explanation for this lies in the fact that by adding the extra generation capacity of another technology such as wind power, they can complement each other by satisfying demand at almost all times of day and year, even at night, differentiating it from the previous case. This leads to a drastic reduction of imports from the grid, and a significant increase in exports, resulting in a greater percentage of load met by generation and a smaller NPC and COE.

To avoid demand peaks, measures were again simulated in which we encourage users to have lower consumption in these critical moments of maximum demand. Since the vast majority of these were between 8 p.m. and midnight, it was sought to reduce electric demand by 10% except at the most critical hour (9 p.m.), when demand was reduced by 20%. Consumption was correspondingly increased in the ‘valley’ hours from 4 to 7 p.m.

It was observed that with the same conditions of generation the percentage load met by renewable generation rose, to a value of 79.23%. It was clear that there was little prospect of increasing it further without introducing a system of energy storage.

8.3. Effects of adding storage capacity to the Capileira energy system

Simulating the system using HOMER suffered from a limitation. Adding a nominal capacity of storage did not lead to any increase in the percentage of load met by renewable generation, since the software assumed that the batteries were charged by imports from the grid, not from the surplus renewable energy. To try to avoid this limitation, some parameters were added in the conditions of the grid, which prohibited the sale of any energy surplus and limited the purchase of imports from the grid. Technically, this change was positive, since the use of batteries now increased the percentage of load met as expected, but economically it was a step backwards, since despite decreasing the amount of imports, a higher initial cost was required for the storage system, and this could not be recovered from the energy surplus which would in reality be sold to the grid.

Two types of lithium-ion and two of vanadium redox batteries were selected for investigation, avoiding the well-known alternative of lead-acid batteries due to their well-known limitations such as low nominal capacity, low discharge depth and so on.

By means of simulations with HOMER, it was concluded that for capacities around 1800 kWh the two lithium-ion types gave better technical performance in that greater percentage load met by generation was achieved, despite having limited their depth of discharge to 10%. However economically they were less attractive than the vanadium redox, surpassing the NPC limit of £1.9 million that was set by the initial system.

Therefore, the combination of the generation system mentioned above plus the complement of 24 RedT 15-75 batteries, with 1900 kWh of nominal capacity was selected. This did not exceed the NPC limit of £1.9 million in the useful life of the project. Technically this combination was productive since the load met by generation was increased by approximately 18.54%, reaching 96.84% with the remaining percentage requiring to come from imports from the grid.

Under these same conditions simulations were carried out increasing the capacity of generation and reducing the nominal capacity of storage, which produced technically better results (increasing the renewable generation), but economically deficient since they exceeded the limit of NPC. Therefore, it was concluded that the system with the best technical-economic performance was the combination selected.

Another study carried out, to illustrate how important the purchase price is to the viability of the network and its technologies. A simulation was conducted with the same conditions of generation and storage within the system, using a fixed tariff and with a lower estimated initial cost price for storage technology. In this case the NPC limit for the project to be economically feasible was £2.2 million, therefore there was the possibility of installing extra nominal capacity up to the figure of 69 batteries, resulting in 98.49% of load met.

There is of course the serious inconvenience of finding space to house the 69 batteries. Therefore, if we could encourage a change in the consumption behaviour of the user and thus avoid peaks in demand, imports could be reduced in the useful life of the system thus reducing the NPC. There would be the possibility of employing 27 batteries, without exceeding the NPC limit of £1.9 M for a fixed electricity tariff, reaching the load met by generation of 98.72%. It was concluded that this measure of demand control achieved more beneficial results. Previously with normal demand in many cases, despite having a nominal storage capacity of 1800 kWh, there was not enough to store all the energy needed to cope with peak demand.

Above all, the viability of a proposed system depends substantially on prices. As is described in the literature, the prices for purchase and sale for the grid network fluctuate at a dizzying pace, although the long-term trend seems to be steadily upward. The price ranges of storage technologies can vary greatly and here the trend is sharply downwards, driven to a large extent by the automotive industry. Lithium-ion batteries are well established here and would be expected to develop better performance and longevity, as well as reduced costs. Renewable energy systems are benefitting from the spin-off in the form of increasingly attractive energy storage packages such as those marketed by Tesla.

The vanadium redox units chosen here are not (in their present form) suitable for automotive use and so are under less intensive development, but costs are still expected to come down. Many other types of chemistry are under investigation, so the possibility of a technical breakthrough (and hence a step change in costs or performance) is reasonably high. The effects of such changes on the findings reported here could be dramatic.

There may be another ally of distributed generation systems, in the form of the electric car. It has been said that the electric car can be a key tool to contribute to the electrical management in a region or community. We could look at the village used in the case study: according to the city council, there are 254 cars registered in the village, of which only 12 are electric, but soon it is expected that the number of these will increase considerably. Imagine a future in which all the cars of the village are electric, for example cars like model S of Tesla with 70 kWh (Tesla Motors Inc, 2015) of nominal capacity of battery. It might be possible to encourage the owners in the village, and even the visitors, to store energy at times of low demand and sell it back to the microgrid at a time of great demand, receiving an economic incentive. It would help to solve the problem of imports and exports without the expense of installation of separate fixed battery units. But whether this is a realistic prospect is far from clear: vehicle owners will require strong incentives to accept the risks and inconvenience that this would bring.

8.4. Demand-side management

A very important factor in the implementation of this type of project is demand-side management. Currently of course this is not a feature in the village of Capileira. It requires the introduction of measures such as:

- The application of a system of variable electric prices and tariffs depending on the times of the day and the year, responding to the availability of local energy and anticipated demand;
- The implementation of procedures to encourage the active participation of the village population in managing their energy demand: users are informed of energy prices so that they can react to them, and in so doing, they contribute actively to the formation of the prices;
- The application of economic incentives for the installation of new equipment

with lower electrical consumption;

- ❖ Training and awareness-raising programs to encourage new consumption patterns;

- ❖ The creation of appropriate regulatory frameworks to accompany demand management programs such as those just described

9. Concluding comments

9.1. Recommendations for future work

The work described here could serve as a template for investigations of other case studies. It has been demonstrated that costs (including tariffs and subsidies) form a vital part of any feasibility study, and it is essential that figures used for present-day or future scenarios are as realistic as possible.

Given the potential future fall in the cost of storage systems, and the volatile nature of electricity 'spot' pricing on national grid systems, it would be interesting to see what conditions would be needed to make the strategic use of storage a profitable business. That would be a useful extension of the present work. As well as battery storage, future studies should consider alternative methods where appropriate, although in many cases the choices are likely to be limited.

9.2. Final conclusions

A number of cases have been presented using renewable energy sources, supplemented by storage devices and demand management, for a mountain village in southern Spain. The village in question is of historical interest and sits within a national park, which imposes restrictions on what can be done. Conclusions have been drawn on the technical and economic feasibility of the schemes presented, and an 'optimal' configuration has been proposed.

Taking more general conclusions from the case study, it has become clear that the economic and regulatory arrangements in Spain could be more supportive of low-carbon initiatives such as the one proposed here, and that conditions must change before much progress can be made. Given the trends in costs of certain key elements in renewable energy systems and increasing concerns over climate change, it seems likely that more favourable conditions will soon emerge. Costs for PV systems continue to fall, and there is intense technological development of battery storage. Future expansion of smart metering and changes in the marketing of electrical energy may eventually make the short-term exploitation of storage systems an attractive financial proposition.

The work has served to highlight the great advantages that the mountainous climate provides in the Mediterranean area for this type of project since by increasing in altitude above sea level, there is a greater potential of sources. Solar power output is directly affected by the amount of vertical readjustment received and the ambient temperature. This location already enjoys high radiation, because it is in the Mediterranean area. Also, the potential of wind energy output will be increased by height in the mountain zones. The winds are driven by a combination of weather systems and thermal effects, and there are no prolonged periods of calm weather. Therefore, the area should see more projects like this as they would help to acquire a certain independence, leading to a global distributed generation in the area with potential for the export of large quantities of energy to meet demand at lower altitudes.

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Appendix I

SURVEY

1. **What type of heating is used in your house, restaurant or hotel?**

Gas	Biomass	Electrical

2. **In case of having electric heating, at what times of the day and for how long are they used?**

Answer:

3. **Throughout the day, at what time is electricity consumed in your house, restaurant or hotel?**

1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24

4. **Could you rate from the 1 minimum demand to 5 with the highest demand from your point of view?**

Answer:

5. **Could you tell me from your point of view what the percentage of electric demand would be for each day of the week?**

Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday