Wydział Elektryczny

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INDUSTRIAL ENGINEER

BACHELLOR THESIS

FEASIBILITY STUDY OF AN HYBRID ENERGETIC SYSTEM FOR HOUSEHOLDERS IN SPAIN

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INTRODUCTION

Objectives

The main objective of the following Project is (as it can be read in the tittle) to study how feasible is to supply electrical energy to a group of householders in a chosen spanish region by using just an hybrid energetic system.
First of all, it is so important to know which is the current spanish energetic context, paying attention to the economical and legal ones overall. Furthermore, our hybrid system is using some renewable energies, thus, the current and future situation of them must also be taken into account.
Once this first part will be over, the technical and economical studies must be completed, followed by the final conclusion (“feasible” or “not feasible”).
In conclusion, there will be many other intrinsic objectives as knowing the energetic spanish context or to learn how much the energy costs currently. Otherwise, these two last objectives are relationed with the academic training of the student.

Hybrid energy system

An hybrid energy system is basically the combination of more than one energy source to supply finally the electrical energy to the consumers (industry, householders…). These sources used together to provide increased system efficiency as well as greater balance in energy supply
This kind of system simply has to convert the energy from each source to electricity and combine all of them, modifying the necessary parameters to fix it correctely.
Currently almost all the hybrid energy systems use renewable energy sources, thus, ours will also do.
Furthermore, these are becoming popular as stand-alone power systems for providing electricity in remote areas due to advances in renewable energy technologies and subsequent rise in prices of petroleum products.

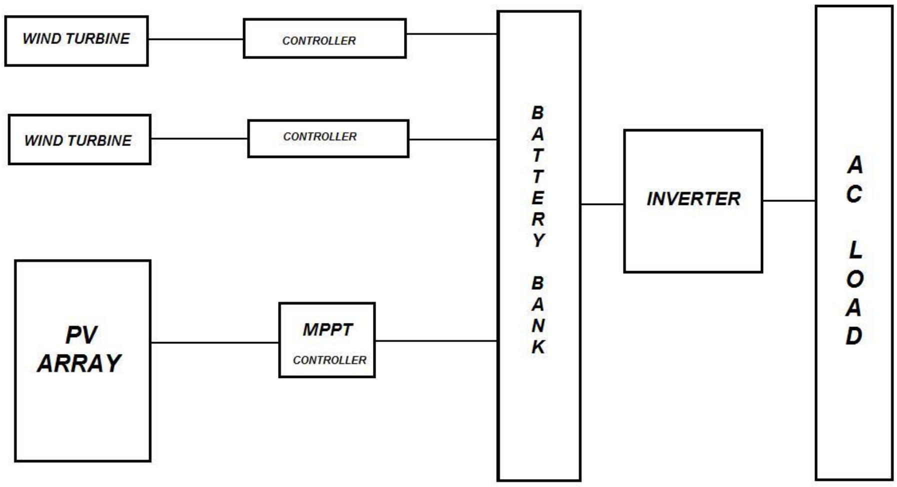


Figure 1. *The picture above consists of a block diagram of a typical hybrid energy system which combines the wind and photovoltauc energies. It is easily observed how the system works: the energy from the different sources are capted (by the wind turbines and the solar panels) to be converted into electrical enrgy which is stored together to be supplied later to the consumers.*

Hybrid energy systems in Spain

The hybrid energy systems have a lot of characteristics and features which make them such a great solution and alternative to the clasical energy systems. Moreover, these kind of systems are expected to help with the "world's environmental commitment". Otherwise and by the moment, the most combined energy sources "for building" an hybrid energy system are the wind and the solar.

Nowadays there are several spanish enterprises and groups of them which are doing a lot of researchings and working constantly to introduce and improve the combination of more than one energy sources, and which are being exposed in the following lines.

Firstly, we could talk about "SME" Enterprise, which in 2008 began a project called "Enviromental Challenge" based on the active working in sustainable measures and whose bases are: the energetic efficiency, the reduction of CO_2 emissions and the minimum enviromental impact. Furthermore, they designed an hybrid system denominated "EcoCube" which collects the best features of each energy system and can deliver a "high quality electricity supply".

Acciona is also investing its time and money in this way of electricity generation and storage.

First of all, there is a program called "Renewat" which consists of an hybrid renewable energy system (combining 5 kW of wind energy and 100 kW of photovoltaic energy along with an energy storage system), and whose main objective is to decrease the energy consumption in a water treatment plant (the consumption of these kind of plants in Spain represent 2213 GWh/year which leads to 27170700 CO_2 tons released to the atmosphere each year).
Furthermore, this enterprise has recently launched the first hybrid wind energy storage plant with batteries in Navarra (Spain). The company has also developed simulation software that will be used in the plant and that has obtained the Eolo Innovation Award 2017, granted by the Wind Business Association.

Taking into account the things exposed above, we could easily conclude that the spanish hybrid energy technology and systems is constantly and slowly developing. Thus, there are also many things which can be improved and deeply developed, and this type of systems could surely help to increase the energetic generattion efficiency and to decrease the CO_2 emissions.

Renewable energy sources in Spain

According to the ***Las Energías renovables en el sitema eléctrico español en 2016*** document published by the REE (Spanish Electrical Network) in 2016, the renewable energy sources in Spain accounted for the 45% of the installed power and almost the 39% of the national electricity generation that year.

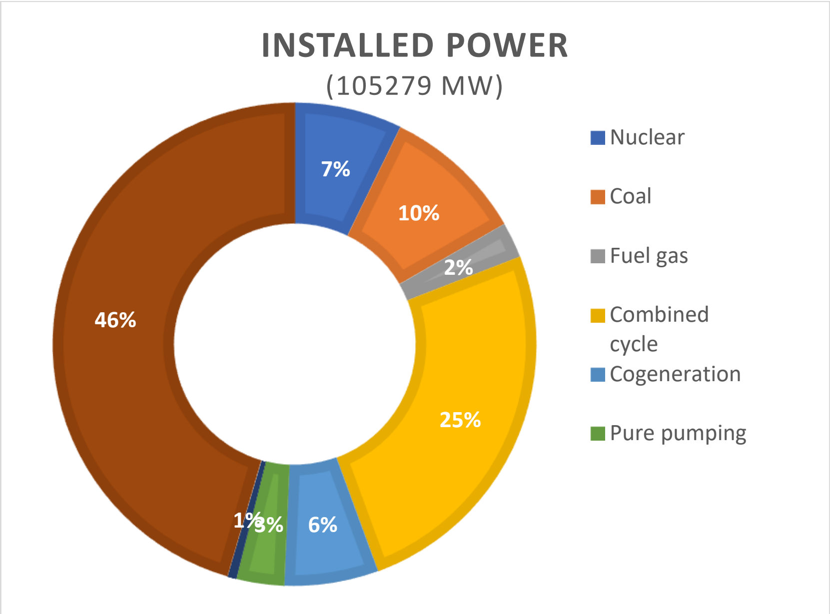


Figure 2. *Distribution of the installed power in Spain in 2016.*

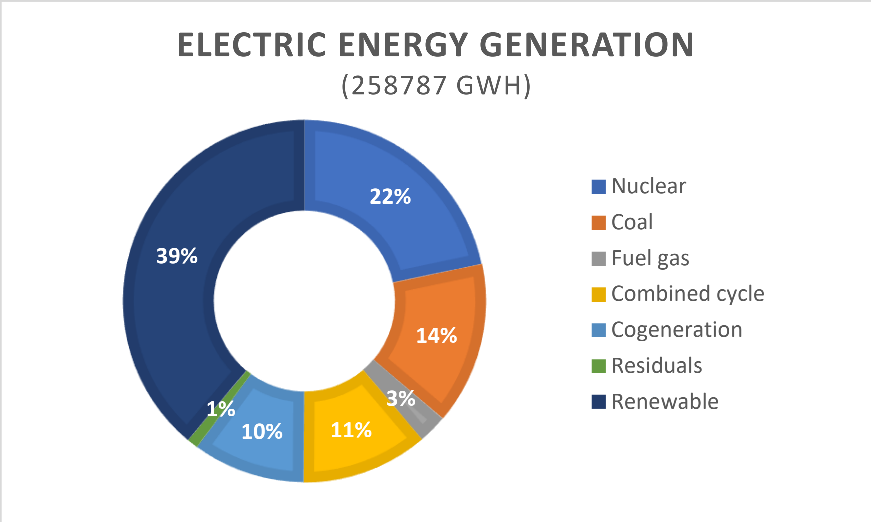


Figure 3. *Distribution of the electric energy generation in Spain in 2016.*

In the graphs above it is easily appreciated that the renewable energy sources played an important role during the year 2016, almost accounting the half of the total installed power and the electric energy generated.

Furthermore, it was not an isolated fact, it was the result of many years of work and effort for arriving to such an achievement since 2006.

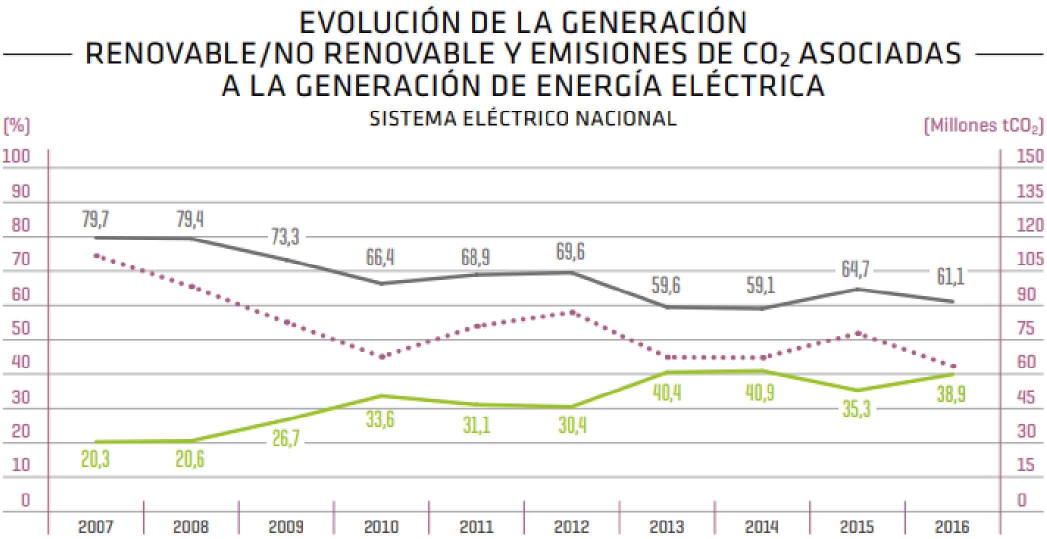


Figure 4. *This graph represents the percentage of generation, using Renewable Energy Sources (green shape) and Non Renewable Energie Sources use (black shape), and the* CO_2 *emissions (dotted purple shape) evolution in relation with the electric energy generation since 2006 until 2016.*

Observing it, we could say that once we increase the use of the renewable energy sources, the CO_2 *emissions consequenly decrease. Thus, by using these kind of energy sources, we are helping to take care of the enviroment, which is being enphazised by many countries around the world the last years.*

In spite of the general increasing of the their use, not all of them have the same importance, being the wind energy the most important. Moreover, this kind of energy has been clearly leading the “renewable energy generation revolution” since 2007 up to these days. In addition, it is the most constant and reliable renewable energy source (which causes that the power capacity of it is increasing), otherwise, it actually depends on the meteorological conditions (being this the only disadvantage). However and besides to the previous one, we can find the hidraulic and photovoltaic energy sources.

On the other hand, it is necessary to know that not all the spanish region have equally experimented this “renewable revolution”. Beside, Castilla y León has considerably lead it and nowadays this is the spanish region whose installed power (22,2% of the total renewable installed power) and electric energy generation (22,8% of the total renewable electric energy generation) are the highest. However, Galicia, Andalucía and Castilla La Mancha also account for an important percentage of the total.

Energy sources in our system and location

During the development of this part is being discussed and chosen the renewable energy sources which are shaping our hybrid system, taking into consideration different facts of each one and comparing between them. Besides, it is also taking into account the location of the the whole system, which must be as close as possible to the group of houses that are being supplied by it.
Firstly, we are discussing and chosing the renewable energy sources of our system. Thus, we must take into consideration the following aspects: power capacity, reliability (it is depending on the meteorological conditions), costs (technical, maintenance…) and durability. Therefore, we are comparing between the currently most used renewable energy sources in Spain and choosing one of them which is being the main and basis source of our system. Once we have the “leading one”, we will choose another “complementary” which can be easily installed the closest the possible to our first one.

From the document ***Las Energías en el sistema eléctrico español en 2016*** we can extract that the most used renewable sources in 2016 were the wind (accounting for 47.3% of the total), the hydraulic (35.5%) and the solar which is divided into two types (photovoltaic with a 7.9% and termal with a 5%). Moreover, these three sources accounted for more than the 95% of the total renewable energy generation. However, it is quite complicated to fix all of them in the same hybrid system, so we must consider just one of them.

Source	Power capacity	Reliability	Power generation costs	Technology costs	Durability
Wind (on-shore)	New wind projects turbine capacity: **2MW/year**	It depends on a meteorological factor. Anyway, in Spain is one of the most reliable	From 0.05 to 0.12 $/kWh	Minimum:0.024 Maximum:0.141 **Average:0.056 $/kWh**	Wind turbines can produce electricity for 25 years before needing an upgrade
Wind (off-shore)	New wind projects turbine capacity: **from 3 to 5 MW/year** Off-shore wind Powers offer a tremendous potential	Off-shore winds are considerably more constant and stronger than on-shore ones.	From 0.10 to 0.21 $/kWh	Minimum:0.096 Maximum:0.208 **Average:0.123 $/kWh**	Off-shore platforms have a shorter usefull life Because they are exposed to harder meteorological conditions
Hybraulic	It depends on the hydraulic head and the available Flow From 2kW to several hundreds of MW per year A typical one around **50 kW**	It strongly depends on the hydraulic head and the availabe flow of wáter Otherwise there are methods to increase its production	Small projects: from 0.03 to 0.115 $/kWh Large projects: from 0.02 to 0.03 $/kWh	Minimum:0.018 Maximum:0.246 **Average:0.051 $/kWh**	About 50 years generally
Photovoltaic	It depends on the number of sunlight hours, but for an average of 5 hours/day: **500-550 kWh/year**	Nowadays its production is quite intermittent It requires of better storage systems	From 0.06 to 0.08 $/kWh	Minimum:0.053 Maximum:0.279 **Average:0.131 $/kWh**	Solar panels long around 30 years and may degrade 4%/year
Termal	-	It generates electricity in a manageable manner, that is, when demand requires it	From 0.06 to 0.08 $/kWh	Minimum:0.182 Maximum:0.312 **Average:0.242 $/kWh**	Solar panels long around 30 years

		It is determined by direct solar radiation			

Table 1. *Comparisson between the different renewable energy sources*

First of all, I would decline the termal due to its highest cost (sum of both costs) in relation with its durability and power capacity. Moreove, the energy delivered from the sun is considerably improving but it hasn´t reached an important level of developing yet, so I wouldn´t use the photovoltaic as main source neither. Beside and as it was commented in the previous part of this document, the wind energy and the hydraulic one are the most used nowadays in Spain.

Furthermore, observing the following table (extracted from ***COMPARISON OF GEOTHERMAL WITH SOLAR AND WIND POWER GENERATION SYSTEMS*** whose autor is **Kewen Li**), we can appreciate that the wind energy is possibly the best option of these three due to its several advantages over the photovoltaic and hydropower energies.

Tech.	**Advantages**	**Disadvantages**
PV	Easy to assess resource	Low efficiency
	Easy to modularize	High cost
	Easy to install	Low capacity factor
	Low social impact	Not weather proof
	Easy to scale up	High land use
	Short construction period	
Wind	Low cost	Low capacity factor
	Easy to assess resource	Not weather proof
	Easy to modularize	High land use
	Easy to install	
	Low-medium social impact	
	Easy to scale up	
	Short construction period	
Hydro	High efficiency	High initial investment
	Low cost	Long construction time
	High capacity factor	Long payback time

Table 2*. Comparison of the photovoltaic, solar and wind power generation systems.*

The hydropower plants require such a high initial investment, and a long contruction and payback times. Therfore, the final decission is to choose the **wind** as main energy source of the system.

Furthermore, the offshore winds are higher, stronger and more constant than the onshore winds. However the initial money investment is considerably higher and it is also more risky and complicated to build an offshore platform than an onshore one.
Attending to the offshore technology we must say that Portugal is succesfully installing and proving the first one in the Iberic Penisland, which is expected to supply electricity to 40000 householders.

Figure 5. *Off-shore wind platform of Vianna de Castelo, Portugal. (The picture is from the official web-page of Repsol, spanish enterprise involved in this project).*

Furthermore, some spanish enterprises have been involved in several projects in relation with this kind of technology (as for example Iberdrola, but it will be developed in the next part of the project). Finally, some studies affirm that the only way to generate electricity by using just renewable sources (desired goal to achieve by Spain in 2050) will be installing these kind of marine platforms.
In conclusion, the main source will be the **off-shore wind**. Besides that, it is necessary to complete the system with another energy source and this may be "provided" by the ocean to easily complete and fix the system. Therefore, we may choose between one of the several renewable ocean sources (ocean waves, tides, salinity, ocean currents and ocean temperature differences).
Comparing them we could firstly and easily avoid tidal and ocean temperatura differences because the first one must be preferably near the coast and the second one is thought to be used in tropical Waters where the temperature difference is higher. Moreover, if we wish to obtain energy from the ocean currents long power cables are required that could affect the marine environment with electromagnetic output, so this option is being declined too.
Finally, we have just two more options and one of them (salinity) as it happened with tidal energy, must be located near the coast, where a river and sea meet. According to it and thinking about the need of our main source (off-shore wind) to be located in the open ocean (some kilometers far from the coast line), we are choosing as complementary energy source the **kinetic energy of the waves** which will be converted into electricity by using special devices that require a lot of space and a big initial economical investement. Otherwise, this source is even more constant and easier to predict than the off-shore wind, thus, it is perfectly complementing our main source.

Once we have decided what are the sources conforming our hybrid system, it is time to choose the location for it. Moreover, we are using to do this **"The Method of the**

Weighted Factors”. This method basically consists of studying different possible locations attending to different aspects which will have different importances according to our own preferences, so, it is a quite subjective method. Anyway, it won’t give us the optimal location but one or some acceptable ones.
First of all, our system must be located in the sea due to the kind of sources that are being used (off-shore wind and ocean waves). Beside, between the multiple locations I have initially selected several possible locations: Palma de Mallorca,Balear Islands (**A**); Alicante, Comunidad Valenciana (**B**); Tarifa, Cádiz (**C**); Las Palmas de Gran Canaria, Canary Islands (**D**); A Coruña, Galicia (**E**), and Santander, Cantabria (**F**)

Figure 6*. The several possible locations correspond with the different red circles shown drawn in the map above. It is easily appreciated that almost every different spanish sea conditions have been taken into account.*

For the used method we must establish some factors and the importance (called the “relative factor weight” and whcih takes a value from 0 to 1) of each one over the rest. The different factors may be: wind’s constancy (0.4), wind’s strength average (0.3), wave’s constancy (0.2) and wave’s strength average (0.1). Furthermore, we are giving now a different punctuation (from 0 to 10) to each factor and obtaining the result.

FACTOR	FACTOR WEIGHT	ALTERNATIVES					
		A	B	C	D	E	F
Wind's contancy	0.4	6	6	6	7	6	6
Wind's strength	0.3	3	3	9	8	7	8
Wave's constancy	0.2	2	3	3	8	7	7
Wave's strength	0.1	2	2	4	8	9	8
Final punctuation		3.9	4.1	6.1	7.6	6.8	7

Table 3. *Method of the Weigthed Factors*

Observing the table above, we could conclude that the last four alternatives are enough good to locate our system. Besides, it is not the most objective method and also must be checked by more than one person.

On the other hand, we can not locate our platform wherever we wish. Moreover, there are many spanish coast zones where it is not possible to install a marine platform, thus, we must precissely know the avaiblable

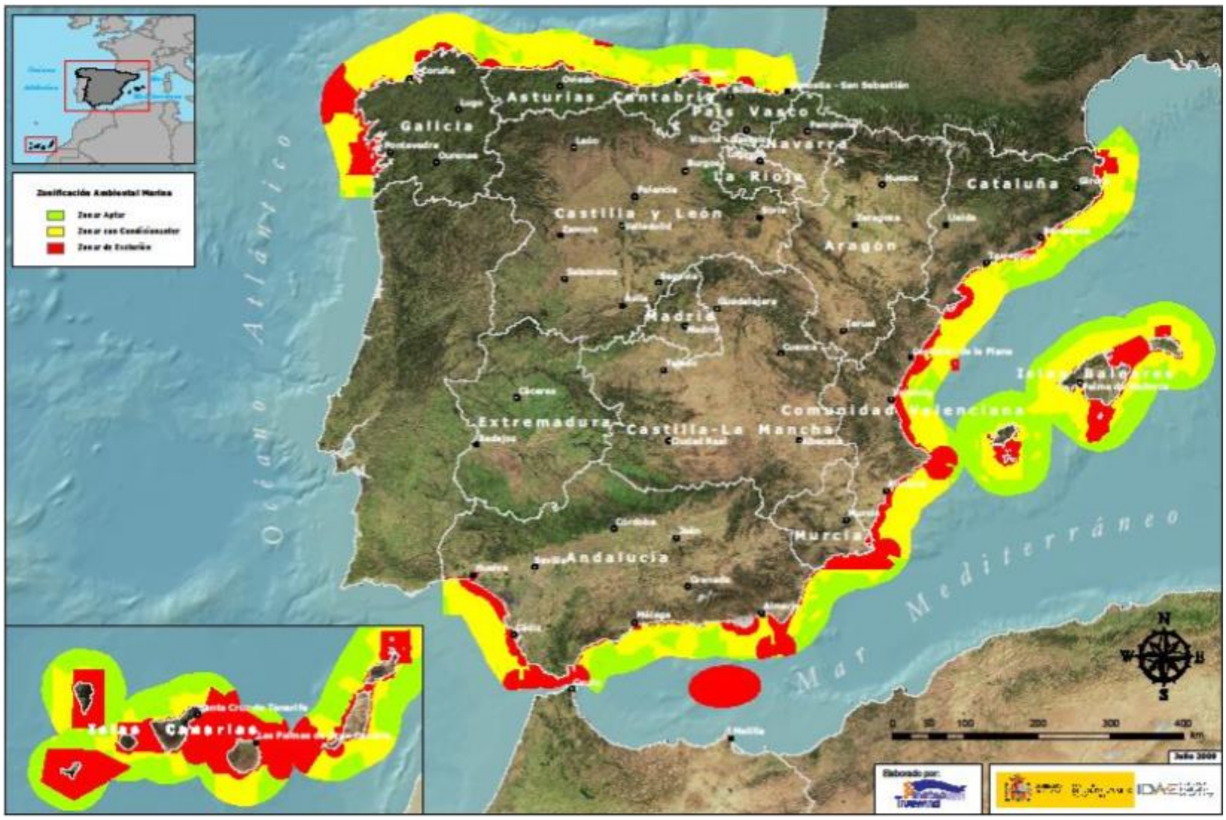


Figure 7. *In the map above we can observe which are the possible spanish coast zones to install an off-shore wind platform. Moreover, the differente colours indicate: green one, availabe zone; yellow one, available zone with conditionants, and red one, non available zone.*

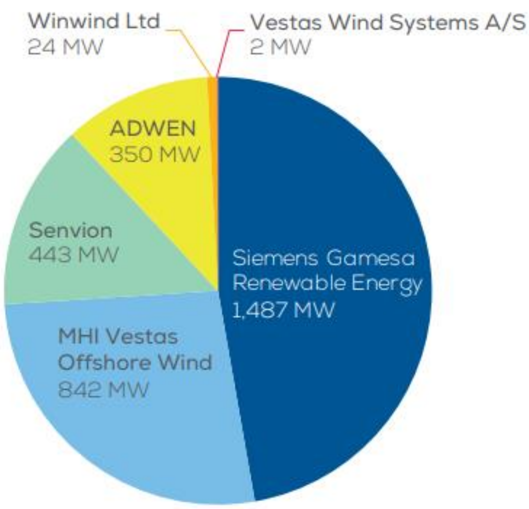
In conclusion and taking into consideration the “Method of the Weighted Factors” result and the available zones to locate marine platforms, the best option is the south-east of Gran Canaria island, as it is circled in the map below.

Figure 8. *Final location of our hybrid system*

State of art of the used renewable energy sources technology

First of all, we must say that our study is focusing and complaining the most developed technologies in Europe and concerning to european enterprises due to the proximity (which will make everything easier) and their knowledge of the meteorological european sea conditions (too many years of work).

Firstly, we are discussing the most advanced off-shore wind technologies and the enterprises which are responsible of their development. Moreover, a previous consultation to the **“Key trends and statistics in 2017”** report from the **windeurope.org** webpage must be done. Therefore and from the main document, we extracted the following information which helped us making an idea about who are the leading manufacturers and owners involved in the biggest projects concerning the annual market in 2017.



It is easily observed that the German enterprise Siemens is clearly leading the off-shore wind turbine's manufacturing (accounting for 51.3% of new capacity). Furthermore, 560 new turbines were connected to the grid and 44% of them were from Siemenes Gamesa Renewable Energy.

Figure 9. "Wind turbine manufacturers' share of 2017 annual installations (MW)"

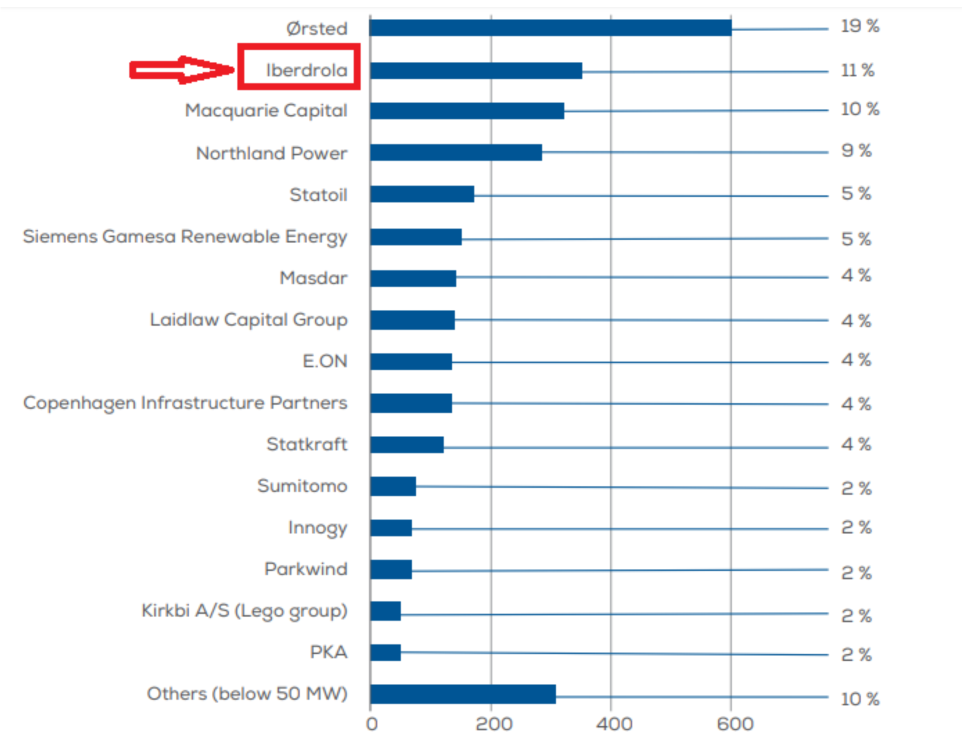


Figure 10. "Developers' share of 2017 annual installations (MW)"

Surprisingly, the spanish enterprise Iberdrola has connected in 2017 the second biggest amount of MW. However, none of them were connected in Spain as it will be commented later.

Once, we had made ourselves an idea about which are the european leading enterprises, a research of the biggest projects was done. Besides, both enterprises

(Siemens and Iberdrola) had worked and are still working together in some of them, Iberdrola normally asks for Siemens off-shore wind turbines.

WEST DUDDON SANDS	
Starting operation year	2014
Economical investment	1600 million pounds
Power capacity	389 MW
Supplying	300000 people
Single power capacity of the turbines	3,6 MW

EAST ANGLIA ONE	
Starting operation year	2020
Economical investment	2500 million pounds
Power capacity	350 MW
Supplying	350000 people
Single power capacity of the turbines	7 MW

Table 4*. "West Duddon Sands" and "Easr Anglia One" offshore windfars main characteristics.*

In both projects the responsible of the turbine manufacturing was the German enterprise Siemens.

It is time now to do a research concerning the most developed Siemens turbine technology. Moreover, we must do a consultation of the different possible solutions that are offered by Siemens, which are being sumarized in the following table.

	OFFSHORE TURBINES				
	GEARED TURBINES		DIRECT DRIVE TURBINES		
FEATURES	SWT-4,0-120	SWT-4,0-130	SWT-6,0-154	SWT-7,0-154	SG 8,0-167-DD
IEC class	IA	IB	IA	IB	S(1B)
Nominal Power (kW)	4	4	6	7	
Rotor diameter (m)	120	130	154	154	167
Blade length (m)	58,5	63,45	75	75	81,5
Swept area (m^2)	11300	13300	18600	18600	21900
Hub height	Site specific	Site specific	Site specific	Site specific	Site specific
Power regulation	Pitch regulated	Pitch regulated	Pitch regulated. Variable speed	Pitch regulated. Variable speed	-

Table 5*. Offshore manufactured turbines by Siemenes.*

LEGAL, ECONOMIC AND CONSUMPTION CONTEXT IN SPAIN

In this part we will discuss more deeply which is the current energetic context in Spain and the development of it in the previous years. Moreover, we will pay more attention to the particular context of Gran Canaria island in order to know more about the location of our final hybrid system.

2004	242.077
2005	252.857
2006	260.474
2007	267.831
2008	268.534
2009	253.079
2010	256.629
2011	248.656
2012	245.687
2013	235.986
2014	233.321
2015	236.752
2016	238.493
2017	241.224

Firstly, it must be outstanded that since 2013 Spain is consuming more and more energy each year which is a syntom of the economical recovery of our country (In 2017 241224 GWh were consumed which means 1,1% more than in the previous year). However, this consumption is considerably inferior than the one concerning to the years from 2004 to 2012 (this fact can easily be appreciated in the table in the left size which has been taken from one bigger table of the ***BALANCE ENERGÉTICO 2017 Y PERSPECTIVAS 2018*** report of **UNESA**). Therefore, during the economic crisis years, the consumption has clearly dropped off (which officialy began in 2008).

In conclusion, we could affirm that the economy and the electric energy consumption have a close relationship (indeed, the economy is also relationed with the production, demand and installed power capacity of a country), this can be observed in the graph below, which relates the PIB (gross domestic product) and the electric energy demand since 1990 until 2015 (the graph has been extracted from ***Evolución del sector eléctrico español (1975-2015)*** document, whose autor is María Teresa Costa Campi*).

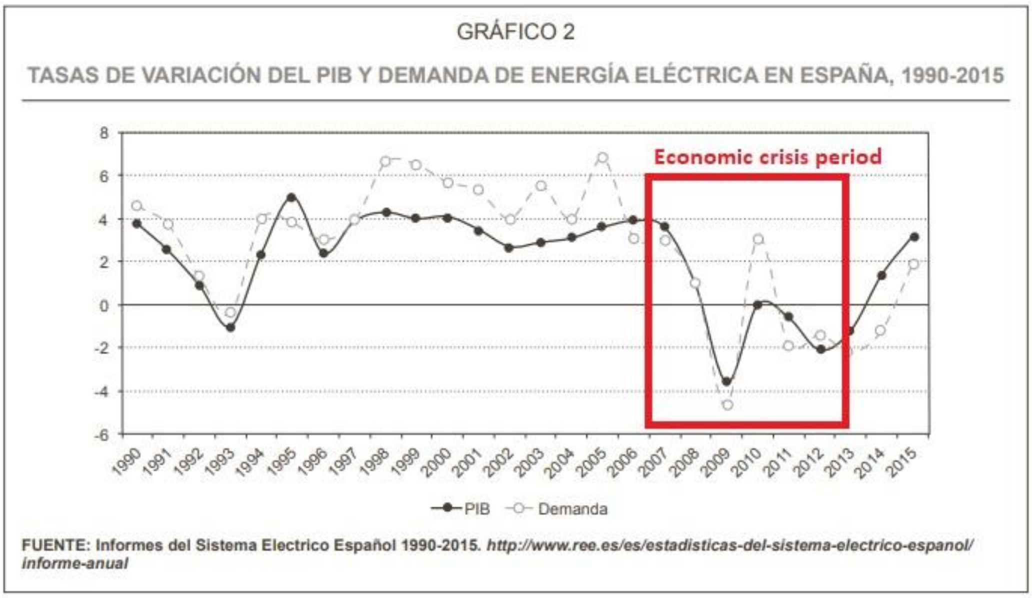


Figure 11. *Rates of variation in GDP and demand for electricity in Spain, 1990-2015*

Classical and typical energy sources in Spain

In this part we are discussing the typical and historical ways and resources utilized to generate electric energy in Spain. However, we must know before that Spain is considered an energy importing country, which means that it buys a big part of the consumed energy to other countries (for example, the nuclear energy to France). Thus, Spain is not generating enough electricity to supply the whole country (including householders, industries, public buildings…).
Anyway, our project consists of "generate and supply", so we are focusing our attention in the generation of energy and the installed power capacity. Otherwise, we must outstand that the installed power capacity is not always a good indicative of the demand (during the economic crisis years the installed power capacity increased while the generation was dopping off). In addition, the best is to study the ratio between both of them (energy generation/installed power capacity).

Firstly, the Spanish Energy System is focused on achieving several goals as for example: reducing the CO_2 emissions or having an interrupted electric supplying. Otherwise, it continues on a path of unsustainability, without improving its energy efficiency and with an increase in CO_2 emissions and other pollutants, as well as external dependence
Moreover and concerning to the the several problems commented in the paragraph above, we are studying the different primary energy sources used and the evolution of their use with the time. Thus we are comparing the situation in 3 different years: 1990, 2008 (the beginning of the spanish economic crisis) and 2017 (the previous year).

Firstly and regarding the data from the year 1990 we find that the conventional energy sources (coal, oil, natural gas…) accounted for almost the 47% of the total generation, "followed" by the nuclear and hydraulic sources (accounting for practicaly the rest of the percentage), so the rest of the sources didn't even represent the 1% of the generation. The total generation this year was about 143 MWh
Secondly and in the year 2008 (we could say it was the peak of the energy generation and consumption in Spain) the escenary is quite different. First of all, the use of conventional sources has increased until approximately reaching a 60% of the total energy generation which consists of an extremely important increase. However, the wind energy has began to be strongly introduced accounting for the 10% of the total generation (one point more than the hydraulic which has a really big importance and it has been used for a lot of time in our country). Moreover, the nuclear generation has also increased (about 5 MWh more than in 1990) but its percentage has dropped off leaded to the increase in the use of the renewable

sources. The total year generation was about 288 MWh, which is twice bigger than the one of 1990. In order to that situation we could say that Spain was experimenting a big generation increase while we were still extremely using the non-renewable sources and the role of the renewable ones wasn´t important yet. In conclusion, there weren´t any serious economic problems yet and so, there were enough money to spend in two different wasys: the importation of foreign energy and the necessary investment for the investigation and development of the renewable energy sources.
Finally and attending to the previous year, we find that the generated electric energy has dropped off until the 263 MWh (which is about 10% less than in 2008). However, the renewable energy sources production account now for almost the 32% and the conventional energy generation has considerably decreased (around a 35%) but is still quite high. Otherwise, the generation of nuclear energy is still the same according to the MWh produced and its percentage over the entier generation.

Energy legal context

During this part, it is basically being discussed the regulatory framework of our energy sources in order to: its technology installation, generation, transport and supply.

BOE

By consulting the "Official Federal Newsletter" (Boletín Oficial del Estado) we are making ourselves an idea about the current legal and administrative situation concerning to the different technologies and uses of the energy sources involved in our project, as well as all the processes which take part in the spanish electric system. In addition, we must develope and build our system respecting the rules and restricitions contained in it (economic, enviromental…).
Moreover, the royal decrees contained in the BOE are not being developed due to their extensión. Thus, we will just do a considerably short sumarize of each one and if there was any important detail which could affect our project, this would be carefuly commented.

Spanish electric system (1955/2000 royal decree)

This decree regulates all the activities in relation with the electric sector: transport, distribution, trading, supply and autorizative procedures of electric energy installations. Besides, its goal is to achieve such a legal framework in which the electric sector activities must respect the 54/1997 of the Electric Spanish Sector.

1.1.1.1. Electricity generation using renewable sources (413/2014 royal decree)

It regulates the electric energy production from the renewable energy sources, cogeneration and wastes.
The use of these renewable energy sources is essential for the reduction of the greenhouse gases and to the ensurement of the energy supply, which are two of the most important and desired objectives of the Spanish Electric System.
Furthermore and during the previous years, this sector has experimented an important development caused by the the regulatory frameworks which establish the economic subsides. Due to the commented development, the frameworks have been evolving in two different ways: allowing these technologies to take part in the electric market and increasing the technic requirements to correctly integrate these tehcnologies to the electric system.

Ocean space managment (363/2017 royal decree)

Its objectives are such as: the sustainable growth of the maritime economies, the sustainable development of the maritime spaces and the also sustainable exploitation of the marine resources.
It is already established that each member state of the European Union is completely and lonely responsible of the managment of its own marine space. Moreover, this managment must take into account the importance of the marine ecosystems and resources, which must be totally respected to avoid: the destruction of the "blue economy", the enviroment deterioration, the biodiversity los and the degradation of the ecosystem services.

Offshore eolic platforms installation (1028/2007 royal decree)

The main decree "establish the adviministrative procedure to process applications for authorization of electricity generation facilities in the territorial sea" (directly extracted from the BOE). It is totally necessary to have a unique rule which reflects all the processes, managments, applications, autorizations, administrations and rules involved in installing an offshore platform due to the vast amount of them and theri plurality. Moreover, this "common norm" is also quite important because of the dimension, required investment, own characterisitics and the current interest (these kind of systems are actually considered very reliable) of the offshore platforms.

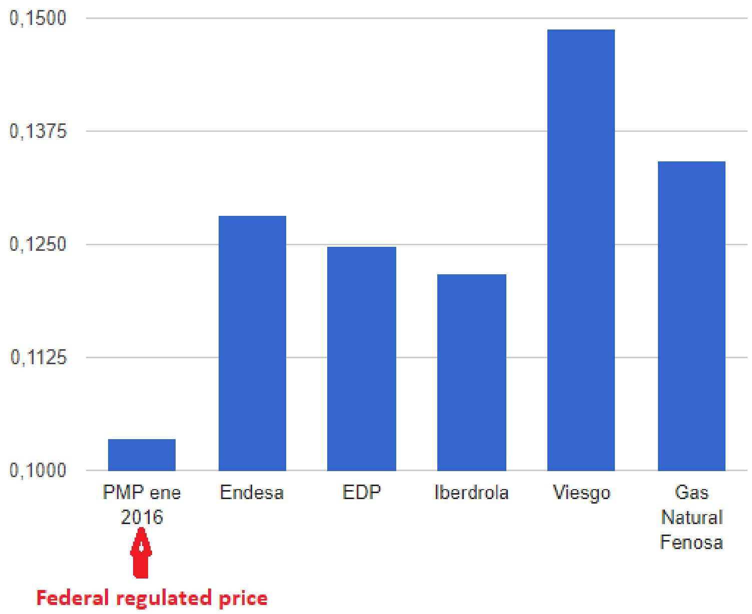
Energy economic context

Electricity Price

The electricity price is not constant, indeed it variates depending on the company and the contracted rate. Otherwise, we could define this as "the amount of money which is paid for kilowat per hour (euro/kWh)", and the kWh is a measurement consumption unit of a household.
Furthermore, we are discussing the different markets which set the electricity price and its differences.

Free market

The electricity price is basically set by the different electric companies, so it can differ a lot. Moreover, each company can also apply the desired discounts and promotions, to make the consumer save some money.



The graph in the left size shows the price of the electricity of the different electric spanish companies (euro/kWh) during 2016.
It is clearly appreciated that these prices are truly higher than the federal regulated price.
(The graph has been extracted from the following web site: https://tarifasgasluz.com/faq/electricidad/precio)

Figure 12. *Price of the electricity of the different electric spanish companies.*

Regulated market

The price is now set by the Goverment and the Industry Ministry which proposes different energy costs and Access tolls for supply. Otherwise, this price could be definded of several different ways: price per hours (the consumer must use a digital counter correctly integrated into the remote management system which rates the supply establishing a price for each hour), weighted average price (set taking into consideration all the different prices during the rating period) and fixed anual price (established for the whole year).

Electric spanish rate

A current spanish rate involves the different things and aspects:
- Fixed power term. It consists of a fixed amount of money which must be monthly paid to the company.
- Consumed energy. Amount of consumed kWh during a period of time.
- Electricity tax. It consists of a special task paid to the electric company and finally given to the goverment, which is calculated as it follows: 4,864% x (consumption cost + power) x 1,05113.
- Rental of measuring equipment.
- VAT. It accounts for the 21% of the total
- Electricity origin.

Electric energy generation costs

The different ways of electricity generation carry different costs, attending to the source, used technology, applied taxes to the resource… Furthermore and in the two following parts we are making a short discussion of the estimated costs. However, the real costs are being deeply discussed during the cost analysis and. Thus, the following costs are just for making ourselves an initial idea. However, real costs variate depending on different aspects as for example the enviromental conditions of the region or the used technology.

Offshore eolic energy costs

The price of this kind of energy varies a lot from one location to another and it also strongly depends on the used technology. In addition, we must take into consideration not only the generation costs but also the installation and the manteinance costs which will be higher or lower depending on the meteorological conditions of the offshore wind farm location.

However and according to the "EVOLUCIÓN TÉCNOLÓGICA Y PROSPECTIVA DE COSTES DE LAS ENERGÍAS RENOVABLES" (TECHNOLOGICAL EVOLUTION AND PROSPECTIVE COSTS OF RENEWABLE ENERGIES) technic study; we could rate it between 9.2 c€/kWh and 13.2 c€/kWh in 2010, and expect it to take values between 6.8 c€/kWh and 9.8 c€/kWh in 2020.

Kinetic wave's energy cost

This kind of energy is currently beginning to play such an important role in many different countries due to the realtion between the energy which generates and the energy which demand each year. Moreover, Europe generates about 280 TWh each year.
According to the production average cost, it was between 24c€/kWh and 28c€/kWh during 2009, and it is estimated to reach 17c€/kWh in 2020 (information of the 2010 RTA report).
Furthermore, this is a kind of energy quite undeveloped by the momento, so the price could easily variate.

Conception of capacity the energy sources in our system

Regarding to the objectives of the Electric Spanis System and almost every electric system in the world, we could easily say that the most important is to have a constant and interrupted energy supply. Moreover, if we are planning to introduce our energy system into this kind of market, we must assure the users that they are having electricity wherever they wish, otherwise, our project won't definetely succeed. Therefore, this parto of the project is consisting basically on designing such a reliable hybrid energy system.

Random character of the renewable sources

The renewable energy sources are such an important alternative to the traditional used sources because they are considerably "cleaner" than the others, and they will long forever (the coal and these kind of resources have a deadline). Thus, these are the main reasons of their increasing use.
On the other hand, almost every renewable source has a **random character**, due to its dependence on the natural and meteorological agents, consequentely, it makes us also dependent. In spite of the current researchs and improvements of their technology, we can actually not apply them in every place due to their reliability lack in several situations. Otherwise, I personally think that once we know how to effectively store their energy, the whole world could be supplied just by these kind of energy.
In conclusion and regarding to the succes of our project, we think that the best way to assure a constant and interrupted supply will be to use one of these traditional sources or even find another renewable source which will be easier to control and more constant. Moreover, it will just work as a complementary source whenever we need it.

An additional energy source

According to the commented above, we must look for a more stable energy source which will complement our other two source, supplying energy in case of fail of the other parts or undesired meteorological situations.
On the other hand, we wish to achieve such an effective system, so we don't want to overproduce or generate more energy than the necessary, because it will be a lost or money and resources. Otherwise and just in case, we could use an overproduction to be sold of stored (for emergy situations), so we are not considering it a big trouble.

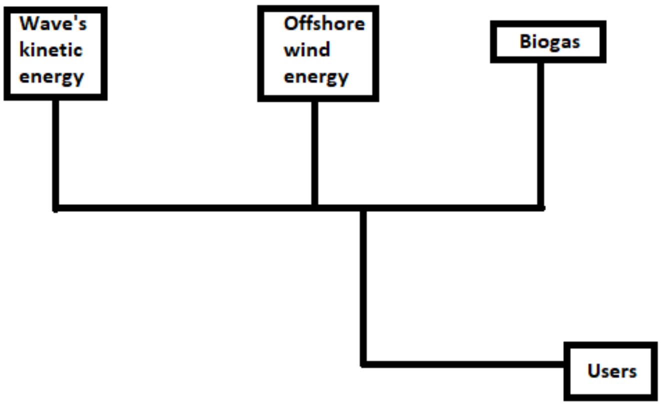
For the choice of our complementary source we must pay attention to different aspects. In addition, we must avoid those which could cause us a big investment because we are already spending a considerably high amount of money to build our marine platform (the price of the offshore wind farms is twice higher than the onshore ones). Furthermore, we should choose a source already investigated, correctly developed and used in Gran Canaria, because working with the local industries will truely have many advantages (no need of transport, lower price…).

Regarding to the choice of the additional and complementary energy source, we are trying to avoid those which are actually expensive and polute considerably. Thus, we find that the best option to succesfuly complete our hybrid system is the **biogas.** This product is obtained using the organic wastes generated by animals and humans during a process called biodigestion in which anaerobic bacterias are used. Moreover, we are choosing this way of obtaining energy for different reasons:

- It avoids the pollution of the air and water, where otherwise the main wastes would be released. Thus, it is good for the enviroment.
- Gran Canaria is the island of the archipielago with the highest amount of cattle and consequently it produces the biggest quantity of waste.

- There is already one installation dedicated to the production of the biogas in the island.
- It is a renewable energy source. Thus, our hybrid system will use just renewable energy sources.
- This is one of the cheapest options.

Finllay our hybrid system will be as it is exposed below in the Figure 13



Simplified block's diagram of the hybrid system

Furthermore, we declined the option of using biomass from the tres due to the restrictive law against the forest's exploitation.

Gran Canaria's electricity demand

Concerning to the main objective of our system (achieving a constant and interrupted supply) we must know which is the Gran Canaria island's electricity demand. In addition, it will be actually useful not only knowing which is the whole year's demand (amount of GWh consumed by the users), but also which is the user's profile.

Firstly, we are doing a research about the electricity consumption of the island during the last few years and assuming a possible average consumption value. However, we must take into consideration that the electric demand may always be higher than the consumption in case we there were any inconvenients or unexpected situations (as an overconsumption). Moreover, there are always losses in the network, thus, a bigger amount of energy than the final consumed must be required (demand).
The following example shows us the relation between the consumption and the demand. Besides, the data are extracted from two different sites.

- The demand in the canary islands during 2015 was accounted for 8666,4 GWh and the losses were of approximately 608,8 GWh. Thus and taking into consideration that the consumption would be the difference of them, it accounted for 8057,6 GWh. This information has been taken from the **"ANUARIO ENERGÉTICO DE CANARIAS 2015"** document.
- On the other hand and according to the provisional data of the **"ISTAC"** (Estadistic Canarian Institution), the electricity consumption of the archipielago during 2015 was of 8029,058 GWh, which is quite similar to the obtained in the first case. Moreover, the consumption of Gran Canaria for that year, the 5 previous and the next one is shown in the table below.

Year	2010	2011	2012	2013	2014	2015	2016
Consumption (GWh)	3306,011	3308,232	3287,119	3186,601	3156,629	3175,987	3212,576

Table 6. *Gran Canaria's electric consumption from 2010 to 2016*

Concerning to the previous table and the example, we are doing the following **approximations**:

- The consumption of Gran Canaria is around 3212,576 GWh (this value represents the median of the values of table).
- The percentage of losses is going to be the same as the archipielago´s one
- (7,025%).

In conclusion we can now calculate the **approximated annual demand of Gran Canaria**, which is accounting for **3455,305 GWh**. The calculation process is developed below (D=GWh demanded, C=GWh consumed and P=GWh lost).

$$P(\%) = \frac{P \times 100}{D} \quad ; \quad \boldsymbol{D = \frac{C \times 100}{100 - P(\%)}}$$

Once we know got to a final annual value of the demand of Gran Canaria is time now to find which is the daily users profile. This information is being consulted in the "REE" (Electric Spanish Network) website. Moreover, we are choosing two different dates of 2016: one of the winter season (15th December) and other of the summer season (15th July).

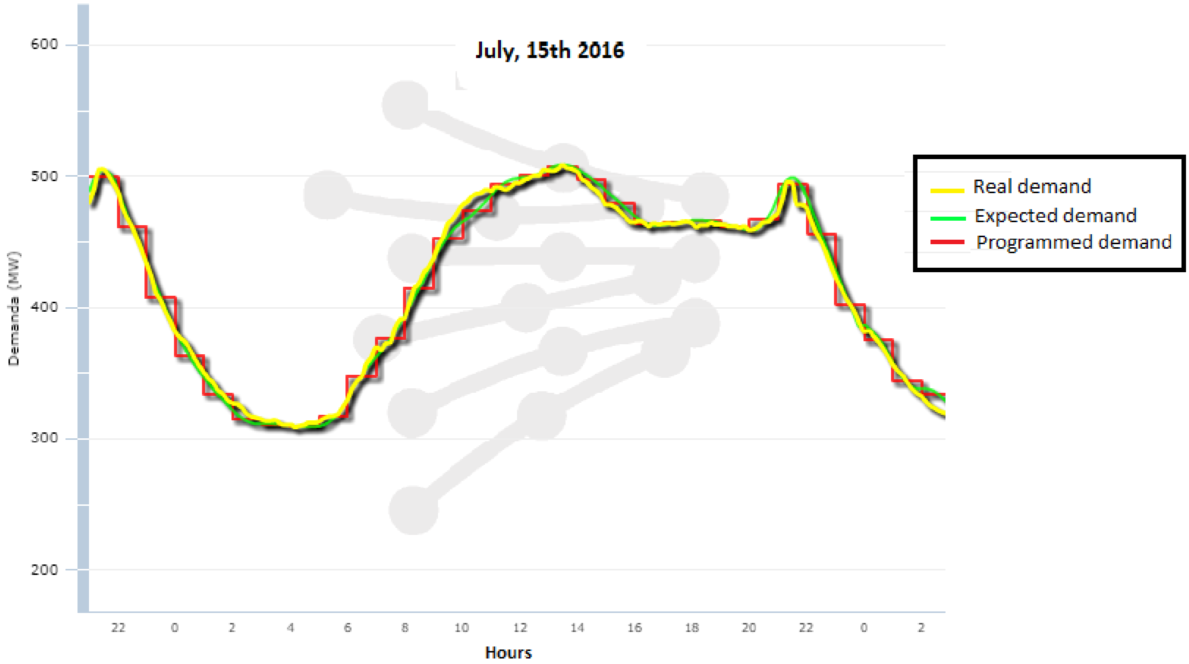


Figure 14. *Daily demand of Gran Canaria during the 15th July of 2016*

Observing the graph above we can easily appreciate that the highest real demand is of 509 MW at 13:29 and the lowest accounts for 308 MW at 04:11

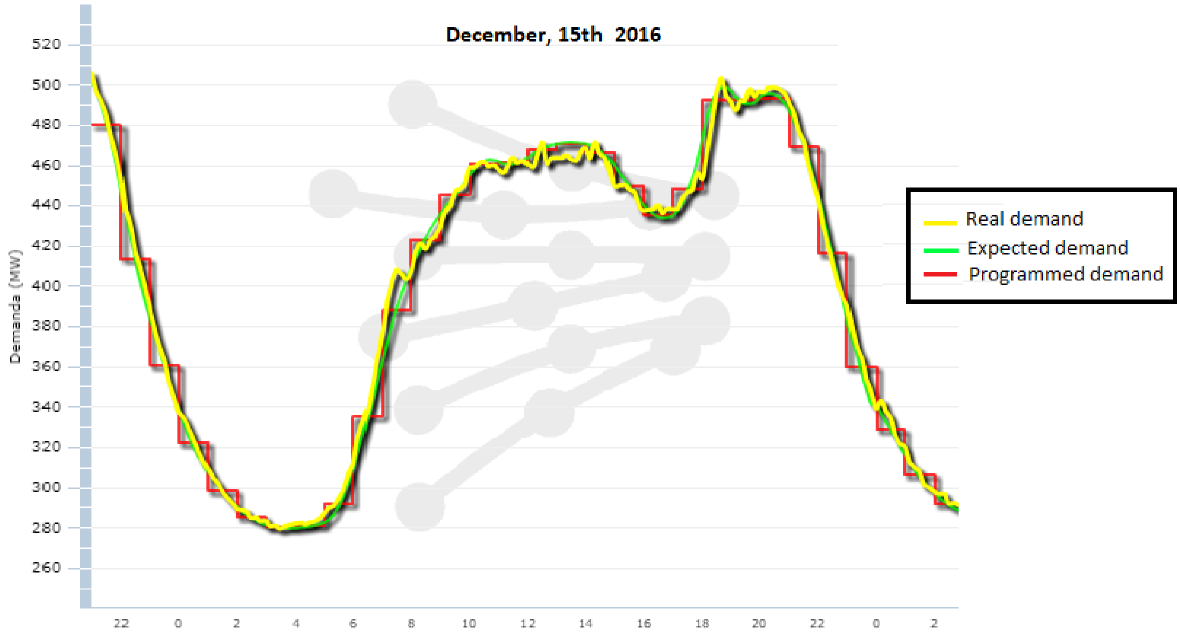


Figure 15. *Daily demand of Gran Canaria during the 15th December of 2016*

Observing the graph above we can easily appreciate that the highest demand is of 507 MW at 18:47 and the lowest accounts for 280 MW at 03:29.

Comparing both of them, we conclude that during the summer seasons the demand is more constant and during the winter it changes more. Otherwise, the maximum and mínimum values of are quite similar (almost the same). The only difference is that during the summer, the highest demand level takes place during the mid-day (possibly due to the use of the air conditioner), and during the winter in the evening (possibly caused by the use of the radiators).

We are now collecting the real demand each hour during a day of each season and calculating an approximation of a possible real standard demand (which will basically consist in the average of the four values).

	REAL DAILY DEMAND (MW)				
TIME	SUMMER	AUTUM	WINTER	SPRING	AVERAGE
0:00	382	359	345	335	355,25
1:00	351	337	313	306	326,75
2:00	327	317	294	286	306
3:00	315	304	280	276	293,75
4:00	311	299	272	271	288,25
5:00	313	298	272	273	289
6:00	329	297	283	281	297,5
7:00	368	317	296	304	321,25
8:00	392	329	295	310	331,5
9:00	437	378	343	356	378,5
10:00	465	424	385	404	419,5
11:00	489	440	414	415	439,5
12:00	495	449	423	415	445,5
13:00	505	458	433	427	455,75
14:00	504	447	436	430	454,25
15:00	479	427	406	405	429,25
16:00	465	408	369	381	405,75
17:00	464	405	367	382	404,5
18:00	464	416	386	387	413,25
19:00	464	421	456	394	433,75
20:00	459	473	471	408	452,75
21:00	472	476	472	461	470,25
22:00	476	438	436	431	445,25
23:00	424	391	384	384	395,75

Table 7

Power capacity level of the different energy sources

Once we know "have set" (indeed we have made an approximation based on the previous existing data) which are the annual and daily demands we must study if it is being possible to totally satisfy it, and in case it was the how to do it.
First of all we must do a research about the power capacity reliability of the three different energy sources which are being used for finding out if they are realiable or not. Moreover, this part basically consists of doing a research about the meteorogical conditions in our location and also the capactity of a biogas plant in Gran Canaria (which is being developed in detail later). In addition and for the main research, we are using the collected information of the "Puertos del Estado" (spanish federal harbours).

Attending to the final area which is being located our marine platform, we find out that there are multiple points which can give us some information about the offshore wind and wave's velocity. However, we are only consulting the collected data of two of them and assuming that the wind and wave's conditions of the entier area are almost the same. In addition, we are taking into account the average data of the last 17 years (2000-2017).

Figure 16. *Location of the SIMAR 4038006 and SIMAR 4038004*

Point	SIMAR 4038006
Latitude	27º75' N
Longitude	15º33' W
Distance from the coast	10 km (Approximately)
Depth	About 70 m

Cadence	1 h

Table 8. *SIMAR 4038006 characteristics*

Point	SIMAR 4038004
Latitude	27º58' N
Longitude	15º33' W
Distance from the coast	32.2 km (Approximately)
Depth	About 2150 m
Cadence	1 h

Table 9. *SIMAR 4038004 characteristics*

Due to the different depths of the points and the technology devices restrictions of each energy source according to this aspect, data of both points is taking into consideration just for the offshore wind's capacity power research. On the other hand, using the information of the closest point to the coast for the waves capacity power is completely enough and the data of farther points wouldn't be really useful because the used installations for this energy source are built near it.

Offshore wind conditions (SIMAR 4038006 and SIMAR 3038004)

Concerning to the wind power capacity, we are basically studying two different parameters which could easily and clearly define its behaviour.

First of all and maybe the most important parameter, we need to know about the velocity of it and its variation. Moreover, this parameter is helping us to know what is the possible power capacity we could achieve in relation with the nominal power of the different aerogenerator types.
Furthermore and according to the international warnings, a reference with ten years of data should be used, although in most of the sites five years are enough to obtain very good result. For our project, we are taking into account ten years (from 2007 to 2017).

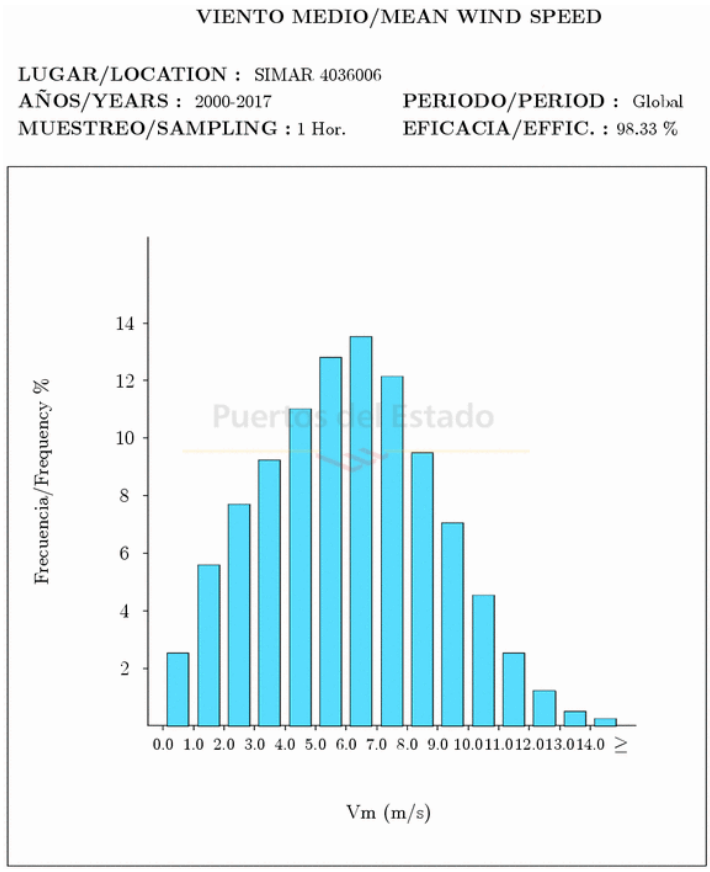


Figure 17. *Hystogram containing the mean wind speed measured by the SIMAR 4038006*

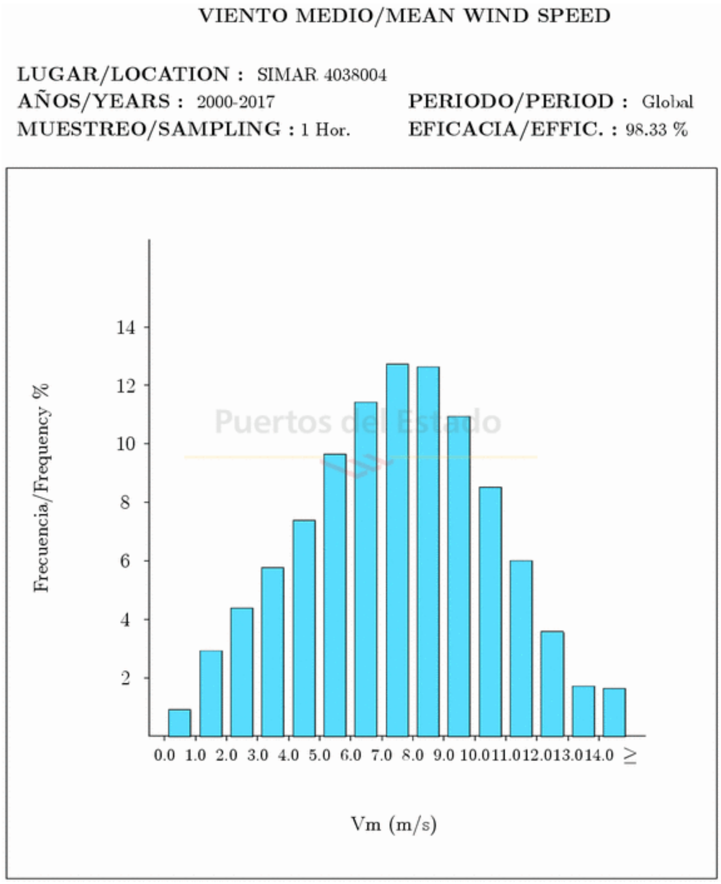


Figure 18. *Hystogram containing the mean wind speed measured by the SIMAR 4038004*

We can easily appreciate that in the point which is closer to the coast line (about 3.8 km) the mean wind velocity oscillates between the values 4.0 m/s and 8.0 m/s. Furthermore, it rarely achieves values over 10.0 m/s or even lower than 2.0 m/s.

On the other hand, farther from the coast the mean wind velocity increases (oscillating between 5.0 m/s and 10.0 m/s) and frequently reaches values higher than 11.0 and even 12.0 m/s.

Thus, our aerogenerators must be selected taking into account these previous aspects.

On the other hand, the direction of the wind is actually such an important aspect. In addition, a correct orientation will lead to a higher energy production which is such a positive thing.

In the following page a rosettes of the two sitew wind is represented.

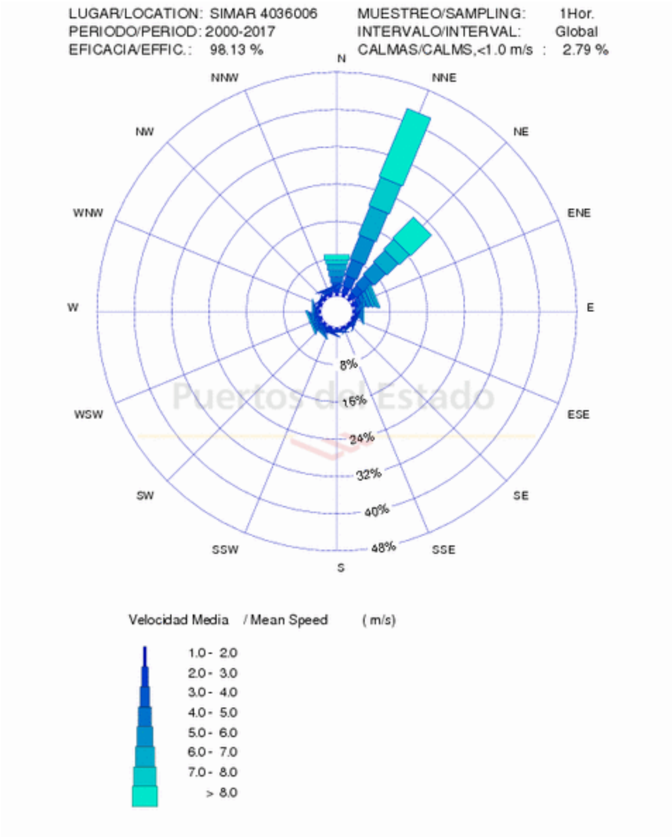


Figure 20*. Rosette of the dominant wind directions and theirs speeds measured by the SIMAR 4038006.*

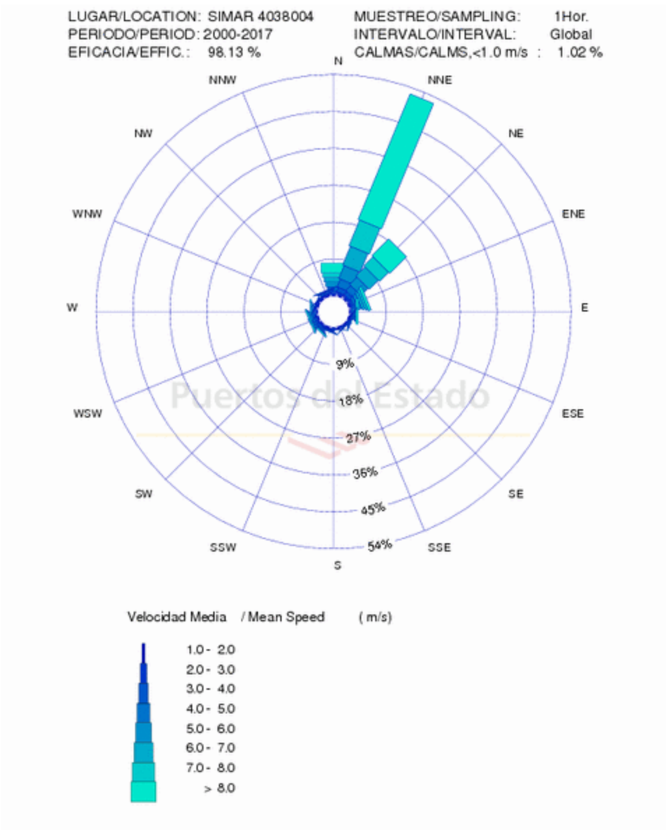


Figure 20. *Rosette of the dominant wind directions and theirs speeds measured by the SIMAR 4038004.*

In the rosettse above, we easily observe that the majority of the winds “come” from basically one direction which consists of a 60º angle between the N and NE. Thus our offshore wind farm must be oriented to the NNE direction.

Waves conditions (SIMAR 4038006)

According to the waves parameters, the most important and useful to know is the significant height of the wave: Hs (m). This one is basically defined as “arithmetic mean of the third of the highest waves recorded in a sample”. In addition, it is actually being quite significant in order to know the possible amount of produced energy harnessing the kinetic energy of the waves.
On the other hand, knowing parameters as the dominant direction of the waves and the mean period could also be truly useful.

Furthermore, all these parameters are being consulted as we did for those of the offshore wind in the “Federal Spanish Ports” oficial website and presented in the main document in the following page.

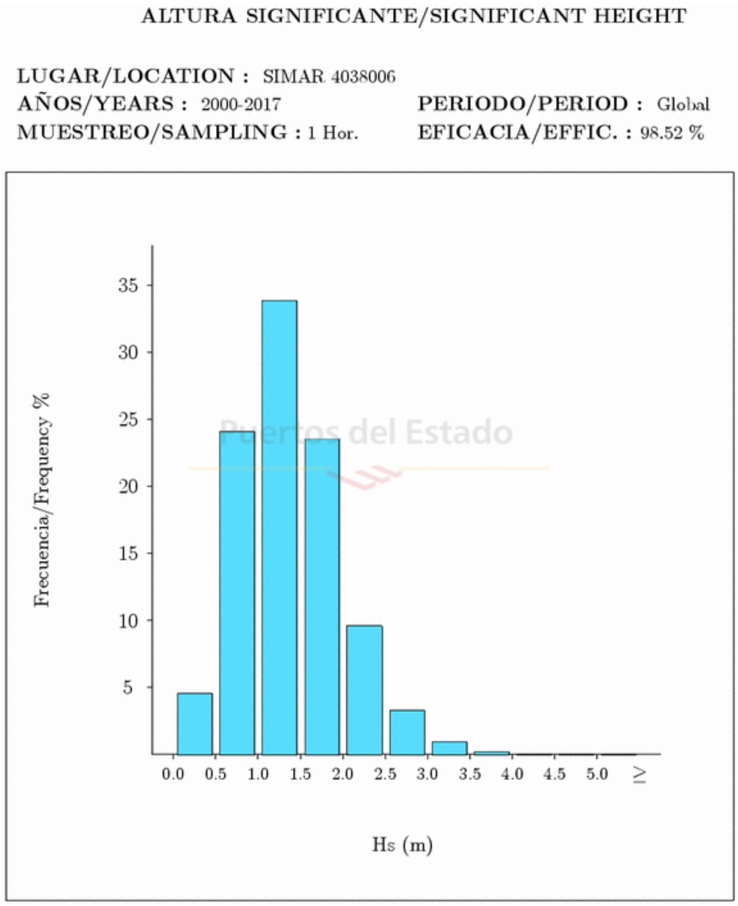


Figure 21. *Hystogram containing the mean wind speed measured by the SIMAR 4038006*

In the histogram above, it is easily appreciated that most of the time the Hs parameter takes values from 0.5 to 2.0 m. Moreover and hardlyever it takes values over 2.5 or lower than 0.5.

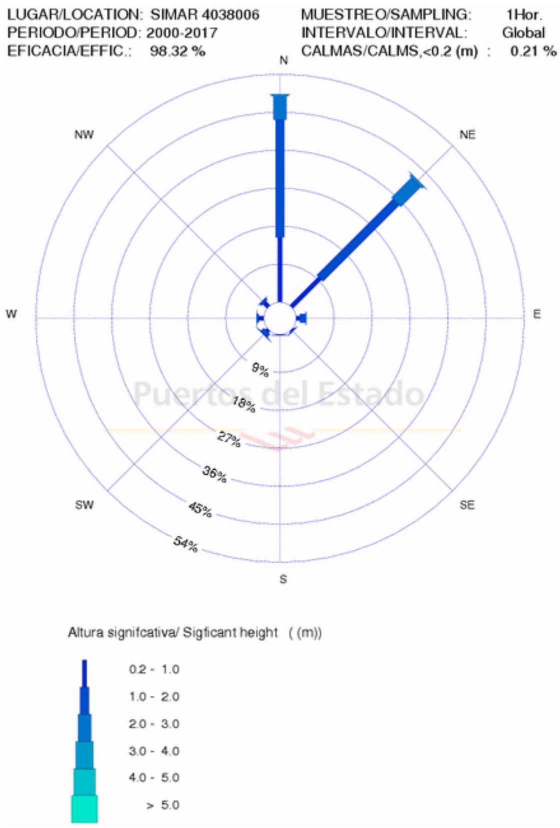


Figure 22. *Rosette of the dominant waves directions and theirs speeds measured by the SIMAR 4038004.*

In the rosette above is easily observed that the majority of the waves come from the NE and N directions. Thus, our design must take into account this aspect.

Biogas energy

This kind of energy is obtained from a procedure which transforms the faeces of animals (and also humans) into electric energy. Furthermore, we are just using those which come from farm animals. However not only the faeces can be used to produce electric energy but the solid urban waste too.

According to a new published during 2015, Gran Canaria accounted for: 11124 cows, 20124 sheeps, 314 donkeys, 55708 goats, 17650 pigs and 1414 horses. In addition, it must be known that the cows and horses are the bigger faeces producers of these five kind of animals. Therefore, we are just focusing on these two types of animals because the bigger is the amount of faeces, the more electricity we produce.

First of all, the following energy relation must be comented:

1 $m^3$of biogas	21.5 MJ	6 kWh

Table 10. *Energy raltion between the faeces used for obtaining the biogas and their energetic potential*

Attending to the cows, they are supposed to produce 49 kg of faeces per day, which leads to 1.25 m^3 of useful biogas and to 7.5 kWh of electricity. Secondly, the horses are supposed to produce 15 kg of faeces which leads to 0.6 m^3 of useful biogas and to 3.6 kWh of electricity.

Finally and honestly, I would like to remark that the data above have been extracted from different websites and I am actually not sure about the reliability of them. Anyway, the character of this source is totally constant due to the daily constancy of its used resource. Thus, we are using it as the auxiliar part of our system and its produced energy will be supplied just in case of interrumptions or fails of the other two parts (offshore wind and waves).

Technology selection

After knowing the capacity of our primary resources, we must select the best possible technology which efficiently exploits them and this choice must be taken in order to completely satisfy the whole Gran Canaria's annual demand. However, our choice needs to be done taking into account the enviromental conditions of the location and the neccesary economic investment. Furthermore the economic investment doesn't consist only of the technlogy devices price but the following aspects must be taken into consideration.

First of all, we may try to manufacture the devices in Gran Canaria or in a location the closest the possible. Otherwise, we will have to transport it from other region or even country which will lead to a higger amount of money, not only regarding to the transportation but the importation taxes maybe too.

On the other hand, we are not able to use as much space as we wished due to the the federal restrictions already commented. Besides, the installation of marine devices is even more complicated because the depth plays an important role and the sea bottom is so irregular. Therefore, our "wind and waves farms" should be designed taking advantage of the space and the chosen devices must fit as best as possible.

Offshore wind technology

The offshore wind consists of our “base energy source” and it is expected to produce such an important and considerable amount of the neccessary electric demand. Thus and according to its technology, we must choose it carefully and regarding not just the nominal production but also the durability and reliability of the devices.
Before choosing which is going to be the type of turbine we must clarify several things according to the electric production of this device.
First of all, the concept of the **nominal power** must be introduced, this basically consists of the power which the turbine will be generating if the enviromental conditions were the designning ones. Thus, we may pay attention not only to the nominal power value but also to the **required wind speed conditions to achieve it.**

According to the already done state of art in one of the previous parts of the main document, we know that Siemens is actually one of the most advanced and best offshore wind turbine manufacturer. In addition, this enterprise has close profesional relationship with Iberdrola (spanish enterprise) which could be so useful in order to make a better deal.
Siemens offers multiple types of turbines which initially could fix in our system. However, there are two which seem to do it better, so our final choice is consisting of one of them.
The models are: *Wind Turbine SWT-4.0-130* and *Wind Turbine SWT-6.0-154*, whose nominal Powers are 4.0 MW and 6.0 MW respectively. In spite of knowing the value of the nominal power, we don’t have the generation curve of the turbine which relates the wind speed and the power output. On the other hand the operational wind conditions data of each one is also known and presented below.

	SWT-4.0-130	**SWT-6.0-154**
Cut-in wind speed	3-5 m/s	3-5 m/s
Nominal power at	11-12 m/s	12 - 14 m/s
Cut-out wind speed	32 m/s applying High Wind Ride Through	25 m/s

Table 11. *Comparisson between SWT-4.0-130 and SWT-6.0-154 turbines*

We ideally want the turbine to supply output power the closest the possible to its nominal value. The wind conditions in our final location were not as high as the indicated in the table above but these must be a reference. In addtion, a real device ideal operation is achieved hardly ever.
For comparing both options and choosing one we are making the following approximation: wind’s speed threshold value for both is 3 m/s, SWT-4.0-130 will deliver nominal power at 11.5 m/s and SWT-6.0-154 will do at 13 m/s. Furthermore, we are linearizing the generation curves of both turbines accroding to the previous approximation.

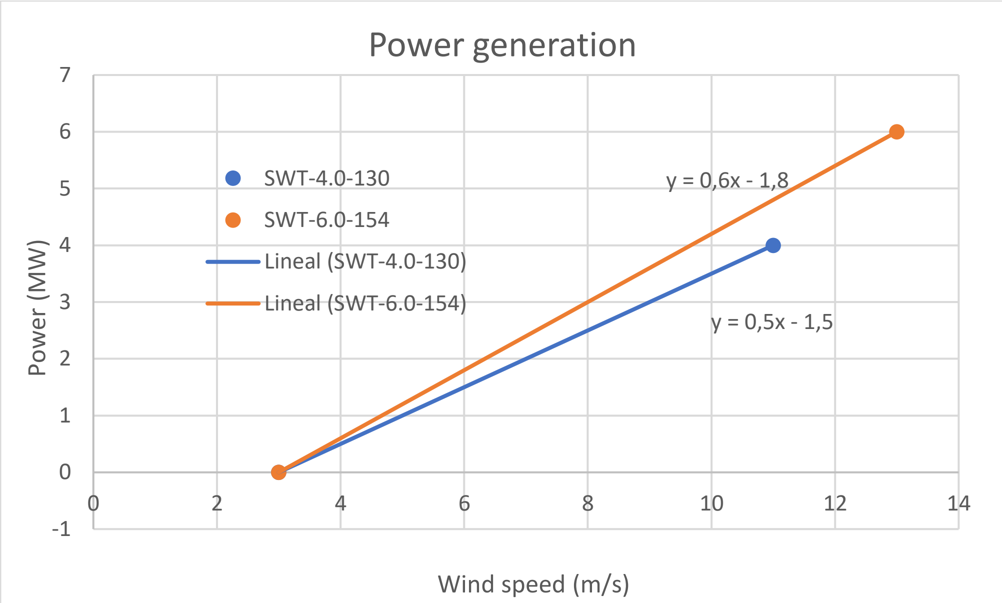


Figure 23. *Linearization of the generation curves of the SWT-4.0-130 and SWT-60-154 turbines.*

It is easily appreciated that according to the previous approximations, the SWT-6.0-154 turbine model will generate more electric energy than the other model no matter the wind speed conditions. Moreover, at the speed of 10 m/s this kind of turbine is expected to produce 26,500 MWh per year, which approximately accounts for the 0.8% of Gran Canaria's annual demand. However, we already know that this speed is not being constant, so the production will be lower.
Anyway, our offshore wind farm will use this kind of turbines, whose main characteristics are shown in the table below.

ROTOR	
Position	Upwind
Diameter	154 m
Swept area	18600 m2
Speed range	5-11 rpm
BLADE	
Length	75 m
WEIGHTS	
Towerhead mass	410 tons
GRID TERMINALS	
Nominal power	6 MW
Voltage	690 V
Frequency	50 Hz
OERATIONAL DATA	
Cut-in wind speed	3-5 m/s
Nominal power at	12-14 m/s
Cut-ou wind speed	25 m/s

Expected average wind speed	10 m/s
MORE	
Expected lifetime	25 years

Table 12. *SWT-60-154 turbine characteristics.*

Furthermore, the height of the turbine is not fixed and can variate dependfing on the location of it. Thus we will choose it according to the requirements of our system and regarding the production differences in order to it.

Kinectic waves technology

The technology of this field is not as developed as it is for the case of offshore wind. Thus, the number of available solutions and options is — considerably lower than it was before.
First of all, we may know and indicate that the power of the waves is higher for farther locations from the coast. In contrast, the current technology is not ready to be placed far from the coast where the depth is considerably big.
Regarding the most developed european technology and the enterprises which manufacture them we find that Wavestar is one of the best solutions for our system. Moreover, this technology has been succesfully tried for different scales (siezes), always achieving posistive reults. In addition and in the following lines directely taken from the website we sumarize how it works.

“The Wavestar machine draws energy from wave power with floats that rise and fall with the up and down motion of waves. The floats are attached by arms to a platform that stands on legs secured to the sea floor. The motion of the floats is transferred via hydraulics into the rotation of a generator, producing electricity. Waves run the length of the machine, lifting 20 floats in turn. Powering the motor and generator in this way enables continuous energy production and a smooth output.”

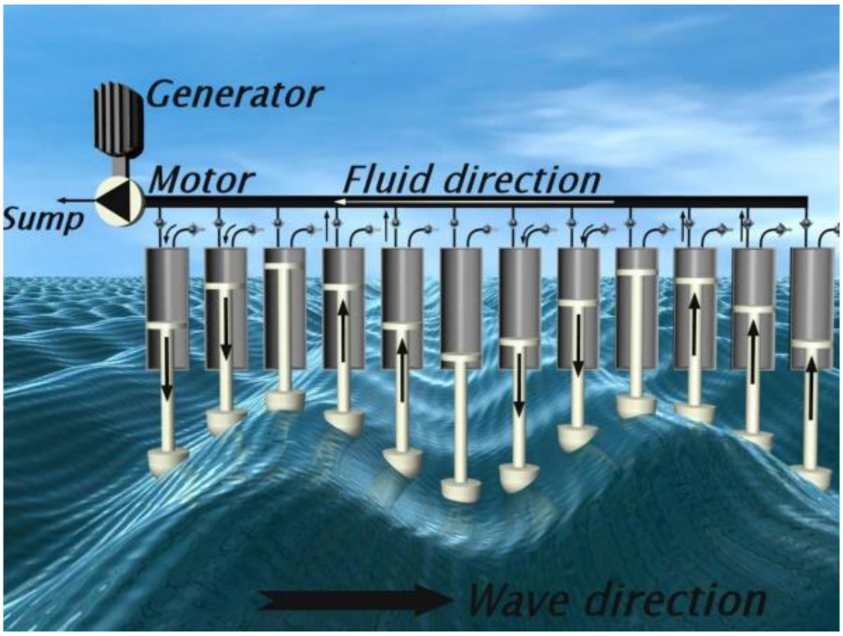


Figure 24. *Wave Star operation scheme.*

In the image above (from the "Wave Star Energy presentation in Bremerhaven 2006-10-23.ppt") it is shown how the technology basically operates.

In spite of its constant electricity generation, Wavestar production is signifincatly lower than the expected production of our wind mill. Moreover, The production of the Wave Star prototype depends strongly on *Hs* ("siginificant wave height"), parameter already studied in the final location.

Furthermore, Wavestar machine seems to have solved the big trouble of sea survavility due to the rough conditions of this enviroment. It can continue production in strong wind and waves, and automatically raises the floats out of the sea when the conditions becomes too stormy and are detected by its sensors.

Figure 25. *Normal operating mode and stormy non-operating mode (left and right respectively). Both pictures are from from the "Wave Star Energy presentation in Bremerhaven 2006-10-23.ppt".*

Biogas farm

A typical bimethanization plant has different parts which are totally neccessary for the success of the process. These parts are shown in the picture below (taken from the website *http://www.abt-grupo.com*)

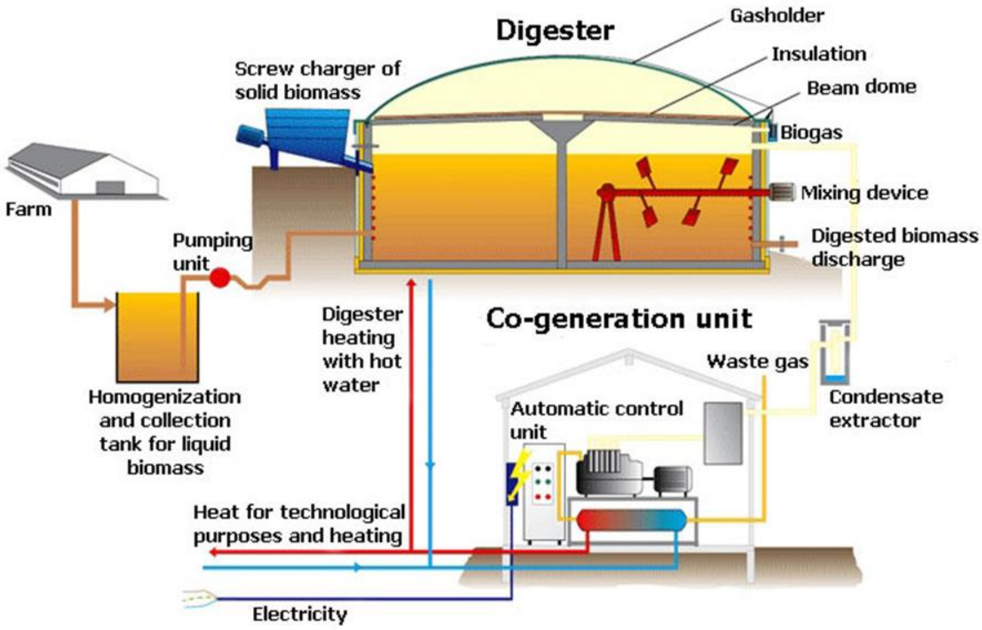


Figure 26. Biogas plant scheme.

It is easily observed that there are three main parts which have a relation with the different parts involved in the biogas obtaining. These are: the homegenizer, the digester and the cogeneration unit. Moreover, each one is composed by other parts (gasholder, automatic control unit, condensate extractor…).

Expected production

Finally, we must relate the two previous aspects and finding out or at least figure it out which is the total and expected electricity production.

Biogas farm production

This is basically calculated taking into account the total number of farm animals present in the island, the quantity of faeces produced by them, the correspondent m^3 of biogas obtained due to the transformation of these faeces and. Therefore, and finally, taking into consideration the realtion exposed above (1 m^3 of biogas produces 6kWh of electricity) we can find out which is the expected energy production in kWh (daily and also annualy) and the power of our biogas plant.
For our plant we are just considerating those animals whose faeces quantity is considerably big (or at least enough). Thus, we are just producing biogas by using the horses, cows faeces and pigs. Moreover we already knew the data for the calculation of the expected daily production for one horse and one cow, which are shown in the table below.

ANIMAL	FAECES (kg)	BIOGAS (m^3)	ELECTRIC ENERGY (kWh)
Horse	15	0.6	3.6
Cow	49	1.25	7.5
Pig	9.5	0.5605	3.363

Table 13. *Relation between the different animal faeces and the possible electric energy which can be obtained with them.*

Furthermore, we also know the number of horses, cows and pigs accounted for Gran Canaria island: 1414, 11124 and 17650. Thus we can easily calculate the expected electric energy production and the nominal power of our biogas plant.

Biogas plant				
Animal	Nº animals	Daily		Annualy
		kWh/animal	Energy production (kWh)	Energy Production (kWh)
Horse	1414	3,6	5090,4	1857996
Cow	11124	7,5	83430	30451950
Pig	17650	3,363	59356,95	21665286,8
			147877,35	
		Nominal power	6161,55625	

Table 14. *Biogas plant production*

If we take a look to the table above, we appreciate that the nominal power of the plant may not supply as much energy as we wished. Moreover, we must consider that our goa lis to totally supply the whole Gran Canaria island which is an ambitious but really interesting point. Therefore, we have decided to use also the human faeces. In addition, this is not accepted by everybody but otherwise, these faeces could possibly be thrown to the sea.

Furthermore, a human approximately produces 0.15 kg of faeces per day and the current population of Gran Canaria is of 838397 habitants. Otherwise, we are just considering about 750000 “useful people” (it is imposible to collect all the faeces of the entier population).

Biogas plant		Animals+humans		
Specie	Nº specie	Daily		Annualy
		kWh/specie	Energy production (kWh)	Energy Production (kWh)
Horse	1414	3,6	5090,4	1857996
Cow	11124	7,5	83430	30451950
Pig	17650	3,363	59356,95	21665286,8
Human	750000	0,0252	18900	6898500
			166777,35	
		Nominal POWER	6949,05625	

Table 15. *Biogas plant production (using human faeces)*

Finally, our biogas plant is supply a constant power of approximately 7 MW. Thus, it is time now to do the energy balance, considering the daily demand curve and the biogas plant contribution.

In the graph below it is shown the power which must be supplied by our offshore wind farm during the whole day. In addition, it is easily appreciated that it is practically equal to the demand because the nominal power of the biogas plant is considerably low in relation with the total demand. However, we may take into account that satisfy the demand of such a big island is not an easy job.

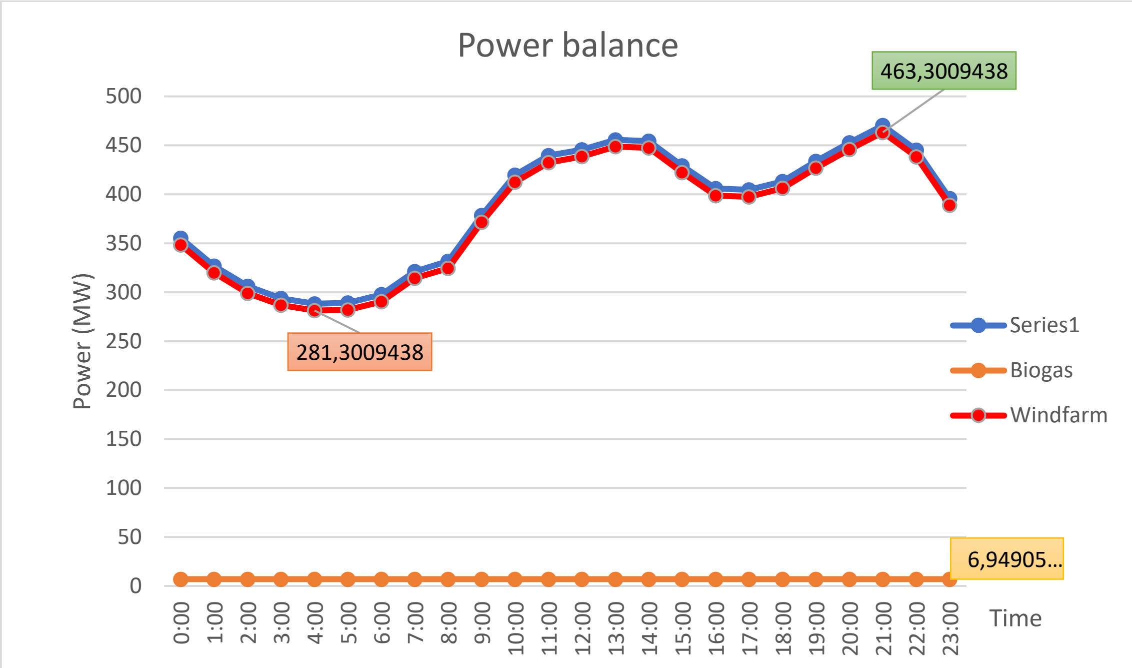


Figure 27. *Daily demand, biogas plant production and required prodcution of the offshore wind farm.*

		CONTRIBUTIONS	
Time	Demand	Biogas	Wind farm
0:00	355,25	6,94905625	348,300944
1:00	326,75	6,94905625	319,800944
2:00	306	6,94905625	299,050944
3:00	293,75	6,94905625	286,800944
4:00	288,25	6,94905625	281,300944
5:00	289	6,94905625	282,050944
6:00	297,5	6,94905625	290,550944
7:00	321,25	6,94905625	314,300944
8:00	331,5	6,94905625	324,550944
9:00	378,5	6,94905625	371,550944
10:00	419,5	6,94905625	412,550944
11:00	439,5	6,94905625	432,550944
12:00	445,5	6,94905625	438,550944
13:00	455,75	6,94905625	448,800944
14:00	454,25	6,94905625	447,300944
15:00	429,25	6,94905625	422,300944
16:00	405,75	6,94905625	398,800944
17:00	404,5	6,94905625	397,550944
18:00	413,25	6,94905625	406,300944
19:00	433,75	6,94905625	426,800944
20:00	452,75	6,94905625	445,800944
21:00	470,25	6,94905625	463,300944
22:00	445,25	6,94905625	438,300944
23:00	395,75	6,94905625	388,800944

Table 15. *Required electric production of the offshore wind farm.*

Offshore wind farm production

The goal of this part is to calculate the number of necessary turbines to completely satisfy the part of the demand which is not covered by the biogas plant production.

First of all we are calculating the demand of a single turbine placed in the final location (approximated coordinates). For the main calculation, we have to input: the geographical coordinates, two points of the generation curve of our turbine (these two are the cut-in and cut-out points) and the bushing height of the aerogenerator. Once we do this, the program automatically calculate the average wind speed and its predominant direction, and the Weibull constant. Finally, the outputs which are explained below are obtained.

Coord X (UTM):	450750 (más próxima)
Coord Y (UTM):	3069650 (más próxima)
Tomo detalle numérico:	GranCanaria6.pdf
Aerogenerador:	Siemens SWT-6.0-154
Altura:	100 m
Cte K de Weibull (100 m):	1.834
Velocidad viento (100 m):	9 m/s
Dirección predominante del viento:	NNE
Energía anual estimada:	17857415.7 kWh
Potencia anual:	2038.518 kW
Horas anuales equivalentes:	2976.2 h

Figure 28. *Production data of a single Siemens SWT-6.0-154 in the offshore wind farm final location.*

From the screenshot above we can extract the following conclusions:

1. The **annual energy prodution** is equal to 17857415.7 kWh
2. The **"annual power"** is 2038.518 kW
3. The **number of equivalent hours working at its nominal power (6 MW)** is 2976.2 h.

Once we know which is the production of a single turbine we must calculate the number of necessary turbines to satisfy the whole demand. Moreover, we are taking into account two things: the annual demand and the daily demand.

First of all and from the point of view of the **annual demand**, we are calculating the electric energy which must be supplied by the offshore wind farm and obtaining later the number of necessary turbines which are shaping it. Thus, we have to considérate the following aspects: Gran

Canaria's annual demand, biogas plant energy production and annual energy production of a single turbine in the final location of the farm. Moreover, these previous aspects are being related as it follows:

-Electric energy production of the biogas plant: consists of the product of the nominal power of the plant times the number of hours of a year.

$E_{BIOGAS} = P_{BIOGAS} \times t_{YEAR} = 7\ MW \times (365 \times 24)h$ =61320 MWh

-Necessary offshore energy annual production:

$$E_{OFFSHORE} = DEMAND - E_{BIOGAS} = 3455.305\ GWh - 61.320\ GWh$$

$$E_{OFFSHORE} = 3393.985\ GWh$$

-Number of nece$ssary\ turbines$:

$$\boldsymbol{Turbines} = \frac{E_{OFFSHORE}}{E_{SINGLEOFFHORE}} = \frac{3393.985\ GWh}{17.8574157\ GWh} = \mathbf{190}\ \boldsymbol{turbines}$$

According to the previous calculations based on the obtained information about the elecetric energy production of a single turbine placed in the final location of our wind farm, we easily conclude that the number of necessary turbines for completely satisfying the whole annual demand couldn't be inferior that 190. However, we must take into account that the Gran Canaria's demand was approximately calculated based on two different information sources and assuming that the percentage of the electric loses of each island of the archipielago were all the same and accounted for the same value as the whole archipielago.

On the other hand, any electric system needs to fulfill also some other conditions. Moreover and maybe the most important is having an interrupted electric supplying. Thus, and taking into consideration that the daily demand is nos constant (which can be observed in a table located in previous parts of the main document), the production of our turbines need to be adapted to this fact. Otherwise, we must respect which is the maximum possible electric energy production per day [MWh] which is equal to the product of the equivalent power of a single turbine (P_{EQUIV}), the number of turbines (TURBINES) and the number of hours of a day.

$$\boldsymbol{E_{MAX}} = \boldsymbol{P_{EQUIV}}[\boldsymbol{MW}] \times \boldsymbol{TURBINES} \times \mathbf{24}\ [\boldsymbol{h}]$$

We already know which is the expected energy that the offshore wind farm may supply each single hour which is completely different. In addition, designing a system which had to vary its production each single hour could suppose such a great problem to us and would be extremely difficult. Thus, the best solution is to distinguish different "types" of demand per day and prepare our turbines production to satisfy them which will lead to few operational points instead of twenty-four different ones.

Furthermore, we study three diferent possibilities concerning the offshores wind farm expected demand: three types (low, medium and high), four types (low, medium-low, medium-high and high) and five types (low, medium-low, medium, medium-high and high). Once we had stablish the limits of each type of demand, we calculated the operational power of each demand type, accounted the number of hours and finally obtained the number of necessary turbines that satisfied the initial condition (maximum possible electric energy production per day). Moreover, the calculation proccedure of each case is at follows:

-Stablish the limits of each type (**n**) of demand (inferior limit (P_{MIN}) equal to 281 MW and superior limit (P_{MAX}) equal to 463): **n** types

$$P_{INTERVAL} = \frac{P_{MAX} - P_{MIN}}{n}$$

-Calculation of the operational power of each type of demand, which is basically the average of all the powers between the limits of the main Interval (type).

$$P_{OPERATIONAL} = \frac{\sum_{i=1}^{N} P_i}{N}$$

Being N the “quantity of powers” between the limits of each demand type which is equal to the number of hours (which is being named “t” later) of this operational point (or power).

-Finally, we can easily obtain the number of necessary turbines by using the following expression:

$$\sum_{i=1}^{n} P_{OPERATIONAL} \times t = E_{MAX}$$

$$\sum_{i=1}^{n} P_{OPERATIONAL}\ [MW] \times t\ [h] = P_{EQUIV}[MW] \times TURBINES \times 24\ [h]$$

$$\boldsymbol{TURBINES = \frac{\sum_{i=1}^{n} P_{OPERATIONAL}\ [MW] \times t\ [h]}{P_{EQUIV}[MW] \times 24\ [h]}}$$

Furthermore and due to being an approximation (assuming different types of demand and not taking into consideration every single hour) we did the calculation for three diferent cases: three, four and five types of demand. However, we exactly obtained the same result for al lof them, which is shown below.

Demand type (3)	P [MW]	Number of hours
High	434,778216	11
Medium	381,000944	5
Low	299,800944	8
	Turbines	185,714423

Table 16. *Three different types of demand*

Demand type (4)	P [MW]	Hours
High	440,412055	9
Medium high	400,800944	5
Medium low	359,925944	2
Low	299,800944	8
	Turbines	185,714423

Table 17. *Four different types of demand*

Demand type (5)	P [MW]	Number of hours	P (sinlge turbine) [MW]
High	442,675944	8	2,37997819
Medium high	407,500944	5	2,19086529
Medium	380,175944	2	2,04395669
Medium low	330,884277	3	1,77894773
Low	292,34261	6	1,57173446
	Turbines	185,714423	

Table 18. *Five different types of demand*

According to the results of the tables exposed above, we can easily conclude that 186 turbines combined with the biogas plant could completely satisfy the daily demand. Otherwise, we had previously obtained that the number of necessary turbines fot satisfying the annual demand was 190. In addition, we have done approximations in both cases: the Gran Canaria's annual demand was calculated supposing that the percentage of loses was the same that the one of the wholw archipielago (Canary Islands), and for the calculation of the turbines number which could satisfy the daily demand we proposed several types of daily demand. Moreover, both demands were extracted from different websites (both of them were oficial and contrasted sites), so the data could slightly differ.

Finally, we are spliting the daily offshore wind farm demand in five types whose limits are explained below and whose operational powers are already calculated in the table shwon above:

-Hihg: total demanded power over 426.6 MW

-Medium-high: total demanded power between 390.2 and 426.6 MW

-Medium: total demanded power between 353.8 and 390.2 MW

-Medium-low: total demanded power between 317.4 and 353.8 MW

-Low: total demanded power between 281 and 326.5 MW

Furthermore, in the graph attached below we can find the delivered electric power of a single turbine during the whole day.

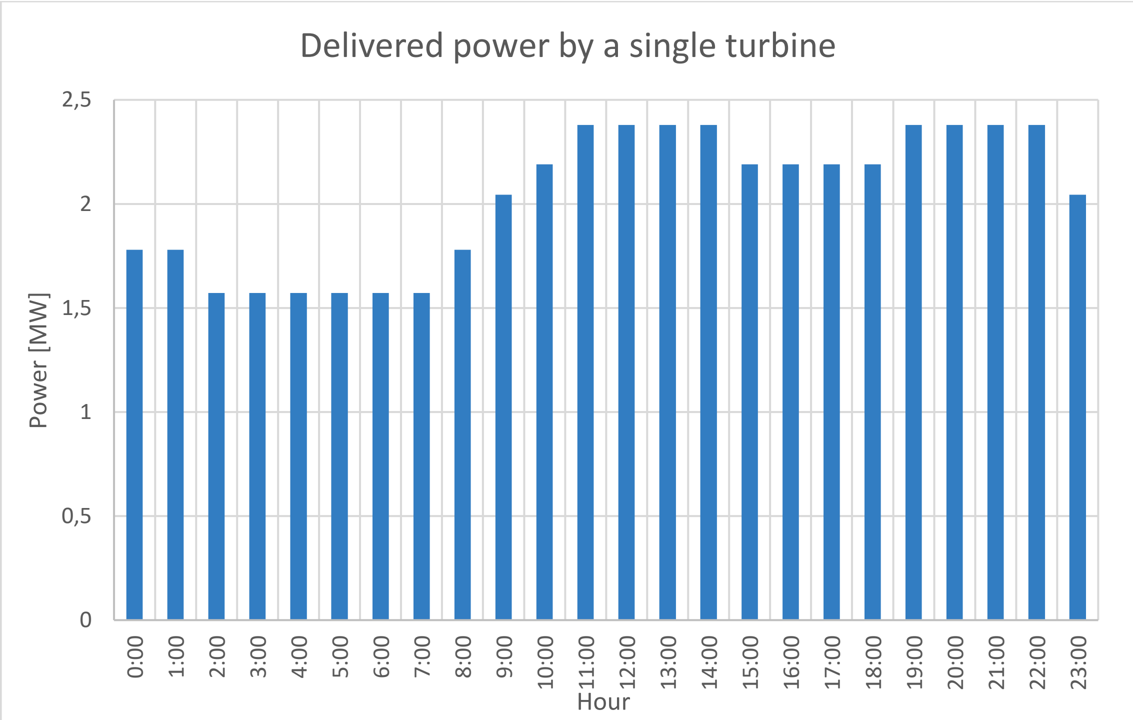


Figure 29. *Daily production of a single turbine*

Once we already know which is the number of necessary turbines for completely satisfying the daily demand, we must find out if it is fisically possible to build such a big wind farm. Moreover, we must take into account several design parameters which must be respected in order to have a higher and better production. Otherwise, we wouldn't take advantage of our technology.

According to these design parameters, there are several theories and indications which are considered truely valid. In addition, all of them establish that it must exist a distance between the different turbines of a wind farm and this distance is a function of the rotor diameter. However, the different theories differ in the values.

Furthermore, I have read several theories and researchs concerning this topic, and I found out one which seems to be really aceptable. In addition, most of the researchs didn´t specify if the design paramaters exposed were applicable to onshore or offshore wind farms. Thus, and extracted from *the Study on wind turbine arrangement for offshore wind farms* documents whose autors are Shen, Wen Zhong; Mikkelsen, Robert Flemming we could extract that "… the optimal separation distance between neighboring turbines for offshore wind farms should be **7 rotor diameters**."

Finally, we can find out if there is enough space in the allowed federal area to place at least 186 or 190 turbines with a separation of 7 rotor diameters between them. In addition, the rotor diameter of the chosen turbine accounted for 154 m, which leads to a separation of approximately 1000 m between the trubines. Therefore, we would need an area of 169 km^2, which is easily obtained with a 13 km side square, where the distance between the different turbines would be the same and the optimal one.

In the picture below it is represented the occupational area of the whole offshore wind farm and it is value, which is practically equal to 169 km^2 as it was already discussed before. Moreover, we can easily appreciate the size of the installation which is considerably big in comparisson with the island. Finally and as it was commented previously, the orientation of the farm is NNE (predominant direction of the offshore wind in this zone).

Figure 30*. Area covered by the offshore wind farm*

Furthermore and in the screenshot attached below we can also appreciate the considerable big difference of depths between the deepest and the shallowest points of the farm (lowest and top corners of the square in the picture above respectively). Moreover the respective and aproximated depths of these two points are: 40 m and 1070 m. Therefore, this is a trouble once we wish to do the installation and it should be taken into consideration.

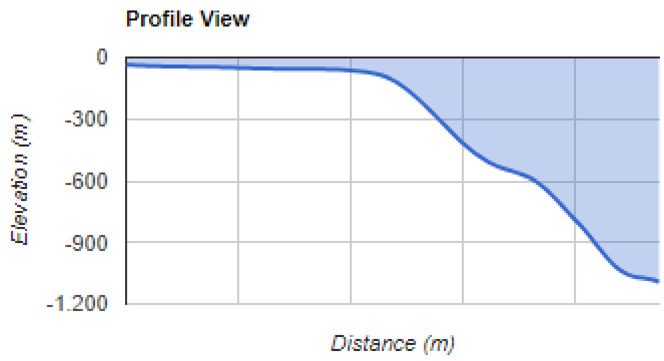


Figure 31. *Marine enbankment of the offshore wind farm*

Waves

Analyzing the obtained results of the different succesfull prototypes a power matrix was developed and an european perspective stablished. Besides, this perspective involves several locations whose enviromental and overall waves conditions have been carefuly taken into account. Furthermore, this european perspective is graphically shown below.

7

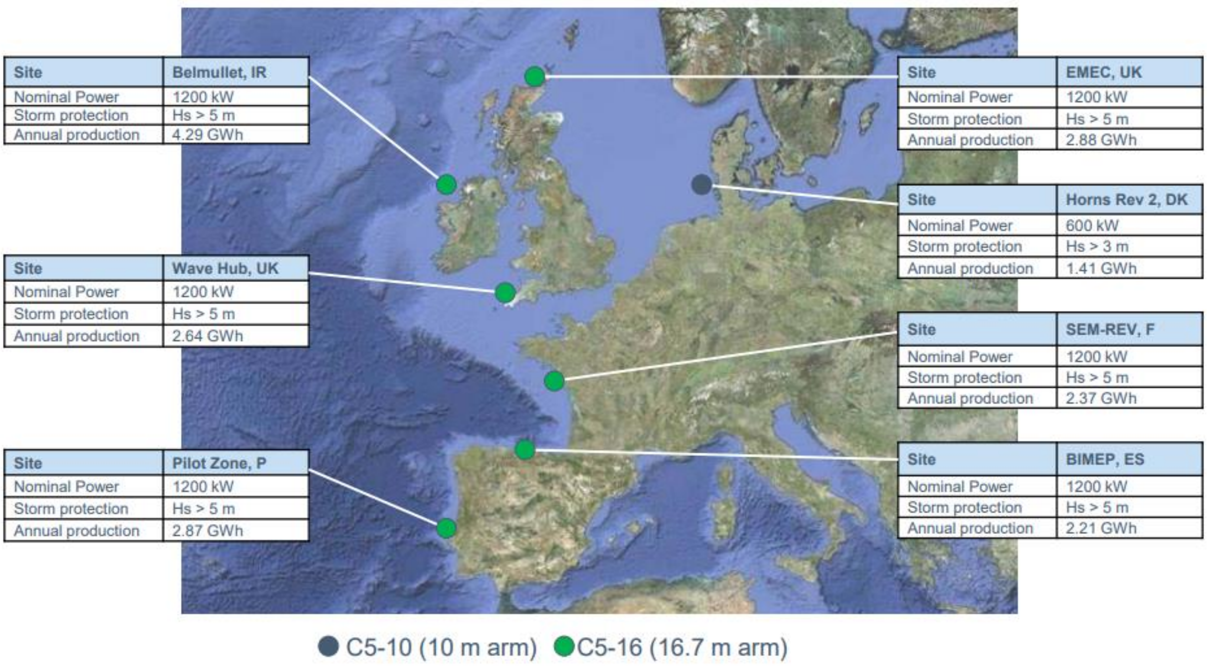


Figure 32. *Wave Star protoypes in Europe*

In the picture above (taken from the “EWTEC2011_2011-09-06.pdf” file which origin is the Wavestar oficial website) we can easily appreciate that our location is not contained on it which initially could suppose a big deal for the calculation of the possible production.

We could initally think of comparing our location and one of the already studied and supposing a possible prouction. Otherwise, this will lead to many approximations and suppositions which won’t worth it. Moreover, the production of this kind of installation is not really big enough yet for being applied to project like ours due to the extremely required high demand.

Furthermore, if we compare the waves conditions in the “BIMPEP,ES” site (Armintza Lemoniz) and our final location we can easily observe a considerable difference between them. Theferore, we conclude that we will never reach a nominal power of at least 1.2 MW so the investment won’t worth it.

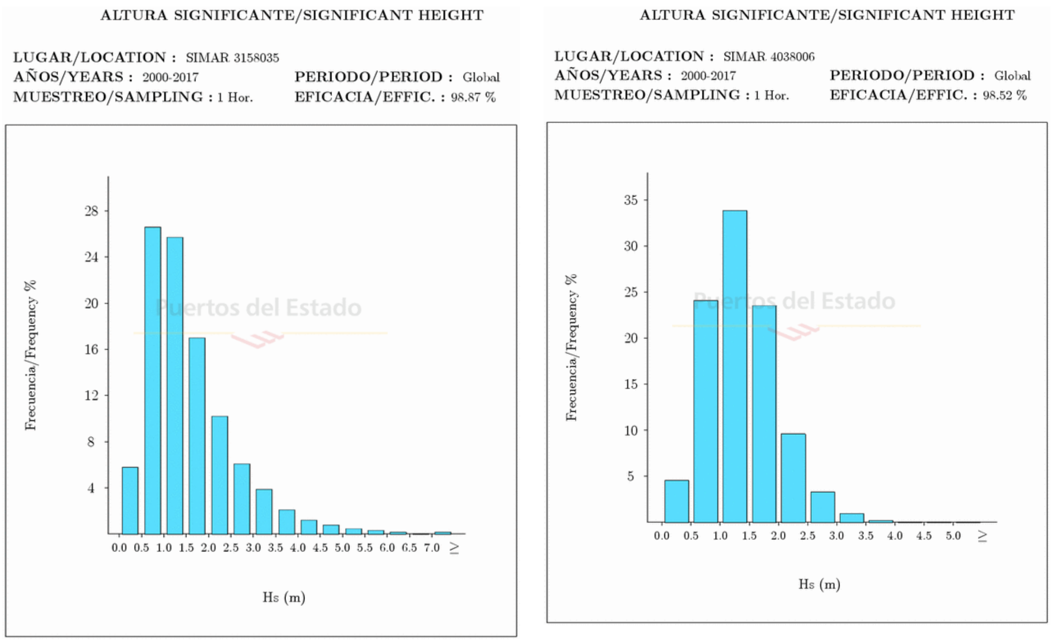


Figure 33. *Both histograms represent the behaviour of the significant height of the wave (Hs) of the two different and compared locations (BIMEP,ES on the left and Gran Canaria’s suth-east coast on the right). Moreover, the Hs takes higher values more often in the histogram on the left. Thus, the potential of the waves source is clearly bigger in Lemonitz than in our location.*

In conlcusion and sumarising all the aspects exposed and commented above, we decide to decline the option of adding the Wavestar technology to our hybrid system due to its still undeveloped technology and its low energy production.

Final conclusions

It is time now to review all the aspects previously exposed and take the decission of implementing or not our hybrid energy system.

First of all and from the point of view of the *conception of the capacity of the energy sources* study, our project **“feasible” but not realistic**. Thus, we could build such a system based on the offshore wind and biogas energy (renewable sources) which could supply enough energy for feeding the whole Gran Canaria island. Otherwise, the construction of the offshore wind farm, which is the energy base of our system, would be considerably difficult and would lead to an extremely high economical investment.

There are several aspects which easily show us the difficulty of the project implementation. Moreover, almost all of them are relationed with the **construction** and the **capacity of the renewable energy sources**. In addition, we must look for a cause and we can truely conclude that satisfying the whole demand of island is a considerably big trouble which leads to an ambitious and almost imposible project.

First of all and if we choose to build the offshore wind farm, it would be the biggest in the world at the moment. In addition, the biggest actual offshore wind farm is the *London Array* which accounts for the 36% of the global offshore energy installed capacity and whose main characteristics are exposed in the table below.

Installed power	600 MW
Area	100 km^2
Number of turbines	175
Latitude	51º 37’ 33.5 ’’
Longitude	1º 29’ 45.5’’
Depth	25 m
Distance from the coast	22 km
Turbines model	Siemens SWT-3.6-107
Total nominal power	630000 kW

Table 19. *Main characteristics of the London Array offshore wind farm*

If we observe the data exposed above, it is easily appreciated that: the area of “our” winfarm is almost 70 km^2 bigger, the number of turbines is also higher and the depth of the *London Array* considerably lower than ours. Moreover, the used turbine model is less developed than ours and thus considerably less expensive.

Furthermore, the *London Array* nominal power is about 1.6 times higher than ours (630000 kW against approximately 387400 kW). In addition and due to the offshore wind conditions of the *London Array* location, we can figure out that the yield of the turbines there is quite higher than ours which indicates that **we are not taking enough advantage of the offshore wind resource in our location.**

Figure 34*. London Array offshore wind farm (22 km from the Essex coasts)*

On the other hand and if we decided to build it, we would find an extremely construction difficulty: the **irregular marine enbankment** (with depth values from 40 to 1070 m). This disadvantage would be "solved" placing rather grounded or floating turbine platforms according to the particular depths. Otherwise, the floating platforms must be fixed by chains whose installation and product costs would be really expensive (and maybe imposible for some depths) which makes it non-viable. Moreover a work like this would lead to an extremely high economical investment and would take a lot of time to be completed (which accounts for mor expenses).

Regarding to the complementary energy source, we find out that the biogas input is considerably low in relation with the whole Gran Canaria's demand. In addition, the potential of the faeces resource is quite low and thus, it is not a good option even for a complementary source involved in such an ambitious project.

Finally and taking into consideration all the aspects exposed below, the realization of the project wouldn't be recomendable. Moreover, the necessary amount of money and time would be extremely high and it is not an easy job to take a part in the spanish electric market, indeed.

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