ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

MASTER IN THE ELECTRIC POWER INDUSTRY

ANALYSIS OF THE TEMPORAL AND GEOGRAPHICAL DISTRIBUTION OF THE PRODUCTION OF ELECTRICITY BY RES GENERATION IN THE SPANISH POWER SYSTEM

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Madrid
July 2017

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i. SUMMARY

The energy industry is undergoing through major changes and challenges. The European Union has set as one of its main goals to achieve a complete de-carbonization of the economy by. the year 2050. Nevertheless, this de-carbonization must be done gradually in different stages. These stages are what is known as horizons.

The 2020 horizon is a set of binding legislation that basically tries to ensure that the European Union will meet its needs for the year 2020. The package sets three key targets:

- 20% reduction in greenhouse gas emissions (from the 1990 level)
- 20% of the EU energy must come from renewable sources by 2020.
- 20% of improvement in energy efficiency.

The target of the European Union is that the total amount of energy consumed over a year must come from renewable sources. Currently in Spain the total amount coming from renewable sources in a year is around 15%. This amount considers different industries, like the transports, energy, residential, etc.

Being other industries more static in the energy transition most of the efforts are going to be done in the electric industry. This means, that the total amount of energy coming from renewable sources must increase in the next years to compensate the immobility of other industries.

Besides this, in Spain there is not a significant number of potential idoneal locations for further hydro development. This means that no major investment is expected in dams or run of the river technologies. Besides this, the topography of the Spanish coast makes offshore wind farms not very appealing because of the high investments that it would be needed to develop large offshore facilities. This is due to the impossibility of founding the windmills directly on the ground of the sea. Moreover, thermosolar technologies are still expensive in their OPEX and CAPEX, and with the current evolution of solar PV this technology is not expected to grow.

For the reasons mentioned above, onshore wind and photovoltaic solar, are the two most probable technologies to meet the obligations with the European Union and its targets for the year 2020.

Red Eléctrica de España, the Spanish Transmission System Operator must develop the analysis of the integration of this new amount of energy coming from renewable sources. This needs to be done to assess whether the current grid will be able to handle this new amount of energy planned to enter the system.

This integration must be done in the most secure, reliable and cheapest manner.

There are several studies to assess the capacity of the planned grid H2015-H2020 to integrate this renewable energy. However, in this master's thesis a new methodology will be proposed to study two different systems. These systems are those from the Canary Islands and the Peninsula.

Summarizing, the purpose of this Master's Thesis in to propose a new methodology to study the integration of the new amount of energy coming from renewable sources in two of the Spanish systems, the systems of the Peninsula and the Canary Islands.

ii. ACKNOWLEDGEMENT

I would like to express my gratitude to Rafael de Dios Alija and Belén Díaz-Guerra, my two supervisors for their patience and the time they have devoted to guide me through all the steps of this Master´s Thesis. I would also like to thank all the people forming the electrical planning division of Red Eléctrica de España for the supportive welcome and experience they have provided to me through all the period I have been part of their group.

Thanks as well to all the MEPI professors and coordinators, whose expertise and deep knowledge in the Electric Power Industry have been crucial to acquire, between other abilities, the knowledge needed to develop this Master´s Thesis.

My special gratitude to my mother, father, sister and brother for their support I have received from them my whole life and for the opportunities they have granted to me with effort and through hard work.

Finally, I would like to specially thank Mihaela for her patience, love, support and the strength she always provides me.

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CHAPTER 1.- INTRODUCTION

1.- Motivation

The purpose of this master thesis is to apply part of the knowledge acquired during the program of the Official Master´s Degree in the Electric Power Industry of the University of Comillas of Madrid during the academic year 2016-2017. This thesis has been supervised by Rafael de Dios Alija and Belén Díaz-Guerra Calderón, from the Electric Planning Department of Red Eléctrica de España (REE).

The Electric Planning Department has already carried out several studies to assess the capacity of the grid in the horizon 2020. However, the methodology followed in these studies could be improved. The improvement comes from new metrics recorded in RES generation in the years 2013-2016. With these new records, a more accurate forecast of RES generation can be develop.

Knowing the RES generation distribution, it could be assessed how new capacity to be installed will affect the grid in different scenarios.

Summarizing, the future capacity of the grid must be as to the granted and if needed the reinforcements of the current grid must be proposed.

2.- Introduction

The European Union wants to be the leader in the transition towards a de-carbonized economy. There are several advantages for the European Union if the economy is completely de-carbonized.

Firstly, the environmental footprint will be reduced and Europeans will enjoy a cleaner air at the same time it helps preventing global warming and all the perverse effects coming from the excess of gasses from a fossil fuel dependent economy.

Secondly, Europe seeks a gain in competitiveness for its industry though cheaper energy coming from renewable sources which variable costs are almost zero. Nowadays wind and solar PV technologies are mature technologies and they can compete against traditional technologies with little or even no subsidization. The combination of low variable costs and competitive CAPEX will help Europe manufactures to compete against other economies such as the Chinese or the North American.

However, the European Union also knows that a lot of energy is not efficiently used, and it is also trying to improve efficiency in the use of energy. Energy efficiency policies, will help both reducing the emissions and improving the competitiveness of the economy.

In this context, the EU issued the 2020 objective. A guidance set of main targets to achieve a de-carbonization of the economy.

This package has three main goals:

- 20% reduction in greenhouse gas emissions (from the levels of 1990)
- 20% of the total amount of energy must come from renewable sources by the year 2020 in the whole Europe.
- 20% improvement in energy efficiency.

Currently the total amount of electric energy produced in Spain by renewable sources is around 41% of the total yearly energy produced. However, the rest of industries are not so advanced in the process of de-carbonization. For instance, the transports are still totally dominated by fossil fuels. Therefore, to meet the European mandates new renewable generation is going to be introduced to compensate the emissions of other industries. With little room for new big hydro projects, and being thermosolar technology still very expensive, the increase of the renewable energy share must come from wind and solar PV.

Currently, thermosolar technology is considered non-competitive compere with the other technologies mentioned. Besides this, the technology is not expected to develop much because its expensive CAPEX. For this reason, it is considered that the installed capacity of this technology is not going to increase in the coming years.

As a conclusion in could be said that massive new RES capacity, onshore wind and solar PV, is planned to be installed in the coming year.

However, a massive entrance of RES generation presents some challenges. For instance, manageability must be solved and the generation profile does not fit with the demand curve shape. This could lead to congestion or spillages.

The responsibility of Red Eléctrica de España in this new paradigm is to provide a reliable and cheap transmission of electricity. Therefore, the TSO needs to forecast the evolution of demand and where and in which quantity new generation in going to be installed. The new generation to be installed is expected to be basically renewable facilities and specifically onshore wind and solar PV technologies.

3.- Objectives

The objectives of this Master's Thesis can be divided into two different major blocks depending on the system to study. Spain its composed by different areas, islands, and territories. Some of them are far away from each other. Therefore, their electric systems are difficult to be connected. For instance, the peninsular system and the system of the Canary Island are, obviously, not connected. These are the main systems that are going to be studied.

The objectives in each of the systems are:

- For both systems, the main objective is to assess whether the future grid planned can handle the future amount of renewable energy coming from the new facilities to be installed. To do this a new methodology to assess the level of RES generation is going to be proposed. The level of RES generation is going to be linked with demand and geographical patterns.
- Characterizing and RES generation patterns and relationship, representative scenarios could be obtained. Once these scenarios are obtained it will be easier to compute future grid needs, just by assigning the forecasted levels of demand and RES capacity installed to each scenario.
- However, the situation in the Peninsula and in the Canary Islands is different:
    - In the Peninsula, there are already studios to assess these scenarios. The objective is to improve the methodology to include geographical and temporal relationship between demand and generation.
    - In the Canary Islands, the studies will be done from the very beginning because before there was no data available to do the studies. Besides this the emphasis is the same, to obtain the link between demand and RES generation.

CHAPTER 2.- STATE OF THE ART

1.- Introduction

The electric industry plays a fundamental role in the economy providing a critical instrument to companies and households. Therefore, the security of supply at the cheapest cost is essential for the competitiveness of the economy and for the welfare of the whole country.

Currently, generation and supply business are carried out in a liberalized environment. However, the economies of scale behind the transmission business make this activity a natural monopoly that must be regulated.

Planning the infrastructures needed for the transmission of energy has as main goal to guarantee the supply in any demand level at the minimum cost possible. To meet these objectives, it is fundamental to forecast the evolution of demand and installed capacity of each technology in the coming years. Once the demand and installed capacity is known, the optimal investments needed to provide a reliable and cheap energy transportation can be assessed.

2.- Grid planning

Red Eléctrica de España, periodically elaborates the studies needed to determine the expansion or improvements that the different systems of Spain should introduce to meet the objective of reliability and economic efficiency.

In this line, the Ministry of Industry, Tourism and Trade, approved in November 2014 the guideline for the development of the national grid for the years 2015-2020. (Planificación energética. Plan de desarrollo de la red de transporte de energía eléctrica 2015-2020)

Nevertheless, the objective of this Master's Thesis is to improve the aforementioned studies.

The main difficulty assessing the level of RES production to consider in grid planning is lack of historical records of RES production. This means that the precise level of production in a node cannot be contrasted with real data recorded.

In past studies, a level of production has been assigned to each technology in but with not a solid statistical reasoning behind.

For instance, solar PV was considered to be producing at a 100% rate when the sun is shining or at a rate of 0% at night. This consideration is too simplistic and it does not represent reality. It is known that, if the panels are not movable, and most of them are not (they are much more expensive and more land is needed), they will just produce at a rate of 100% few hours in a whole year.

3.- Red Eléctrica de España a worldwide pioneer.

Red Eléctrica de España has been a pioneer in RES generation in the whole world. Currently they are able to integrate a large amount of energy coming from wind and solar resources in real time, minimizing the spillages and providing a reliable and secure operation of the system.

In addition, REE has available a reliable dataset of hourly metering of demand and wind and solar generation. For this reason, REE is ahead other TSOs that simply do not have this data available and their studies must be done using other methodology that may not fit the reality in some parts of the grid.

It could be said that the studies this Master's Thesis will propose are quite innovative and that in few places have been done because the lack of recorded data.

CHAPTER 3.- PROBLEM DESCRIPTION

1.- Introduction

In this Chapter, it is going to be explained in detail the problems that are going to be solved in the next chapters. As already mentioned before, two clear different problems compose this Master's Thesis. One of them comprises the system of the peninsula and the other one comprises the systems of the Canary Islands.

2.- Peninsula

The Transmission System Operator assesses the suitability of the grid for the coming years by developing studies for the horizon years. Currently the horizon corresponds to the year 2020. The methodology to study the horizons consist basically in plan studies and capacity studies. These studies are obviously already done, but Red Eléctrica de España wants to prove if the hypothesis considered when these studies were done are sufficient and whether they match with the series recorded between the years 2013 and 2016.

It can be assumed that between demand and RES generation a link can be found. This statement can be easily argued, because for instance the coldest hour of the year may correspond to a scenario with no sun and a lot of wind. For instance, a night in January. Therefore, the demand will be high and there will be a lot of energy coming from wind and no energy coming from solar PV.

On top on this, there is other variable affecting the relationship between RES and demand in large systems. The geographical distribution. It has been said that in cold days the production of wind is going to be high. Nevertheless, it will not be high in all parts of the system because it depends on how the cold fronts of wind hits the system. Normally wind fronts enter the system through a point and leave the system throughout another. The areas not touched by the front remain normally with little wind resources. Obviously, fronts hitting large systems in cold days follow different patterns and it is quite difficult to forecast their distribution. In this master thesis, the geographical distribution of energy will be study grouping regions of Spain that share the same characteristics.

The relationship between RES generation with temporal and geographical issues is especially interesting, because with conventional technologies there is no need to consider this demand-geographical-temporal relationship. This means that just by knowing the demand, and solving an economic order dispatch problem the generators that are going to produce can be identified. Generation is not linked with demand by a temporal and geographical relationship, just by more certain economics terms.

Therefore, the objective of this part of the Master's Thesis is to obtain the relationship between demand, time, and regions of Spain to carry out a statistical analysis of the RES production from the recorded years 2013-2016 in the whole peninsular system. This study will be contrasted with the level of RES generation considered in the studies done for the Horizon 2015-2020. To see whether the planned grid will still be able to handle the future needs of the Horizon 2020.

3.- Canary Islands

The main objective of this part is to obtain the scenarios for the studies of future grid requirements in the Canary Islands electric systems in the horizon year. This means, to characterize the patterns of demand and generation coming from Renewable Energy Resources and try to characterize simultaneous patterns among them to evaluate common and critical situations for the grid. It is expected to find that demand and RES generation share some features.

The scenarios that are sought are those corresponding with a normal or mean status of the grid and with extreme levels of demand and RES generation. Once they are obtained the next step is to compare them to assess whether the possible reinforcements needed are economic viable or whether the extreme situations could be managed with other mechanisms like; interruptions in demand, spillages, etc.

The Canary Islands are an archipelago that consists of seven islands: El Hierro, La Palma, La Gomera, Tenerife, Gran Canaria, Fuerteventura and Lanzarote. The systems of these islands are quite small and none of them interconnected but the ones of Fuerteventura and Lanzarote. Nevertheless, the system of La Gomera is going to be connected with the one of Tenerife that is why they are going to be treated as a whole.

In this Master Thesis, just the systems of Gran Canaria and that composed by Tenerife and La Gomera are going to be studied. This is because those are the systems for which reliable measurements have been recorded through the years 2013 and 2016. It is important to remember that the systems of Tenerife and La Gomera are not connected yet. However, as the systems soon are going to be merge they are going to be considered as a whole.

The systems of the Canary Islands are expected to suffer quite a deep change in the near future. Not just because the connection of the systems of Tenerife and La Gomera, but also due to the integration of large capacity of wind and solar energy. Talking about solar the technology expected to be introduced is photovoltaic solar. Nevertheless, the forecasted main energy to be installed is onshore wind.

As mentioned before, the systems of the islands are quite small and not interconnected. For this reason, the studies are not going to consider the relation between islands. The generation coming from RES is going to be considered as a ratio between the total production of the islands with respect to the total installed capacity in the island. This consideration will allow comparing the systems without considering the size of the installations currently in place.

The final objective is to obtain the critical and mean scenarios for the system.

CHAPTER 4.- PROPOSED METHOD

1.- Introduction

The proposed method is different for each of the system understudy. The size, topology, interconnections of the systems are different. Moreover, in the Peninsular Island there is a geographical relationship between the renewable resources in different areas that due its size and lack of interconnections it is not needed to be considered in the Canary Islands.

That is the main reason the same methodology cannot be applied to both system and each system.

Each methodology proposed is presented in different sections.

SECTION I.- SPANISH PENINSULA ANALYSIS

1.- Studies of integration of renewable energy generation.

From the perspective of the system development, there are different types of prospective studies carried out periodically by Red Eléctrica de España in the different schemes of Grid Access and Grid Planning, focused to assess the possibilities of generation coming from renewable sources and its technical viability.

Besides the studies that try to identify the technical requirements of the installations of the system, particularly of the generators, with the objective of enable a greater integration paying especial attention the security of the system.

There are different types of studies as the following ones:

- From a general perspective associated to the whole system. The sufficiency of the generator (installed capacity available) throughout the studies of the demand coverage (studies of the expansion of the generators). These studies enable to assess the reserve of generation to handle the different situation of generation forecasted and to be more specific in the more demanding situations (peaks in demand in winter or summer). Besides this, depending on the models used, these studies try to forecast, but generally in a very approximate way, the conditions for the operation of the different types of generators in different future scenarios, estimating the hours of renewable generation, cogeneration and wastes, in the production (hours and energy) that reflects the limitation of the system to integrate the prior generation. In this case of the renewable generation, this can be translated as well in spillages of energy. These spillages of energy are a misuse of the primary resource associated to the associated installed generation. This results in a more complex operation of the system and a challenge for the security of this.
  However, these are generally "single node" studies. This means, the grid is not modeled, but the limitations and the conditions are not considered. But this lack of relationship between the nodes and the electric zones of the grid, is the responsible for the assessment of the capacity of connection.
- The grid studies are the most important one to assess the capacities of connection by their relationship with the different topologies (nodal, zonal, …). Or, in other cases the identification of the necessities for development of the

transmission grid. In these cases, the combination generation-grid forecasted in the future scenarios are acceptable and sufficient.

- The Spanish legislation (RD1995/2000 y P.O. 12.1), tells that the grid studies must be based in the application of the security criteria, regularity and quality of supply, like to guarantee the basic directives of the meshed grid and basically the design criteria and the development of the transmission grid. These studies must be done over feasible scenarios that represent the more predictable conditions in the horizon of study for the transmission grid planned. Moreover, these studies simulate the behavior of the system in case of total unavailability of the grid and in contingency conditions (selected unavailability of the different elements of the transmission grid) align with the aforementioned legislation. Thus, the behavior of the system is analyzed by two different perspectives:
    - Reliability: capacity studies, that simulate the functioning of the system in static conditions (throughout charge flows in the situations of availability mentioned and short-circuit analysis) and assess the capacity of evacuation of different topologies, nodes and zones.
    - Security: acceptability studies, that simulate the functioning of the system in dynamic conditions. Paying special attention to the transient and permanent regimes after the perturbations considered in the functioning and security admissible criteria. The main objective of this special regime of the electric system does not compromise the transient stability of this.

      For being more complex studies in which it is not suitable a simplified parametric treatment. In these generally the limits of generation are not determined but they are simulated in extreme situation previously defined and they are validated the capacities already computed with the reliability studies. This circumstance avoids the difficulty as well of having connection capacity in the general application in the zones understudy.

Considering the Spanish system configuration, as especially the transmission grid (mesh level and distances), are the reliability studies (static behavior) the more relevant ones, for the decisions derived from them and the time required for its fulfillment.

2.- Integration capacity analysis of RES in the transmission grid.

Grid studies assess initially the capacity of the system from a nodal perspective (connection point to the transmission grid o transmission node affected by the generation to be connected in the distribution grid) modelling a parametric variation (progressive increment) of production for the whole system. However, the results of these results coming from individualized nodal analysis are not enough because the resulting capacities are not compatible and that requires the consideration of a wider topologic spectrum with the objective to have a minimum sense (to avoid chronic restrictions in the operation of the system and a minimum coverage in the security of supply). Therefore, wider topologic ranges are considered, to electric zones defined by the different group of nodes placed in every region. Having said that, it has been pursued to maximize the capacity of connection in the different areas associated to each region.

2.1.- Study of the integration capacity in the grid: methodology.

The analysis to be carried out is centered in the evaluation of the reliability of the planned grid in the Spanish electric systems (Peninsula and Canary Islands) to integrate the new renewable energy forecasted after the deep changes registered after the first study for the development of the transmission grid Horizon 2015-2020 considering the horizon 2016 considered in the firsts evaluations.

The reliability studies include the analysis of the Load Flows -LF, applicable to all short of generators and short-circuit capacities-Scc, to be considered in non-controllable generation.

a) The reliability studies of Load Flows (LF), in general terms the following topologic situations are considered in the Operation Procedures of REE:
   a. N situation: total availability of all the generators and lines of the system.

b. N-1 contingency: unavailability of one element of the system: circuit, transformer or generator (generally not relevant for the calculation of the evacuation capacity)
c. N-2 contingency: failure in the double circuit lines that share towers in more than 30 km.

The aforementioned situations must satisfy the acceptability criteria associated to guarantee of the following flow limits by the lines or the grid elements (% of the nominal capacity or assigned to the lines associated to the weather conditions of summers, because this is the most restricting situation in the evacuation limitation):

a. 115% for lines
b. 100% for cables
c. A 10% for the transformers in winter a situation of N-1. In multiple failures, an overload of 20% in winter and 10% in the rest of the year are admitted.

These studies assess initially the capacity from a nodal perspective (connection point to the transmission grid o the node of the transmission grid affected by the generation to be connected in the distribution grid). For this, a progressive increment is modelled in the renewable production in the node understudy, and the behavior of the grid is studied under that conditions. The maximum capacity of integration of renewable energy in that node is given by the limit situation by the acceptability criteria mentioned.

However, the individualized node analysis is not enough because the evacuation capacities in each node are not compatible with one another in specific zones with restrictions that determines the evacuation nodal limits. When the sum of the individualized capacities of the nodes is greater than the capacity of evacuation of the zone it has been seek the combination of the nodal capacities respecting the zonal restriction that allows the maximization of integration of renewable energy sources in the system understudy.

b) The studies of Short-Circuit Capacity (Scc) enable the possibility of studying the Short-Circuit Capacity expected in each of the nodes of the transmission grid in the considered scenarios. Paying attention to the RD 413/2014, this allow the determining another additional limit to the evacuation capacity for non-controllable generation (like the 5% of the Scc calculated in an average scenario- percentile 50%).

3.- Methodology used in the Peninsula.

In this point in his going to be developed and explained the methodology used to study the grid.

3.2.- Multi-scenario methodology

3.2.1.- Model of the transmission grid

Considering the connection possibilities, not just the current ones but the expected ones in the middle-term, the temporal framework of the horizon 2020 is considered with the OS previsions in the expected plan 2015-2020. These previsions have not changed from the final plan finally approved.

In that scenario, the current grid is considered as the reference one, with the incorporation of the new entrances forecasted in the horizon 2020 that can be found in the document "Transmission grid planning of electric energy and natural gas 2015-2020" (in Spanish *"Planificación de redes de transporte de energía eléctrica y gas natural 2015-2020"*) approved by the *Ministry of Energy and Tourism* and approved by the ministry council the 16th of October 2015.

3.2.2.- Zones understudy

To study the peninsular system the production and installed capacity in each province is going to be summed. Then the relationship of zonal patterns in production is going to be determined considering the different regions. If two regions can be considered that follow the same patterns they will be studied together.

Moreover, the regions will be classified attending to both wind and solar PV production. This means that the same region can follow the same pattern with another in terms of wind but a different one regarding solar production. That is why to different classifications will be done, for wind and solar.

The Spanish electric power system is divided into provinces, considering the relations inside the province and the other provinces obtain in the historical data available for wind and solar production available.

Figure 1 Provinces of Spain (each color is a Region)

3.2.3.- Demand

The study has been done in taking into account four scenarios of the Horizon 2020 that represent most of the hours in a year and with demand levels collected in the table 1.

Dividing the year in two periods, winter and summer, situations of peak and valleys: cases 2 and 4 are considered for both winter and summer.

	Winter						Summer					
	1	2	3	4	5	6	1	2	3	4	5	6
p.u. vs Peak	1	0,9	0,84	0,68	0,5	0,35	1	0,92	0,85	0,69	0,51	0,45
Duration [h]	15	225	487	3982	374	5	15	258	468	2705	221	5

Table 1 Demand scenarios analyzed

Every province is analyzed in all the four cases of study: two and four in winter and two and four in summer. In total, those cases represent more than 85% of the hours in a year.

3.2.4.- International exchanges

It has been considered the most feasible international exchanges in the horizon 2020. The magnitudes of these exchanges are shown in the following table 2.

	Horizon 2020	
	Capacity [MW]	Exportation/Importation
France	1.800	Importation
Portugal	2.000	Exportation
Morocco	600	Exportation
Total	800	Exportation

Table 2 International exchanges considered

3.2.5.- Generation

In the analyzed horizon, a generation scenario has been considered. This scenario considers the conventional generation expected and the renewable generation expected, basically wind and solar energy.

- Nuclear generation: 100% of the value currently existing.

- Conventional thermal generation: minimum generation needed to guarantee enough spinning reserve to face the variations of production in non-controllable generation and to guarantee the reliability of the system.
- Hydro generation: considering a wet year scenario.
- Renewable generation: self-producers and biofuels up to a 70% of their installed capacity.

  Wind and solar PV generation: and statistical study will be done to assess the level of generation corresponding to each province for each block of demand and considering the intra-relationship between provinces. The process followed will be explained in the point 4.5 of this document.

The table 3 shows, the expected wind, solar and other renewable like cogeneration or waste generation installed considered in this study. It is to notice that this generation does not match the capacity installed considered in the 2015-2020 plan. Being in all the cases bigger with the objective of analyzing the access to the grid expected by the promoters, as well as by the plans of the *Regional Governments.*

3.3.- Scenarios of RES generation.

To study the planned grid is needed to assess the level production coming from RES. It is known that wind and solar PV are not manageable resources. This means that their production is subject to exogenous factors like wind and solar availability. This singularity of RES makes the study of the grid a more complex process.

Moreover, it can be affirmed that not all the installed capacity of wind and solar PV is going to be producing at the same time. Statistical data has shown that there is a high volatility in the production of windfarms in different hours allover Spain. Solar PV, even when is a more stable energy source, has also a range from which its production varies.

In addition, from past data it can also be assessed that the patterns of wind energy production follow some kind of geographical pattern. This means that within the Spanish country, when wind is blowing at a high speed for instance in Galicia, it is doing the same in regions like Castilla y León, Castilla la Mancha and part of Comunidad Valenciana. On the other hand, when the wind is blowing at a high speed in Galicia the wind production in all the northeastern part of Spain if rather low, and the same happens in the southeastern part. The next figure illustrates this situation recorded the day 11/02/2016 at 21:00h.

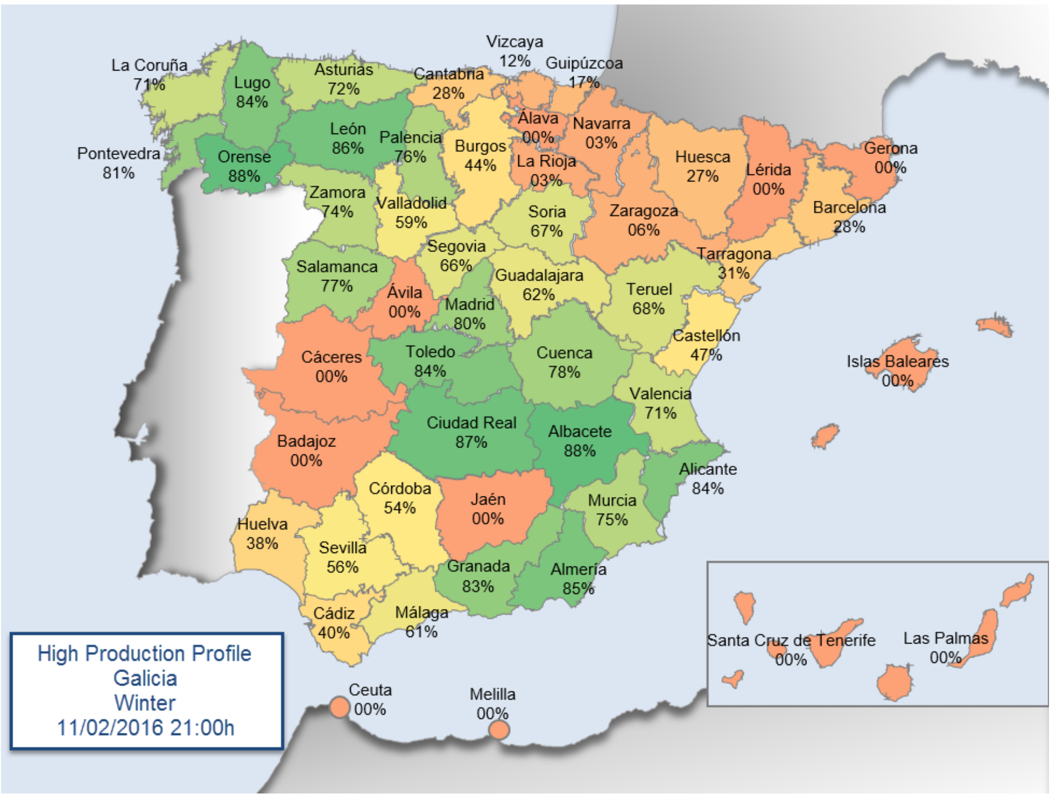

Figure 2 Wind production profile the 11/02/2016 at 21:00 h. Percentage respect to the total installed capacity in each province

This makes the solution of the problem especially difficult, because there is an interdependency between the different geographical areas in Spain and therefore the same level of production cannot be applied to all the Peninsula.

The same happens with the production coming for Solar PV facilities. It must be kept in mind that the production form Solar PV depends in a large manner on the disposition of the solar cells. If the solar beams do not impact the cell forming a 90 degrees angle, the cell will not produce at its full capacity.

There is also a geographical relationship between the different regions of Spain. This means that when, for instance, the sun is shining in Andalucia it may be shining less in other parts of Spain.

In the figure 3 it can be observed how when in Andalucía is producing at a high rate, the production rate in Galicia and Asturias is lower.

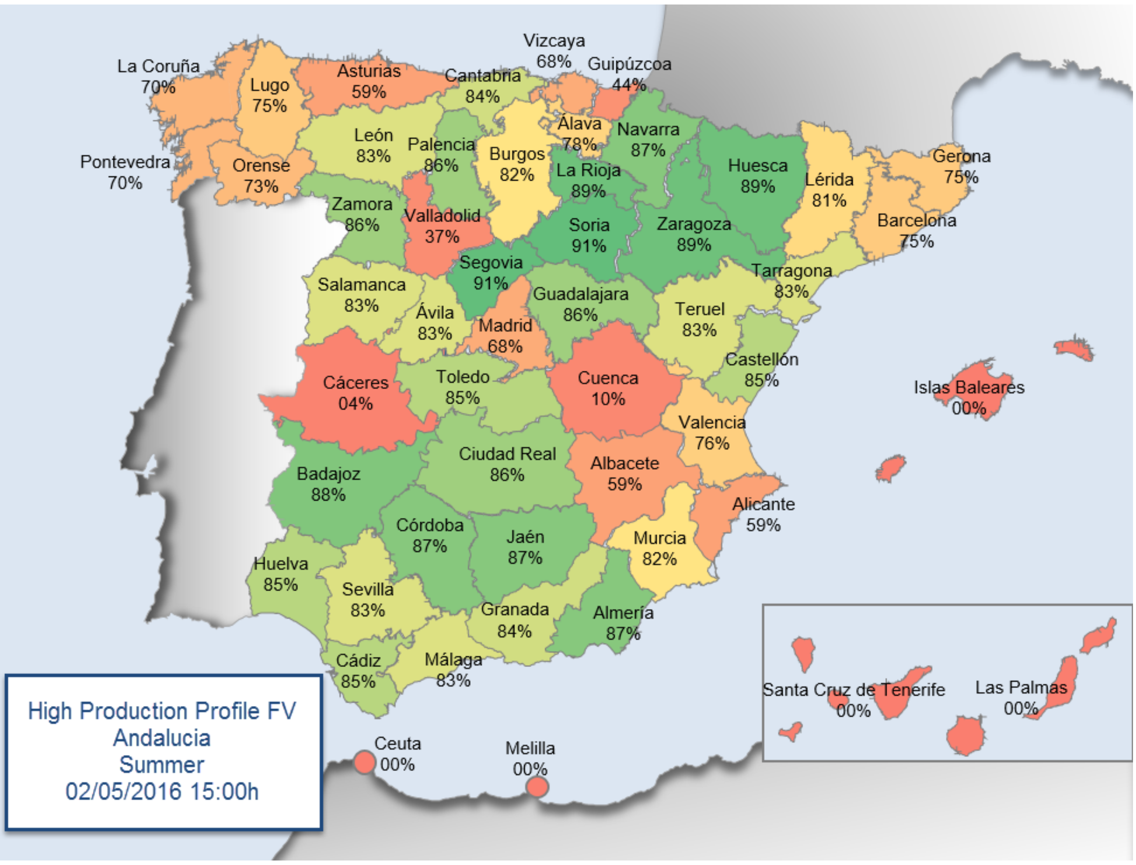

Figure 3 Solar PV production profile the 02/05/2016 at 15:00h. Percentage with respect to the installed capacity in each province.

To be able to study the whole peninsula, some arrangements are needed to be done to solve the interrelation between zones.

But firstly, it has to be studied whether there is a temporal relationship between the different blocks shown at point 4.4.3 and the level of RES generation for each of those blocks.

3.3.1.- Temporal relationship between demand and RES generation

Red Eléctrica de España has provided the data of RES generation and demand for the years 2013 to 2016. It is going to be studied the temporal relationship of each block and the level of RES production.

The temporal relationship referred means that demand and RES generation are linked. This means, demand is driven mostly by climate circumstances and economic behavior. The climate circumstances must have an impact on RES generation. For instance, the maximum hourly peak in demand in summer may correspond to the hottest hour of the year. It can be though that this hottest hour of the year must correspond to one of the hours with higher production of Solar PV production and that at the same time wind production may be low.

To do this, the following methodology is going to be followed:

- A load monotone curve for the average of the four years is going to be obtain. This means that the demand in each of the hours of each days for the four years is going to be sum and then divided by four.
  By doing this, it will be obtained a standard load monotone and the hours of the year with higher or lower demand located.
- This average load monotone is going to be split in winter and summer, because demand has a seasonal pattern in those two seasons of the year and it can be studied together. This means that in winter there are more valley hours than in summer. It can be seen that block 4 in winter has more than 1000 hours more than block 4 in summer.
- Sorting the demand in each block in a descendent way it is easy to find the specific day and hour of the year corresponding to the each of the blocks.
- Having identified the days and hours of the year corresponding to each block, the level of production of each province with respect to its installed capacity for each hour of each block can be calculated
  Grouping the days and hours corresponding to each block for the four years recorded will allow to carry out a statistical analysis to determine the normal and extreme levels of RES production corresponding to each block.
- The statistical analysis consists on finding the Percentile 95 and 05 of production of each block and the mean. The meaning of these indexes is in the case of percentile 95 the level of production that is just surpass a 5% of the hours and in case of the percentile 05 the level of production not reached in

less than 5% of the hours. These indexes will correspond with a high and low profile of RES generation.

This methodology gives a temporal relation between the demand and the actual production coming from RES.

The process of this computation is quite long and it does not give much information that is why they are not going to be included in this document.

Two maps corresponding with two of these indexes are going to be shown, for illustrative purposes. These cases are the corresponding to a Percentile 95 of wind and solar PV production for summer and winter respectively.

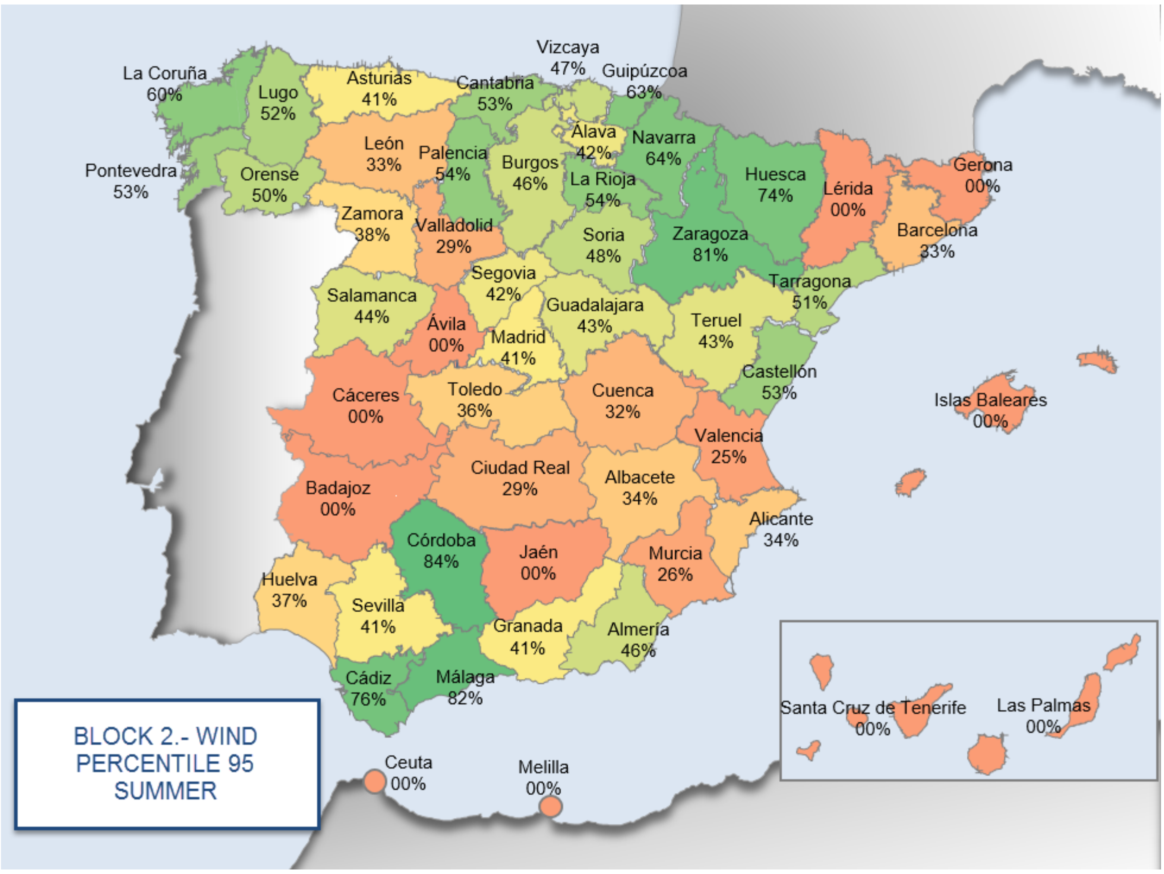

Figure 4 Percentile 95 of Wind production for block 2 in Summer

Figure 5 Percentile 95 of Wind production for block 2 in Summer

3.3.2.- Wind and Solar resources of the peninsula.

But to study the temporal relationship of the demand is not enough, because then the geographical relationship is loss. This means, that the percentile 95 in block 3, for instance, will show for each province the production that it is just surpass in 5% of the hours. However, there is also a geographical relationship that must be considered. Because the hours of the year corresponding to this 5% of production vary from province to province.

To study the relationship between different zones of the peninsula, a first step is study how wind and solar resources distribute across Spain. With this data, some areas which share the same characteristics could be obtain and therefore grouped.

For study the distribution of wind resources across Spain, the map of the average wind speed for the whole peninsula is going to be used. This map is provided by the IDAE (the Spanish *Institute for Diversification and Energy Efficiency)*.

The map is shown below:

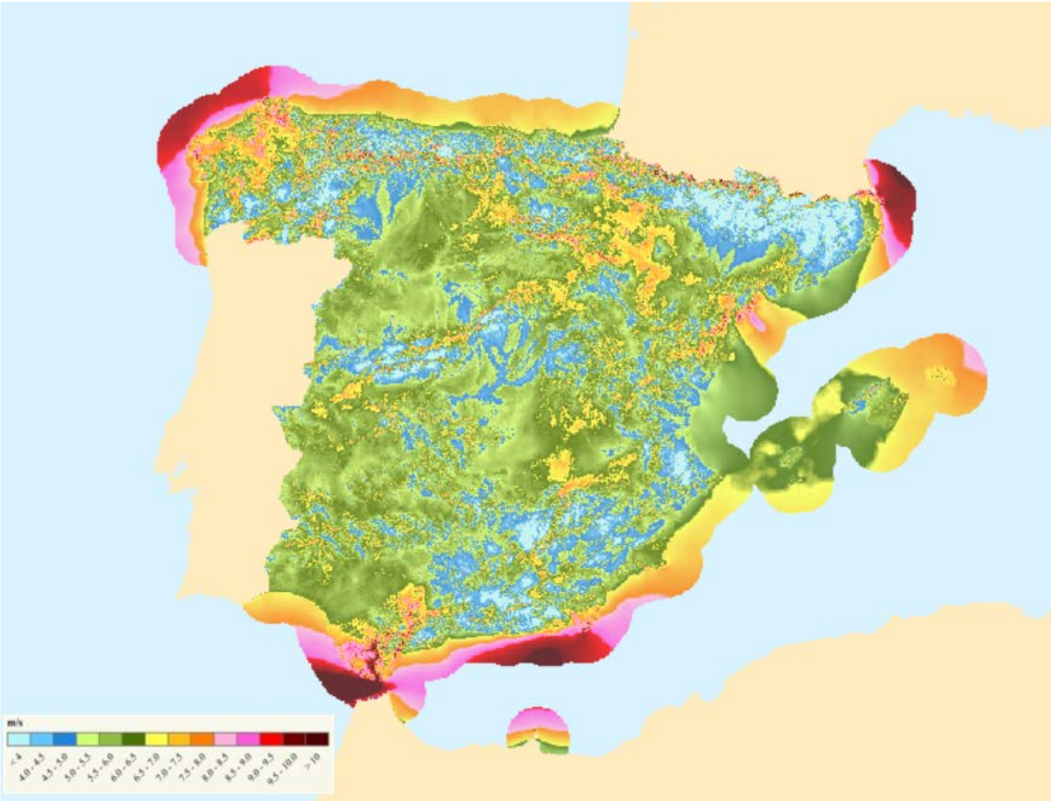

Figure 6 Average wind speed in the Spanish peninsula. Source: IDAE.

Attending to this map, the peninsula can be classified in different areas wind the same wind resources available. For instance, it can be clearly seen that all the area bellow the Pyreneans has a very low availability of wind resources. On the other hand, Galicia and Aragon have quite a lot of wind resources.

Following this logic, the following areas are proposed:

Geographical zones attending to wind speed distribution
Galicia
Asturias, Cantabria & Pais Vasco
Aragón, Navarra and La Rioja
Cataluña
Comunidad Valencia & Murcia
Andalucia & Extremadura
Castilla y León
Castilla la Mancha & Madrid

Table 3 Geographical zones attending to wind speed distribution

The same process is going to be repeated with solar resources available in the peninsula to determine different zones with the same patterns in production.

This time the map of the average radiation for the period 1983-2005 is going to be used. This map is provided by the AEMET (National Spanish Meteorological Agency)

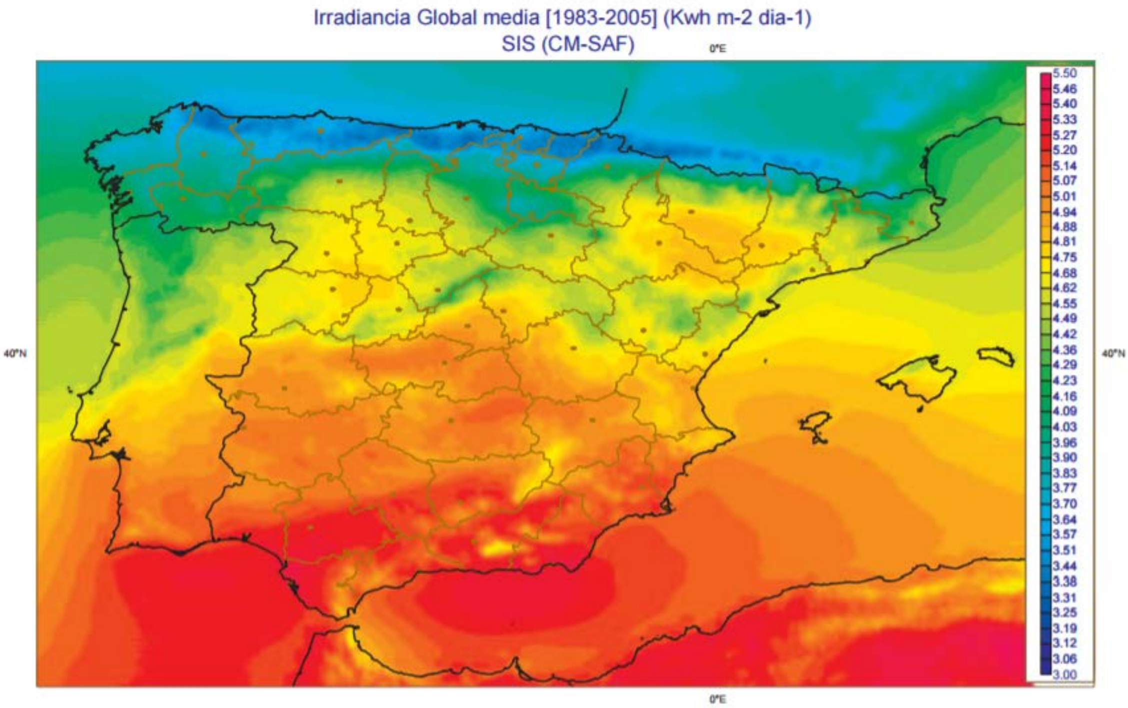

Figure 7 Average solar radiation in the Spanish peninsula period 1983-2005. Source: AEMET

It can be seen how the solar resource in the southern part of Spain is higher than in all the northern zone. Attending to this map the following zones are proposed to be studied:

Geographical zones attending to solar irradiation
Extremadura & Castilla la Mancha
Andalucía & Murcia
Comunidad Valenciana, Cataluña & Aragón
Castilla y León & Madrid
Navarra & La Rioja
Galicia, Asturias, Cantabria & País Vasco

Table 4 Geographical zones attending to solar irradiation

3.3.3.- Scenarios for each block of demand

In the point 4.4.3. of this thesis, the demand has been sorted in blocks. Each of these blocks correspond to a period corresponding with a demand level, this means Block 1 corresponds to the super-peak demand of that period, Block 2 corresponds to the peak demand hours, etc.

In the last part, it has been shown how the production of RES varies geographically. To be able to simulate this geographical distortion a methodology is going to be followed.

Each of the six blocks corresponding to winter or summer is going to be assigned to a zone of wind and solar production. The way this is going to be done is the following:

- Each block is going to correspond with a high profile of wind and solar PV production in a specific region.
- The regions are going to be assigned to each block following the logic that the regions with more production are going to be assigned to the blocks with more hours. This is going to be done in a descendent order, the blocks with less hours are going to be assign to the regions with less production.
- Each block is going to be filled with this logic:
    - The zone corresponding to each block is going to be assigned the value of the Percentile 95 of production of the study done for the corresponding block.
    - The other zones are going to be filled with the values corresponding to a high production in the zone of the block. This means, a snapshot is going to be taken of the whole peninsula when the production of the zone corresponding to the block is producing at a high rate. The behavior of the other regions is going to be observed, and the values obtained assigned to each province.
    - For instance, if block 3 in winter corresponds to a high production of wind in Galicia, a snapshot of the whole peninsula is going to be taken to know what happens in the other parts of Spain when in Galicia the wind is producing at its maximum rate. If in this snapshot the rate of production in Burgos is 67% this value is going to be assigned to

Burgos. In Galicia, the rate is going to be the percentile 95 corresponding to that block of demand. None of the values assign to a province is going to be higher than the Percentile 95

- Both blocks 4 in winter and in summer is going to be used as balancing block. These blocks are the blocks with more number of hours and normal-low demand. This means that the production in these blocks is going to be fixed to have an energy production for the whole year that is between the logical margins.
- Blocks 6 in winter and summer are going to be filled with the maximums in wind production. To represent the worse scenarios that have happened till now.

With this methodology is considered the geographical interdependency between zones in Spain. And the different scenarios are simulated in each block.

Two of the resulting blocks are going to be presented for illustrative reasons. Nevertheless, the whole results cannot be presented due to confidentiality in data protection terms.

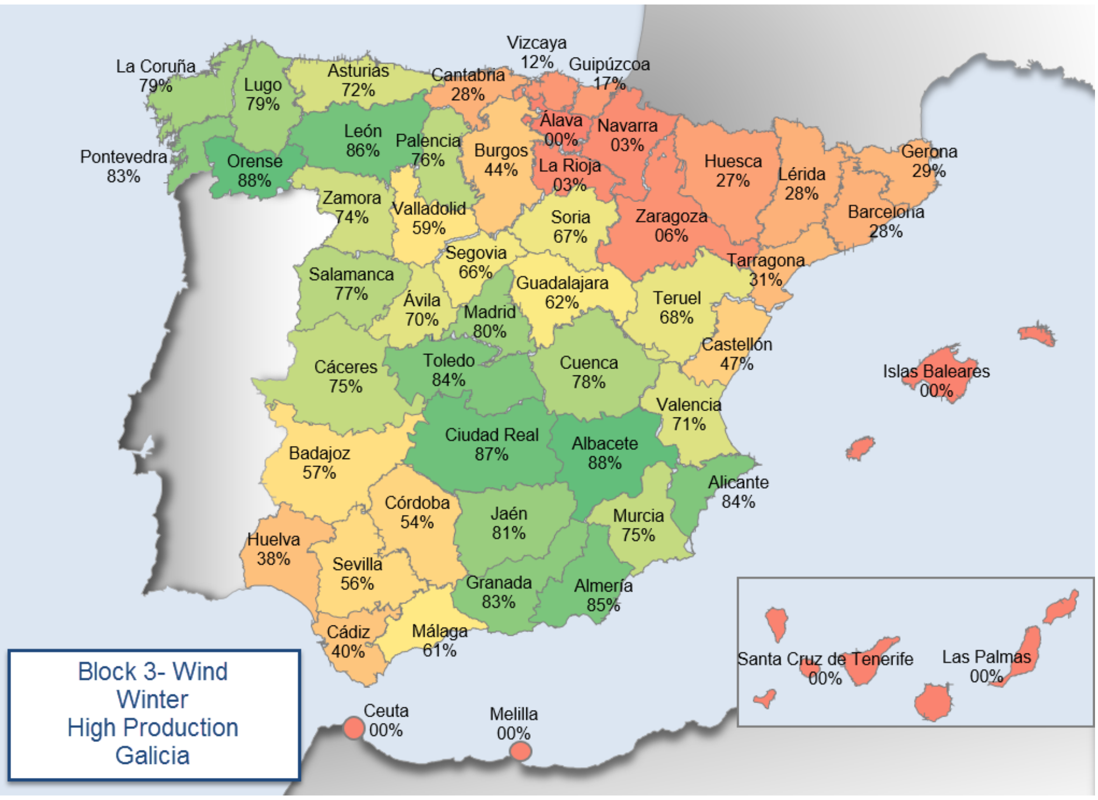

Figure 8 Scenario of wind production block 3 of winter. Corresponding with a high production in Galicia

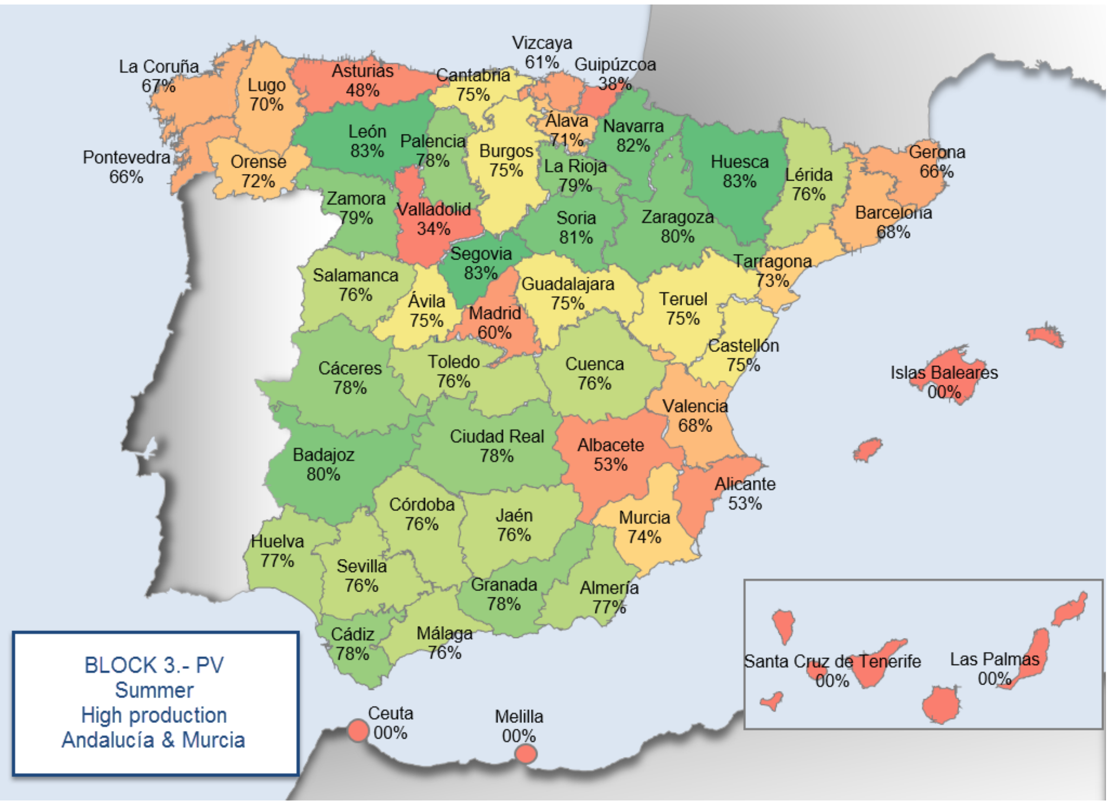

Figure 9 Scenario of solar PV production block 3 summer. high production in Andalucia.

SECTION II.- CANARY ISLANDS SCENARIOS DEVELOPMENT

1.- Introduction

To identify the scenarios a series of steps are needed to be done.

Firstly, it will be needed to identify possible seasonal patterns affecting demand and RES generation. If a seasonal behavior is observed it will be needed to create and characterized different scenarios separately.

Even when the seasonality of the demand is a problem well studied in previously, in this Master's Thesis the study is going to go further. The improvement is to study the seasonality of RES generation and its simultaneity with demand

To study the seasonality of RES generation, the profile of wind and solar PV production must be studied to assess whether there are particular periods of the year with a specific generation profile of wind, solar PV or a combination of both. In order words, the primary fuel of wind and solar facilities is precisely wind and solar. Obviously, these fuels are not manageable and it cannot be assured that when wind is producing it is doing it at a rate of a 100% of its capacity. Additionally, it will be tried to identify if there is any kind of relationship between the rate of production of wind and solar and the period of the year. For doing this, the relationship between some statistical indexes like the average, mean, or percentile 95 of both technologies are going to be considered. The data for these studies is provided by Red Eléctrica de España from the measurements recorded between the years 2013 and 2016.

2.- Study of demand seasonality.

2.1.- High and low demand periods

It is known that the main drivers that affect the demand are temperature and economic activity. It must be found the months of the year where these two factors combine producing high and low demand needs.

In addition, the Canary Islands are a very touristic spot in Spain and therefore their economy depends largely on this industry. In can be though that the demand can be higher when there is more affluence of tourists, because obviously there will be more people needing to satisfy their needs of electricity.

To study the temperature in the Canary Islands the data provided by the AEMET (The Spanish National Meteorological Agency) is studied. It has been chosen the registers of monthly average temperature from a series of historical data from year 1981 to 2010. Not only the total average temperature is considered but also the average of the minimum and maximum temperature. This is also very important because it shows the necessity of cooling/warming systems.

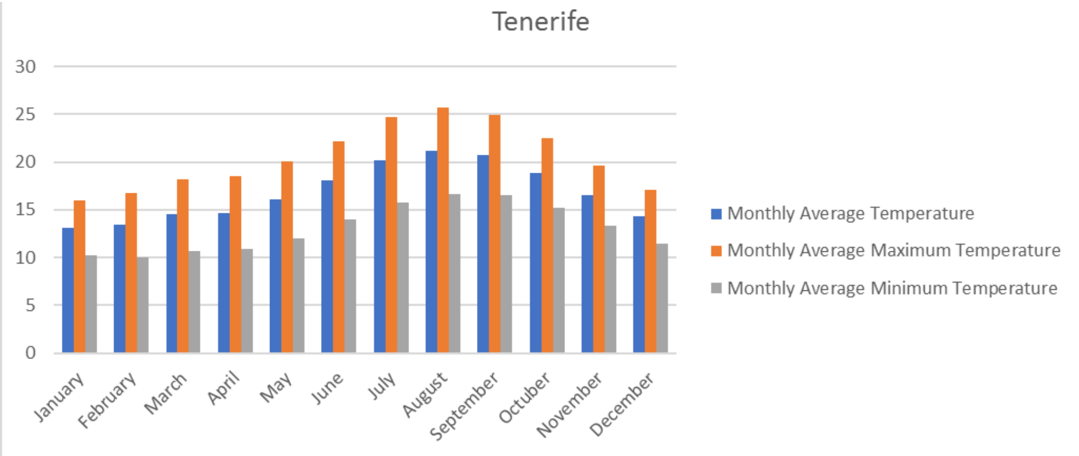

Figure 10 Average Temperature distribution in Tenerife series 1981-2010. Source: AEMET

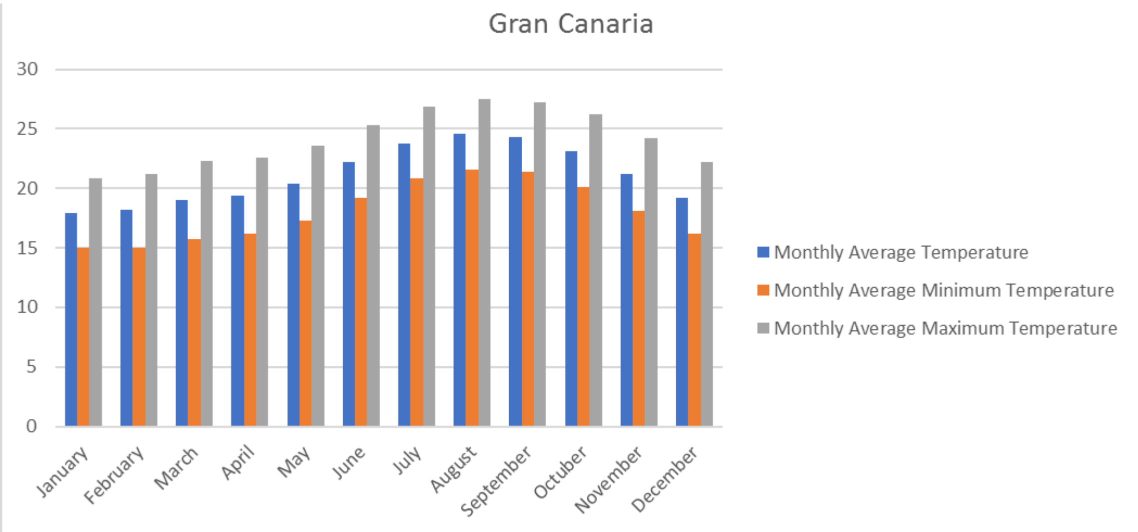

Figure 11 Average Temperature distribution in Gran Canaria series 1970 2016. Source: AEMET

The figures above clearly show that there is a trend in the weather of both islands. In other words, a distinction could be made in months with high temperatures and months with low temperatures. The months with high temperatures are: May, June, July, August, September and October. On the other hand, the months with lower temperatures are: January, February, March, April, November and December.

However as said before, the influence that the economic activity has on the demand must be considered. It could be said that tourism is the main industry of the islands. Attending to the data provided by the Tourism Agency of the Canary Islands the occupation rate of hotels and holiday apartments for the years 2015 and 2016 were:

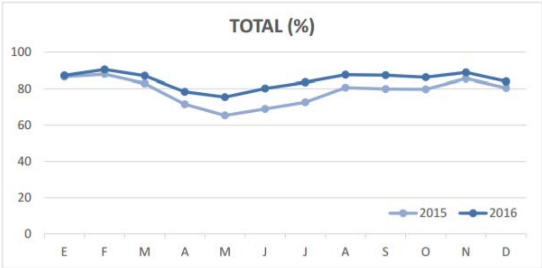

Figure 12 Rate of occupation of hotels and holiday apartments in Tenerife
Source www.turismodecanarias.com/

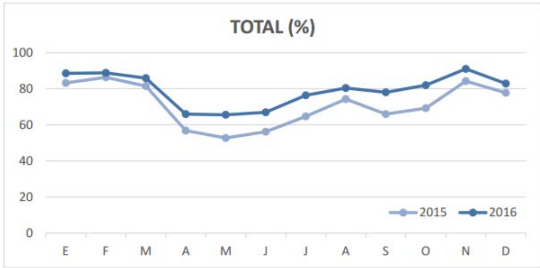

Figure 13 Rate of occupation of hotels and holiday apartments in Gran Canaria.
Source www.turismodecanarias.com

Analyzing the graphs, it could be said that the period of the year with more occupation are those going from November to March in the case of Gran Canaria and from August to March in the case of Tenerife.

Therefore, considering the combination of both temperature and tourism we could expect two periods of the year of high and low demand. These periods may correspond to the months going from January to June (Low demand) and the ones going from July to December (High Demand).

To assess whether this affirmation is correct, the demand is going to be studied to see if it is possible to considered the moths suggested as the months with high and low demand, and if this intuition is certain.

The following indicators will be studied to make the distinction: the average demand of each month, the maximum demand of each month and the Percentile 95 and 05 of the demand of each month. All these indicators provide information not just about average values but also of how these average values are distributed. Also, they give information about unusual peaks in demand.

For Tenerife and Gran Canaria the following indicators are obtained:

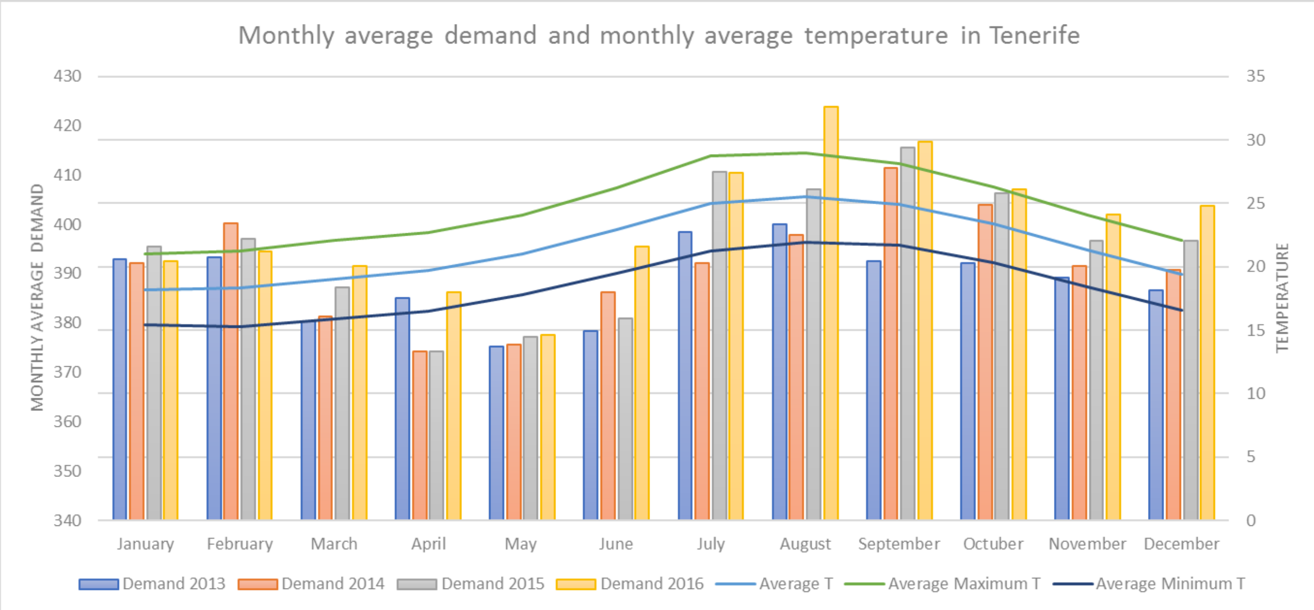

Figure 14 Average Monthly Demand(MWh) in Tenerife in the years 2013-2016 vs. average temperature series 1981 to 2010

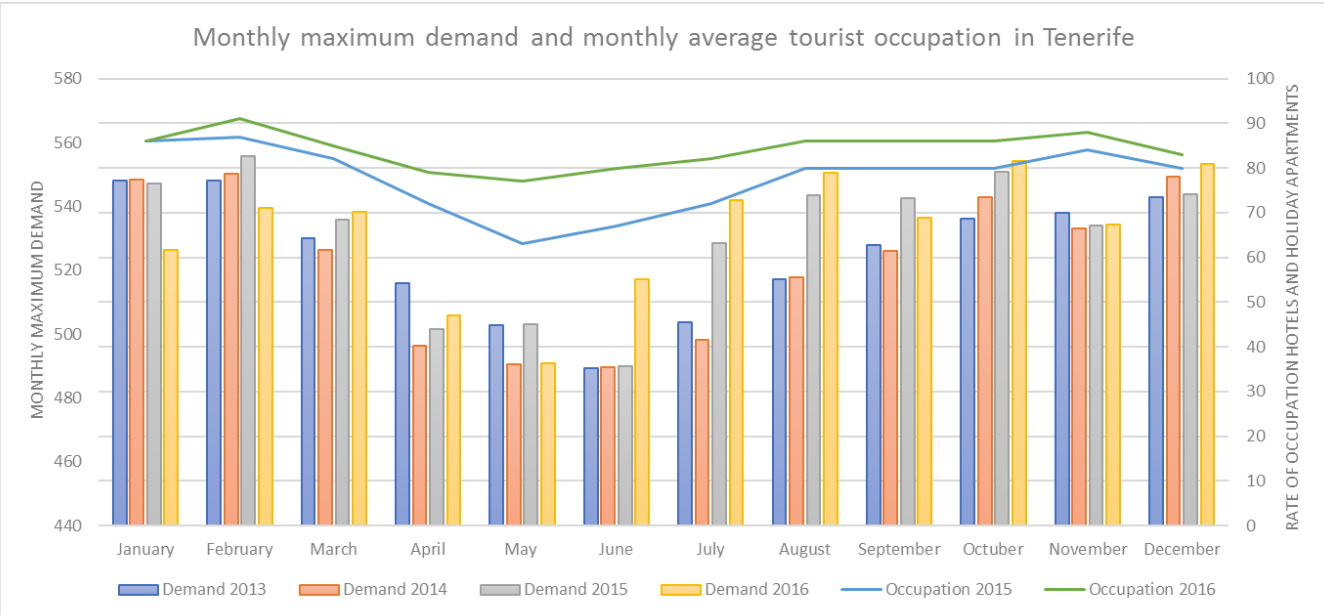

Figure 15 Maximum Monthly Demand(MWh) in Tenerife in the years 2013-2016 vs. average occupation series 2015 and 2016

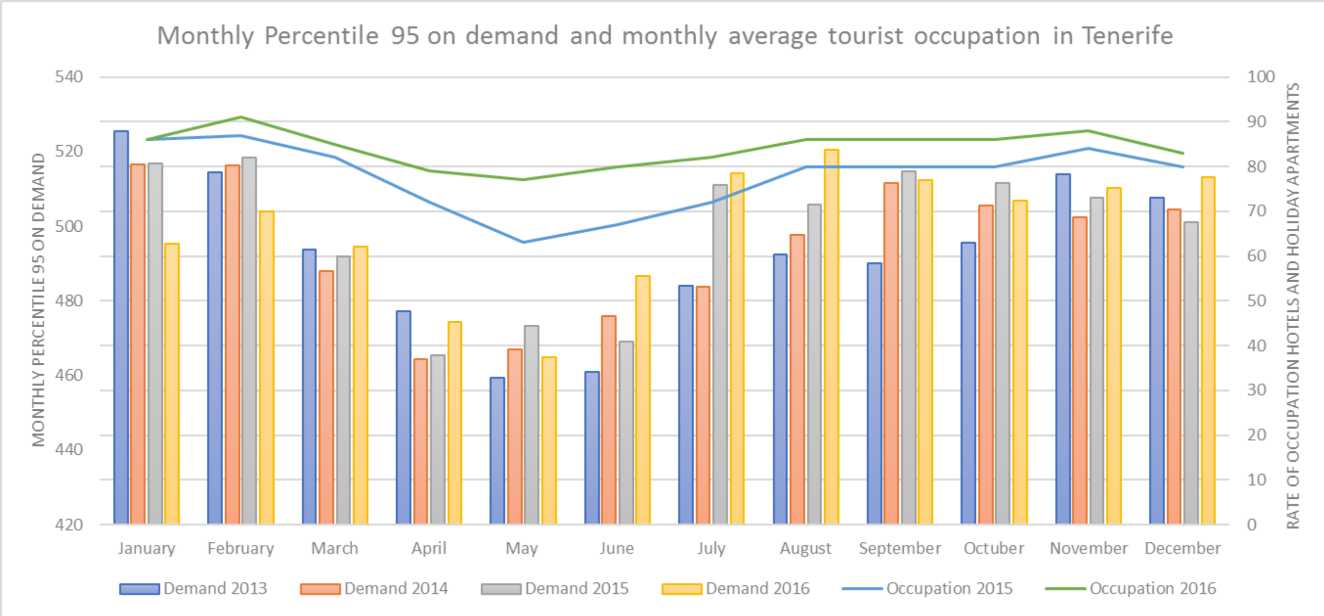

Figure 16 P 95 Monthly Demand (MWh) in Tenerife in the years 2013-2016 vs. average occupation series 2015 and 2016

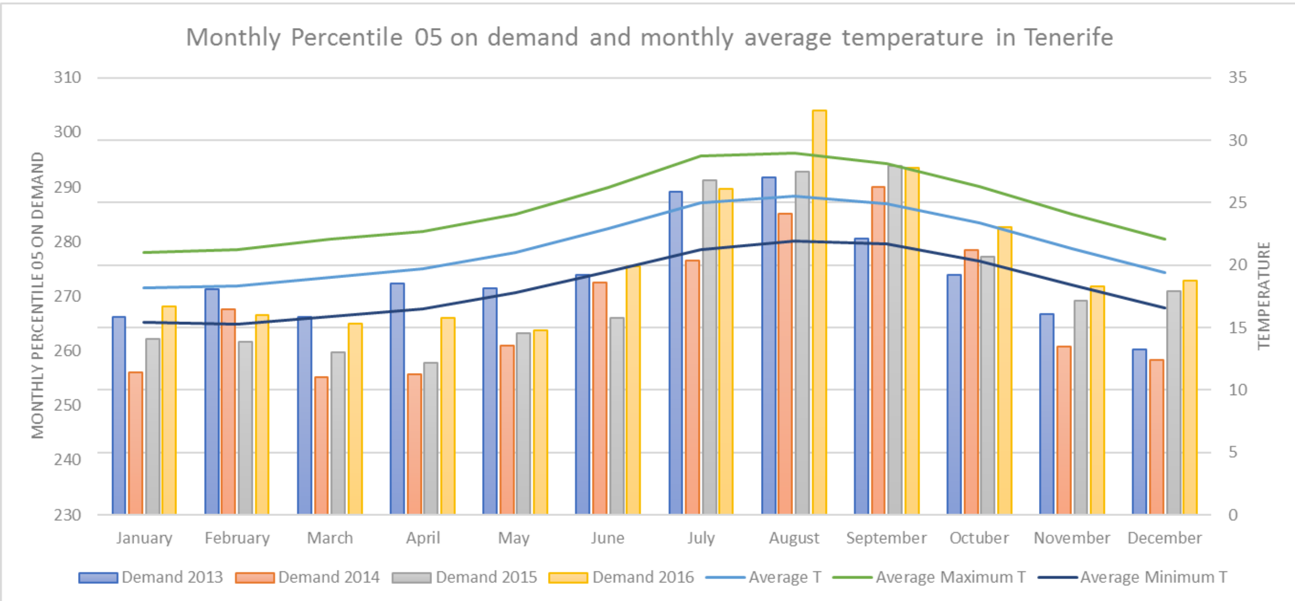

Figure 17 P 05 Monthly Demand (MWh) in Tenerife in the years 2013-2016 vs. average temperature series 1981 to 2010

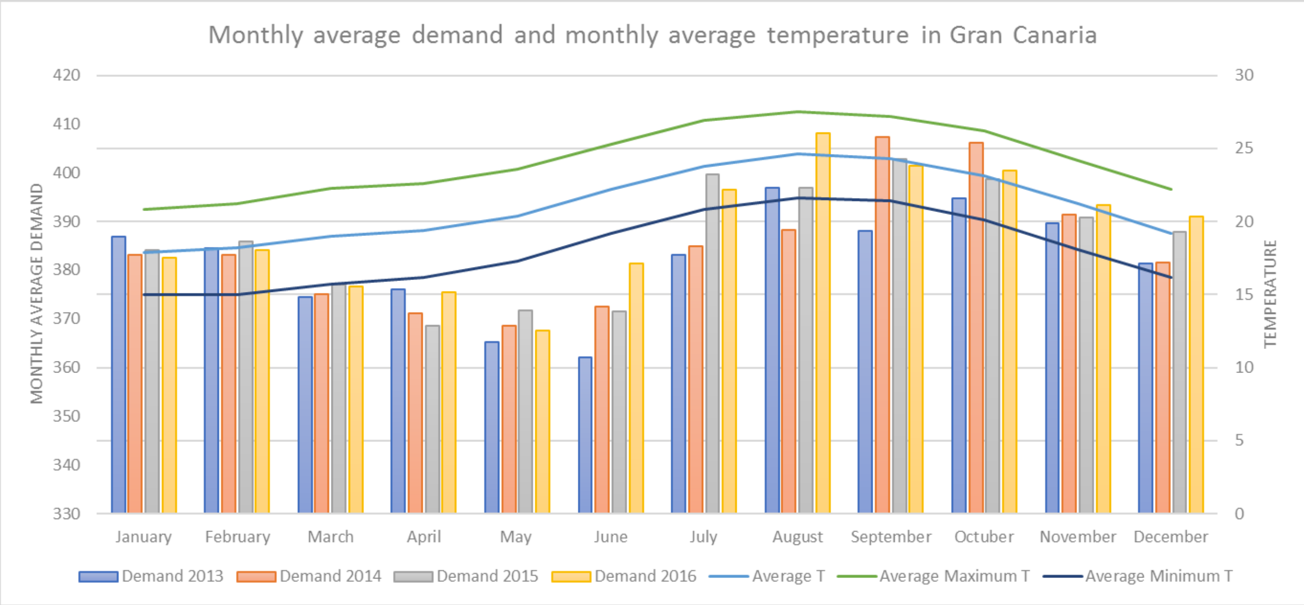

Figure 18 Average Monthly Demand(MWh) in G. Canaria in the years 2013-2016 vs average temperature series 1981 to 2010

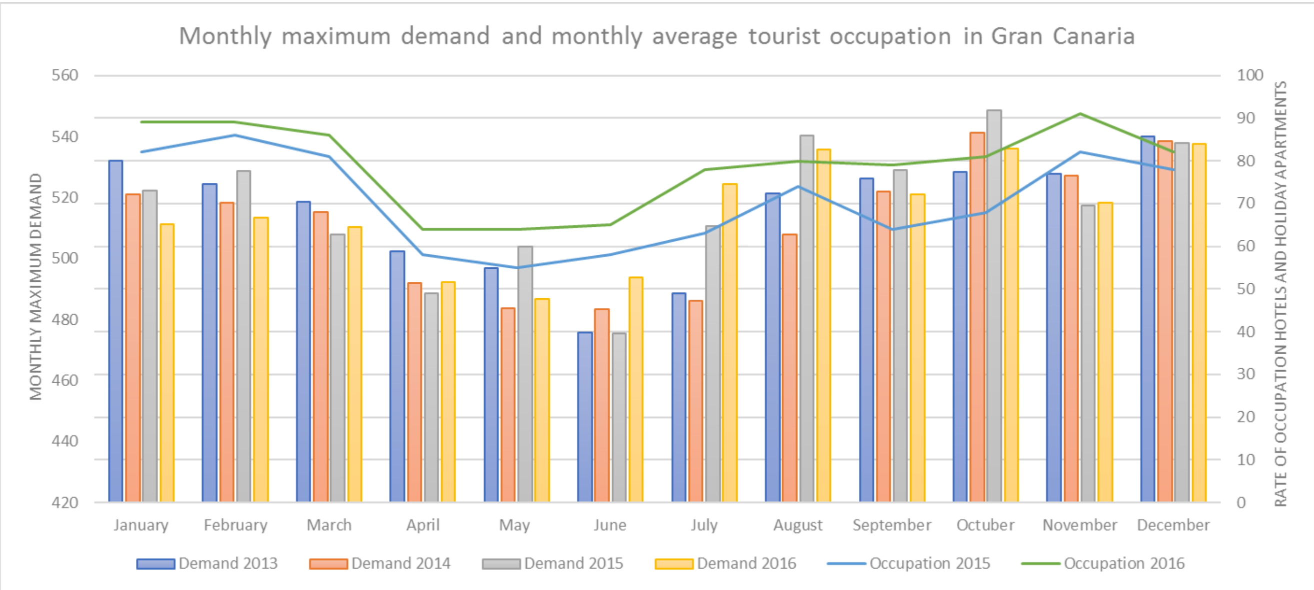

Figure 19 Maximum Monthly Demand(MWh) in G. Canaria. Years 2013-2016 vs. average occupation series 2015 and 2016

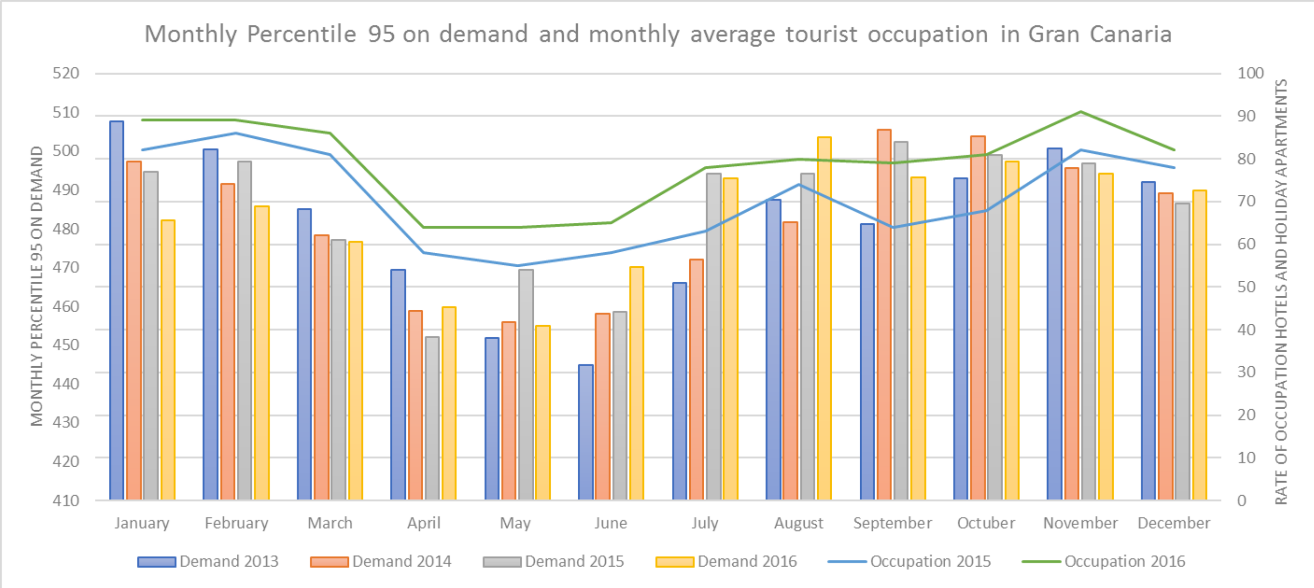

Figure 20 P.95 Monthly Demand (MWh) in G. Canaria. Years 2013-2016 vs. average occupation series 2015 and 2016

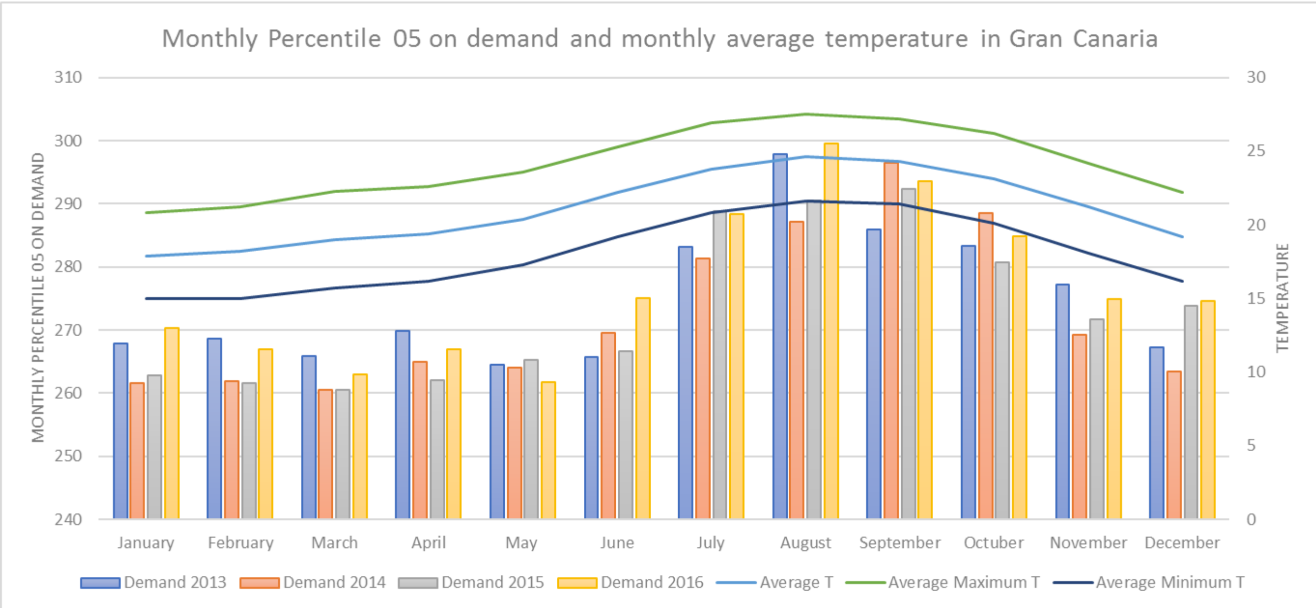

Figure 21 Percentile 05 Monthly Demand (MWh) in the years 2013-2016 vs. average temperature series 1981 to 2010

In both islands, the same patterns are observed for all the indexes. The average production is clearly higher in the months with higher temperatures. Nevertheless, in months like January and February when the temperatures are lower the average demand is also quite high. This effect suggests that there are other elements influencing the demand on those months.

The Percentile 05 illustrates clearly the relationship of the hottest months of the year and the temperature. It can be seen how the hottest the month the highest the Percentile 05. This index suggests that there is a higher base demand in hot months, probably related with a constant need of cooling systems that may work the whole day.

Looking at the maximum and Percentile 95 indexes it can be seen that they are clearly related with the main economic activity of the islands, the tourism. The rate of occupation of hotels and holiday apartments perfectly matches the with the trend of the maximum and Percentile 95 demand. Then it can be said that the peaks in demand are dependent on the economic activity of the island. This makes sense as a hypothesis. Even when the average temperature in January and February is lower, circa 20ºC, and the need of cooling systems may be not that high, if there are more people consuming the daily peaks are higher.

In addition, it can be observed how in the months with lower occupation rate, all the indicators are rather low. This means that less people means less demand. The only indicator that remains constant is the Percentile 05. This is because even if less people means less demand, the temperatures starts increasing, that means that less people may be consuming more as base demand.

From the previous observation, it could be proposed that the year could be divided in periods of high demand and low demand. The period of low demand will correspond to the months of January to June, and the one of high demand will correspond to those from July to December.

Even when the average demand, the maximum demand, and the Percentile 95 demand in January and February is quite high, the division proposed is the correct one. This reason behind is because climatological conditions are a more stable variable than tourism occupation. This means that a lower rate of occupation in January and February may make the classification incorrect if these months are considered within the months of high demand.

Summarizing, the demand can be divided into blocks of high and low demand for both islands. The months of high demand are the ones from July to December and the ones of low demand the ones from January to June.

2.2.- Seasonal patterns in the RES generation.

Once the patterns in demand have been analysed it is needed to identify the trends of the Renewable Energy Systems, mainly wind and solar PV.

It is known that wind and solar are intermittent energy resources, and that its production is subject to the availability of their fuel, wind resources and solar beams. These two elements are not controllable and thus wind and solar energy cannot produce at a fixed rate when needed. It is to be assess whether, from past data a specific trend in wind and solar production could be obtained to be combined with the patterns of electric demand.

The historical data analysed comes from the measurements recorded by Red Eléctrica de España, of the production of current facilities in place in the years 2013-2016.

2.2.1.- Wind production

The methodology to analyse production patterns is very much the same as the one to characterised the demand. The data will be sorted by months in which some statistical indexes are calculated: the monthly average, the monthly maximum, and the monthly percentile 95 and 05 for a specific hour.

The production is represented in percentage of the total installed capacity in an island, this enables the possibility of computing for a new facility the expected production from the total capacity installed no matter where it is installed.

For Tenerife and Gran Canaria the following indexes are obtained for wind energy production:

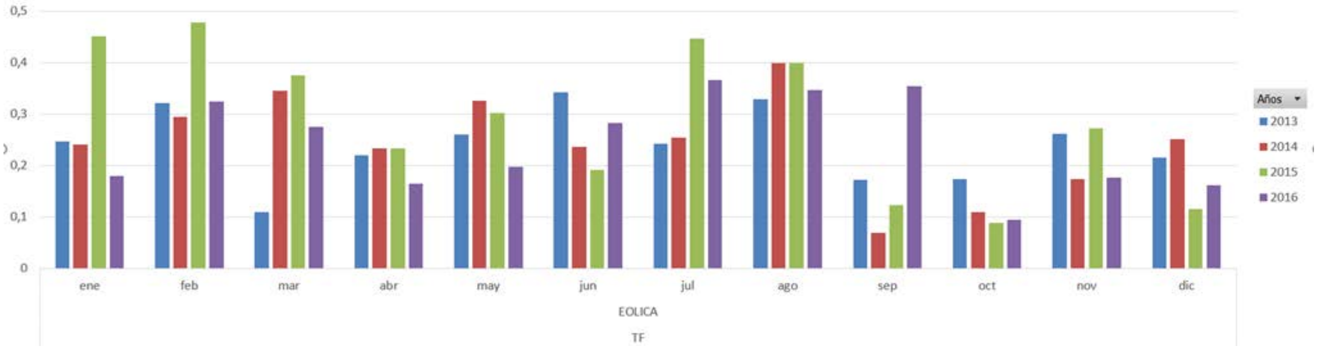

Figure 22 Average Wind Production. - Percentage respect to the total installed capacity. Tenerife

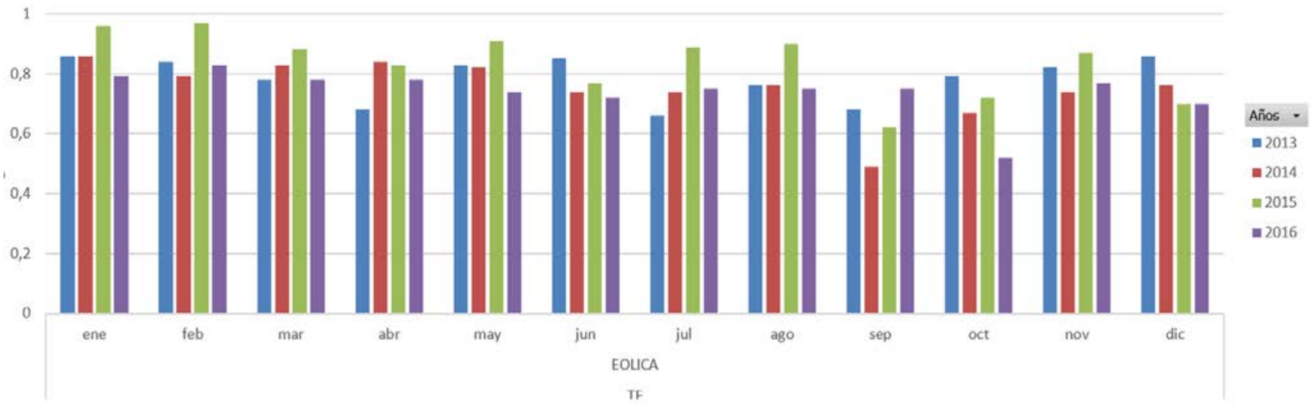

Figure23 Maximum Wind Production. - Hourly percentage respect to the total installed capacity. Tenerife

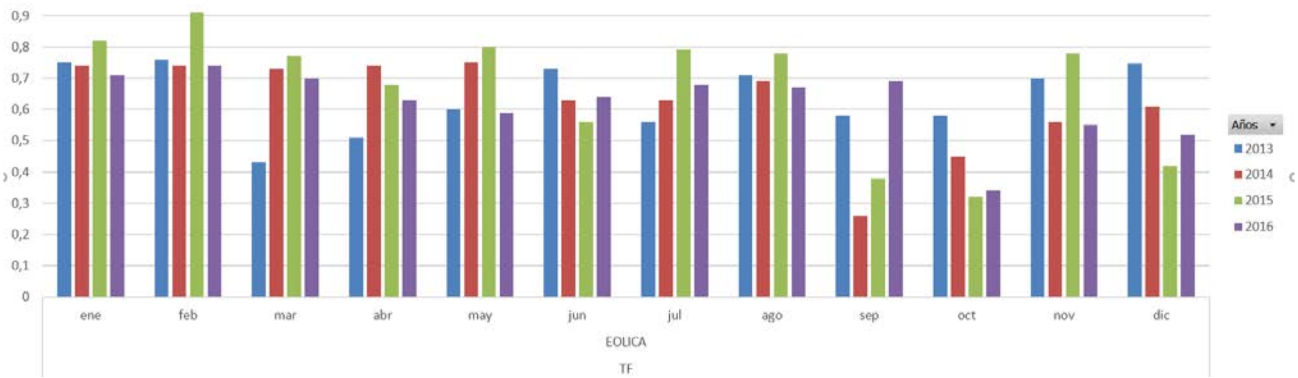

Figure 24 Percentile 95 Wind Production. - Hourly percentage respect to the total installed capacity.Tenerife

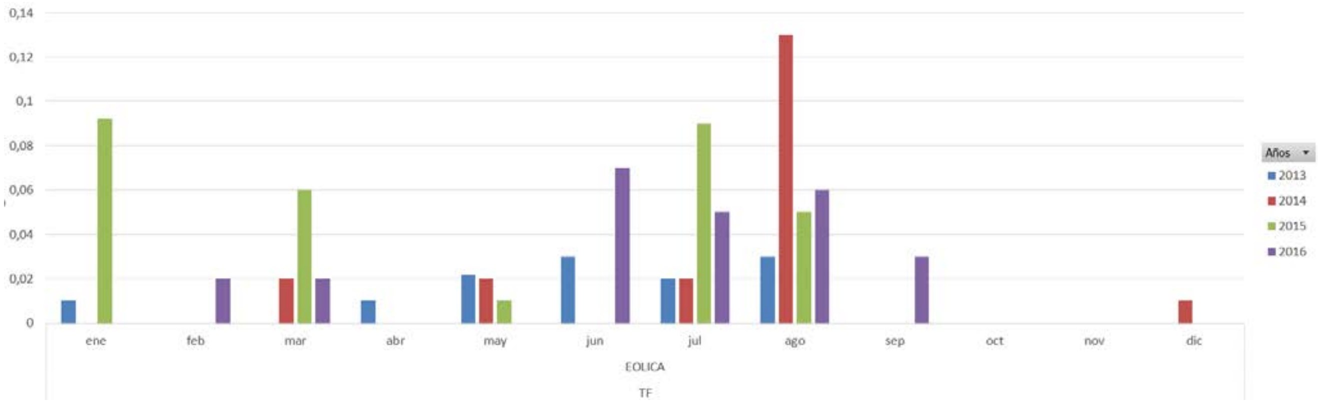

Figure 25 Percentile 05 Wind Production. - Hourly percentage respect to the total installed capacity. Tenerife

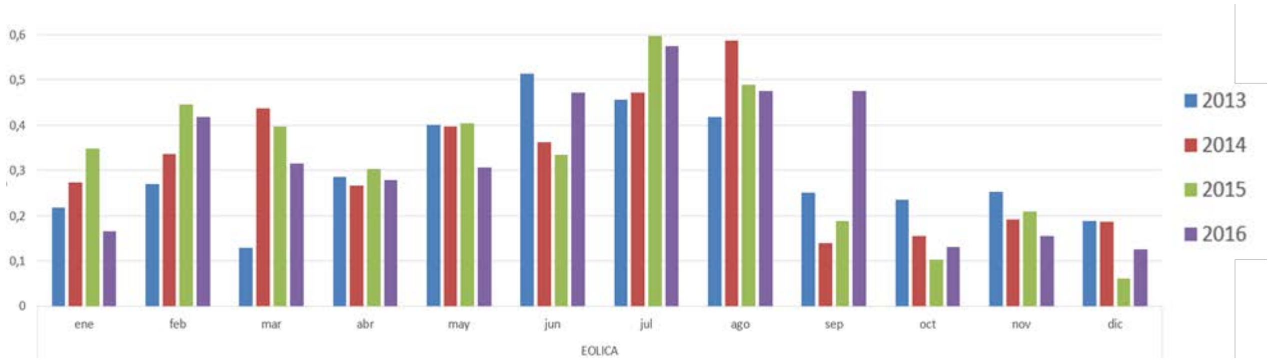

Figure 26 Average Wind Production. - Percentage respect to the total installed capacity. Gran Canaria

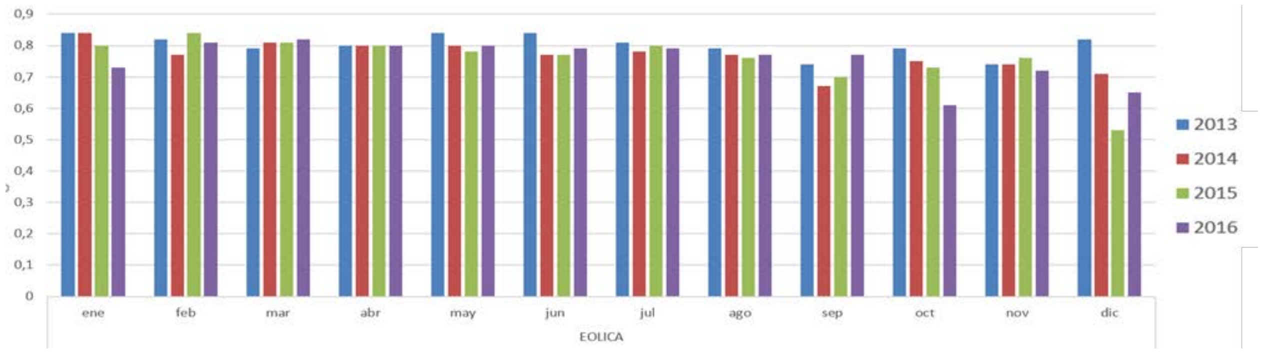

Figure27 Maximum Wind Production. - Hourly percentage respect to the total installed capacity. Gran Canaria

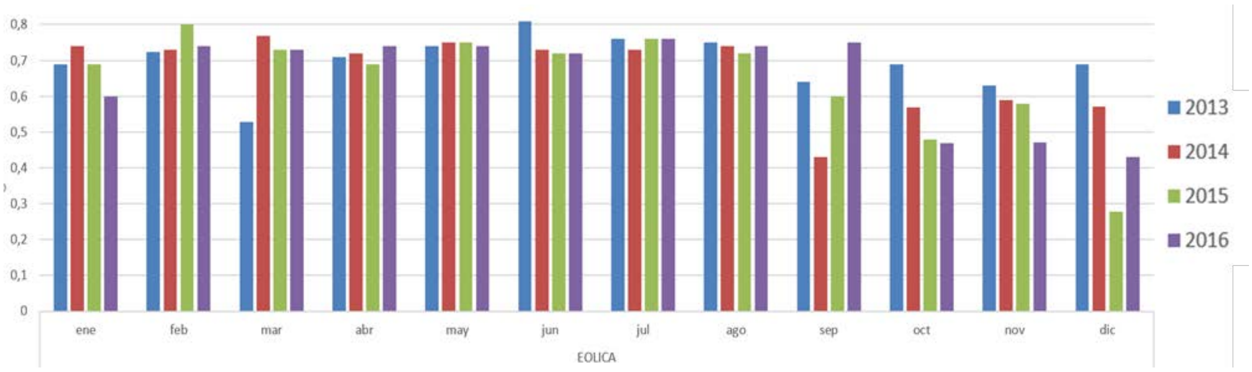

Figure 28 Percentile 95 Wind Production. - Hourly percentage respect to the total installed capacity.Gran Canaria

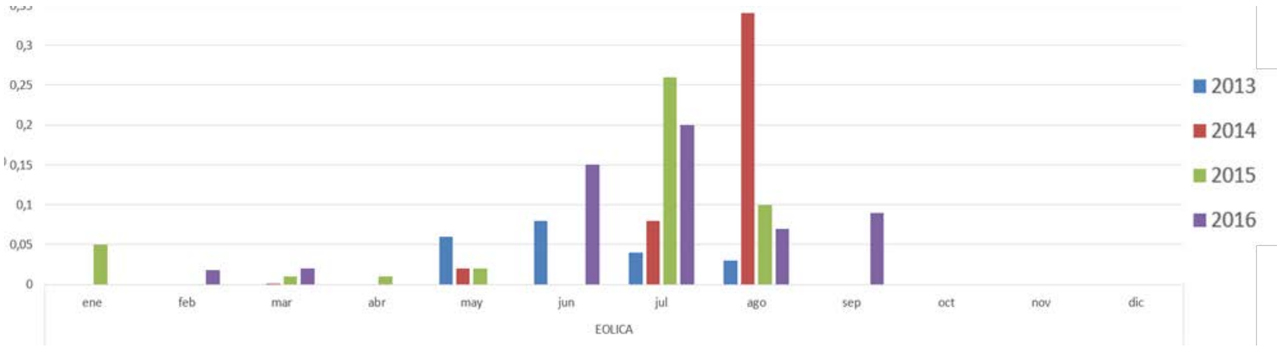

Figure 29 Percentile 05 Wind Production. - Hourly percentage respect to the total installed capacity.Gran Canaria

Paying attention to this graphs, it can be seen how the islands do not follow the same patterns in average wind energy production. Whereas in Gran Canaria some central months with higher proction can be distinghuised, from May to August, in Tenerife the patterns are quite ramdom. This could be explained because there are different wind currents in the islands that interfere in the average production.

Nevertheless for developing the scenarios for future grid needs it is more interesting to find the most demaning scenarios for the grid. This means, the highest RES resources scenario.

Therefore, taking a look at the maximum hourly production for both islands it can be seen how the maximum hourly production in both islands is more or less constant. Meaning that even if the average production is different the peaks all along the year remain more or less the same as the Percentile 95 also illustrates.

The final conclusion is that, the year could be divided in two periods attending to the Percentile 95 index. This index does not take into consideration extreme hours of production that distorb the results. However it provides a suitable frontier from the periods of the year where wind is higher and lower. Therefore, two periods are going to be considered in the year for wind production. High production: January to August. Low production: September to December.

2.2.2.- Solar PV production

The same methodology as with wind is going to be followed to determine whether solar can be divided in two different blocks of high and low production.

The data will be sorted by months in which some statistical indexes as the monthly average, the monthly maximum production for one hour and the percentile 95. This time the percentile 05 is not going to be studied because it is going to be zero.

The production is represented in percentage of the total installed capacity, this enables the possibility of computing for a new facility the expected production from the total capacity.

The average production is going to be displayed together with the monthly average hours of sun to show their relationship. The data of the number of average number of hours correspond to the series between the years 1981-2010 provided by the AEMET in their webpage (www.aemet.es).

For Gran Canaria and Tenerife the following indexes are obtained for photovoltaic energy production:

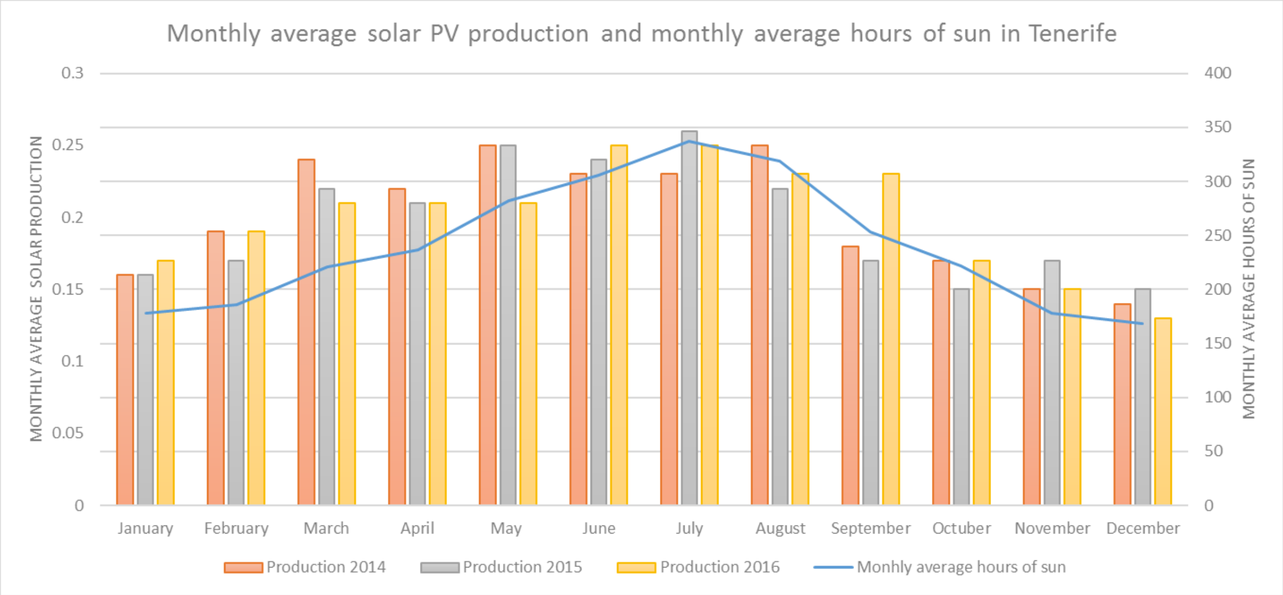

Figure 30 Average PV Production hourly percentage respect to the total capacity in Tenerife vs number of hours of sun

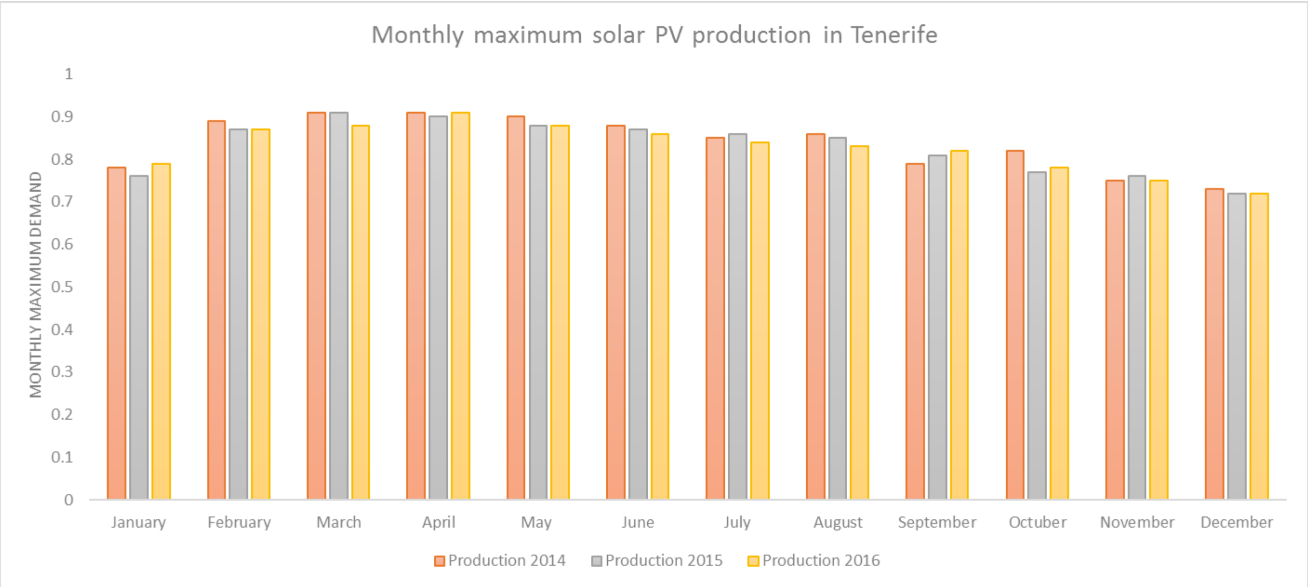

Figure 31 Monthly maximum hourly PV Production percentage respect to the total capacity in Tenerife.

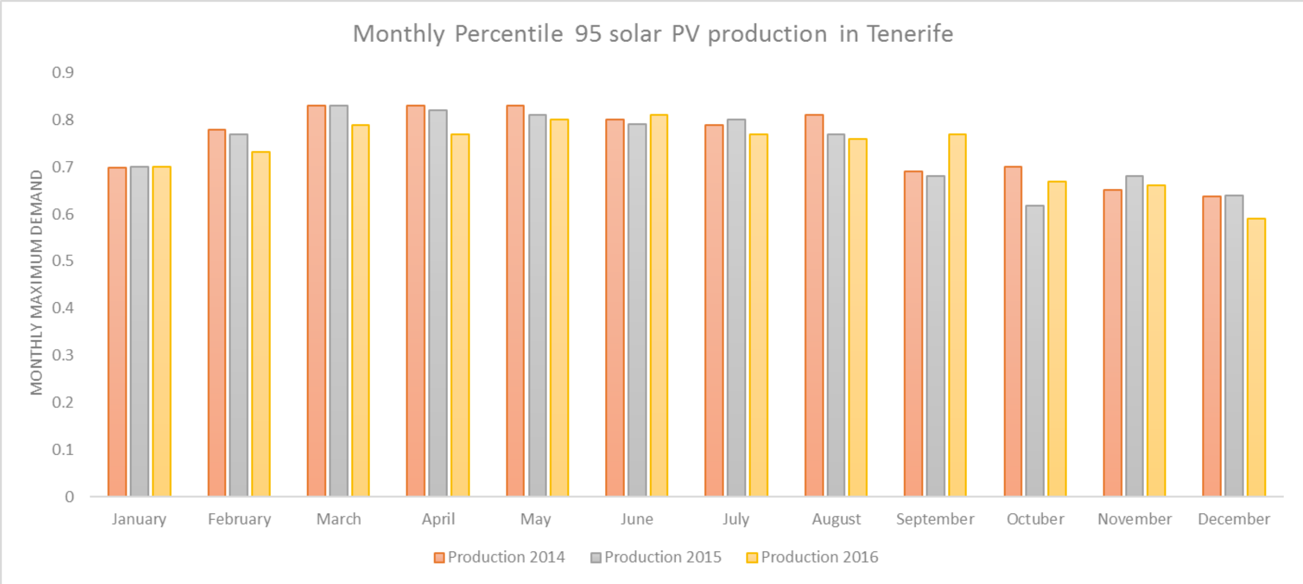

Figure32 Percentile 95 PV Production percentage respect to the total capacity in Tenerife

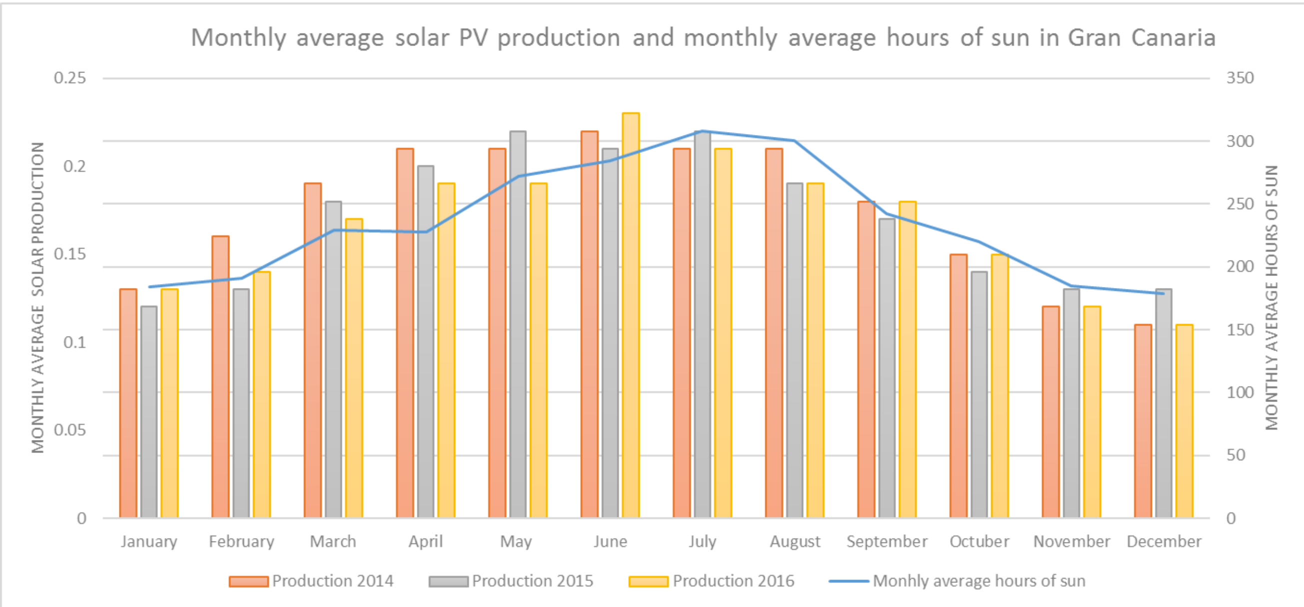

Figure 33 Average PV Production hourly percentage respect to the total capacity in G Canaria vs number of hours of sun

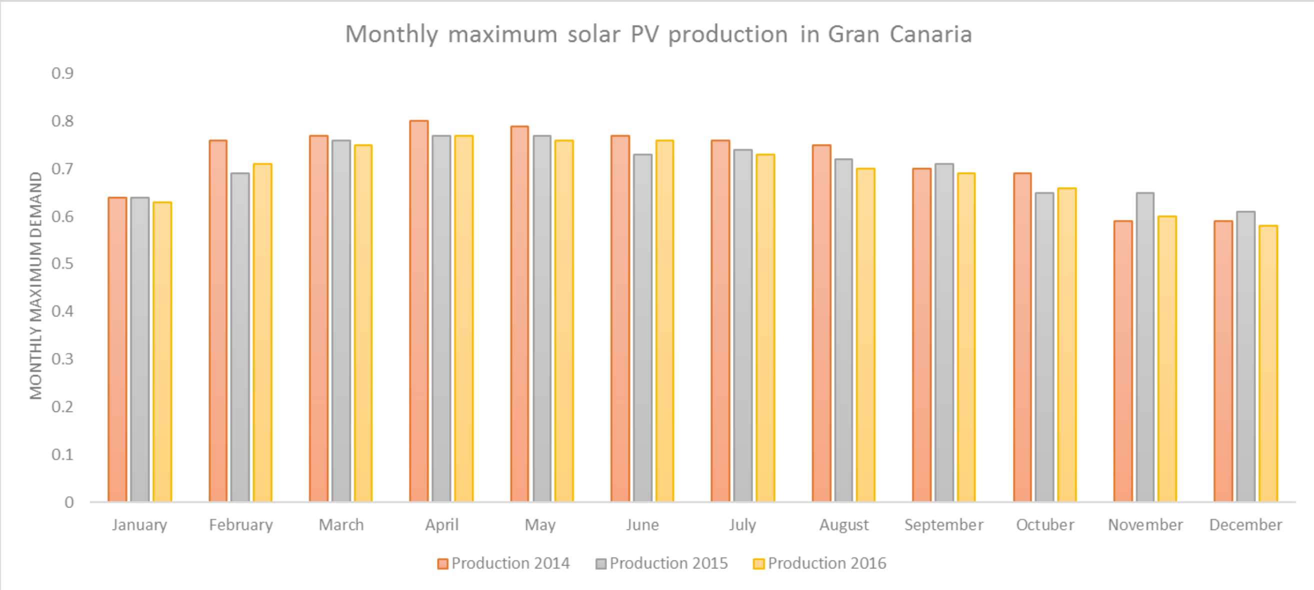

Figure34 Monthly maximum hourly PV Production percentage respect to the total capacity in Gran Canaria.

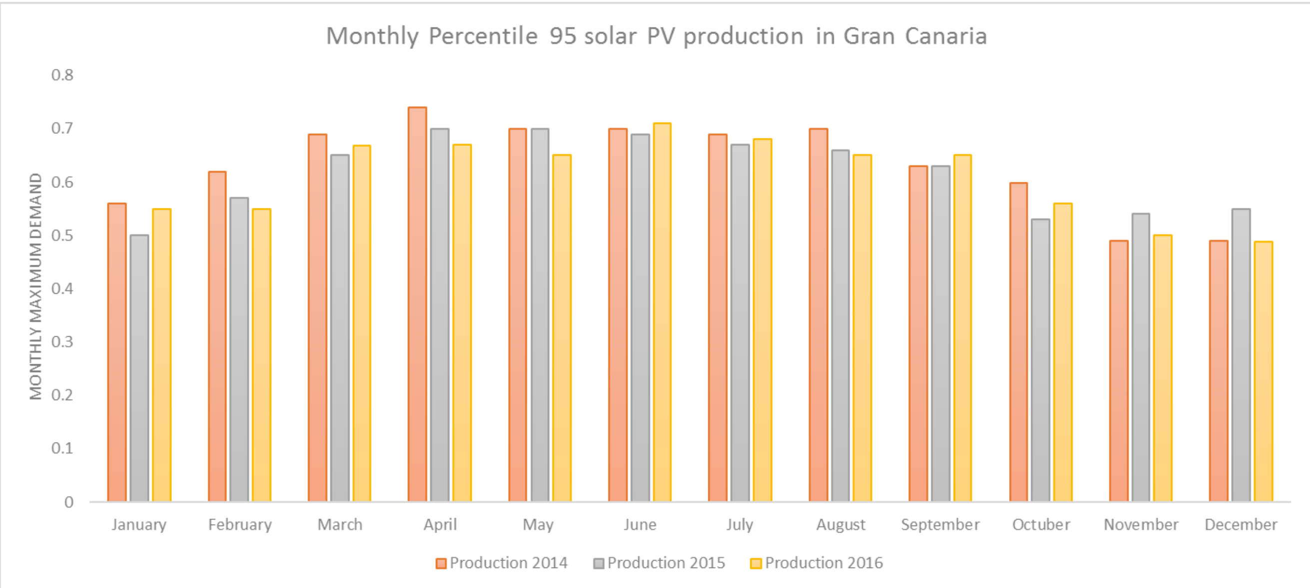

Figure 35 Percentile 95 PV Production percentage respect to the total capacity in Gran Canaria

At a first glance, the results are the expected ones. What means that in the months with more hours of sun the average production of solar PV is higher. This makes sense because sun is the primary fuel of solar PV cells. The hours of sun are directly proportional with the energy produced.

With respect to the indexes illustrating the maximums in production, it can be seen that there is not much variation form month to month. It does exist a variation, but it is not very big. Solar is more stable than wind and when the sun is shining solar cells produce more or less the same. This depends on the angle of the impacts of the beams. But in the daily peak it is quite similar through all the months.

Nevertheless, as with the previous study for wind, the most extreme situations are pursued. This means that the indexes to pay attention to make the division into periods are the Maximum and Percentile 95 indexes.

Looking at the maximum production chart, it can be distinguished that in the months going from September to February the production is lower. The percentile 95 also shows the same results. It can be said that there are two different periods of high and low production of solar PV. One of high production from March to August and another of low production from September to February

2.3.- Combination of demand and RES seasonal patterns.

In the previous points the demand and generation has been studied separately. It has only been considered blocks of high and low demand and production.

However, to build reliable scenarios both demand and generation have to be considered simultaneously. This will provide scenarios with high demand and low production of RES and with high production of RES and low demand.

The following table summarizes the seasonality obtained separately for demand and RES generation:

	January	February	March	April	June	July	August	September	October	November	December
Average Demand	Low	Low	Low	Low	Low	High	High	High	High	High	High
Wind Production	High	High	High	High	High	High	High	Low	Low	Low	Low
Solar PV Production	Low	Low	High	High	High	High	High	Low	Low	Low	Low

Table 5 Monthly Average Demand, Wind Production and Solar PV production.

In the previous table, it can be seen how there are periods of low demand combined with periods of high productions of wind and low production of solar PV, periods of high demand and production of wind and solar PV and periods with high demand and low production of wind and solar PV.

To homogenize the different periods corresponding to demand and RES production a representative division of the year is sought to optimize the rid planning. In the near future, more wind facilities than solar PV are going to be introduced in Canarias. For this reason, wind seasonality is going to be considered more important than solar PV.

A possible feasible and reasonable division of the year could be to divide the year into two blocks, one from January to August and another one from September to December. These two periods satisfy the conditions for the study. The answer why these scenarios are selected is going to be explained:

- Block 1 (January to August): this block will consider the scenarios of high wind production. It is good to remember that a great increase in wind capacity is expected in the islands. Therefore, to consider a block of high wind production and another of low wind production may be the more satisfactory division to be proposed to study the new grid working conditions. This high wind production scenario includes periods of high and low demand and solar PV production.
  The scenario where high demand and wind and solar PV production is the most interesting for the network planning because it is when the grid will be more stressed and with the new RES capacity the production mix will be completely different from what it happens today.
  It will also consider valley scenarios where the demand is not very high but the production of wind and solar PV is high. This is the worst scenario for potential spillages and it is interesting because potentially changes in could bring new needs in voltage constraint
- Block 2 (September to December): it will study the scenarios with high demand and low wind and solar PV production. This scenario which is more similar to the current one is representative of the situation in nearly half of the year. So, it is worthy to be studied alone. It does not have to be forgotten that the grid should support these situations too.

Moreover, the division proposed can be assimilated to the current and the future situation. The period of high wind production includes periods of high and low demand and solar PV production. These situations are combined in all its possible combinations. It could be said that this scenario will study all the possible situations with the new arrival of wind capacity.

On the other hand, the period of low production of wind could be assimilated with the current situation in the most demanding situation. This situation includes high demand and low production of wind and solar PV.

From now own, these two periods will be called High Wind Season from January to August and Low Wind Season Block from September to December. This is made just for the sake of simplicity.

3.- Scenarios development

Once the year has been divided in two seasons the next step is to define representative scenarios to be used for studying the grid.

3.1.- Demand classification

It is important to point out that the objective of this studies is to determine the need of specific reinforcements of the grid due to a change on demand or the integration of new capacity both conventional and RES Therefore, to study whether the new possible scenarios deserve the investment in new lines two situations must be studied: the considered normal situation and the critical situations.

Normal situations include the hours of the year with an average demand and a normal RES generation for that specific hours. It is obvious that this normal situation will be representative for a high number of hours.

On the other hand, extreme situations correspond to those hours where the demand is high and on top of that non-manageable generators are producing at a high rate.

Once these two situations are identified they must be given a probability of happening. It must be assessed whether the possible investments needed in critical scenarios are worthy considering its probability of occurrence or, whether these very extreme situations within the year could be handle with other mechanisms. For instances: interrupting the demand, spilling the energy, etc.

Therefore, the first step to develop the aforementioned scenarios is to classify the demand of each season in different blocks showing the same demand patterns. After this, it must be calculated the extreme and average RES production for each block.

For that purpose, first the monotone load profile of each system will be divided into two periods corresponding to its Wind profile. Then this monotone will be divided in 6 blocks to study the Super-Peak, Peak, Shoulder, Average, Valley and Super Valley hours. These blocks correspond to extreme, normal and low demand scenarios.

To study the demand the monotone load curves for the years 2013-2016 provided by Red Eléctrica de España are analyzed. Nevertheless, as the demand and RES generation are wanted to be linked by exogenous factors, climate conditions, the demand must be corrected. This means that the calendar effect should be considered and corrected. This effect is the influence on demand that the considered day of the week has on it.

If the calendar effect was not corrected demand keeps being affected by other elements that do not influence the RES production. For instance, the hottest day of the year can coincide with a Saturday. In normal circumstances, this would be the day with the highest demand. Nevertheless, this non-working day distortion disturbs the results.

To correct this problem, the demand is corrected by multiplying it by a coefficient that would remove this asymmetry in the demand. If this was not done, in further steps the result would be not accurate enough. This means that a certain level of generation would be assign to a specific day and hour of the year, because its demand, considering that there is some kind of relation between demand and RES generation. Nevertheless, demand also depends on which day of the week is considered. By multiplying the demand by this factor this phenomenon is removed.

Once the demand is corrected considering the calendar effect, each monotone is normalized and sorted together to determine the different blocks in each of the periods of high and low demand.

It is important to clarify that it is sought to divide both islands in blocks with the same hours, for the same of simplicity.

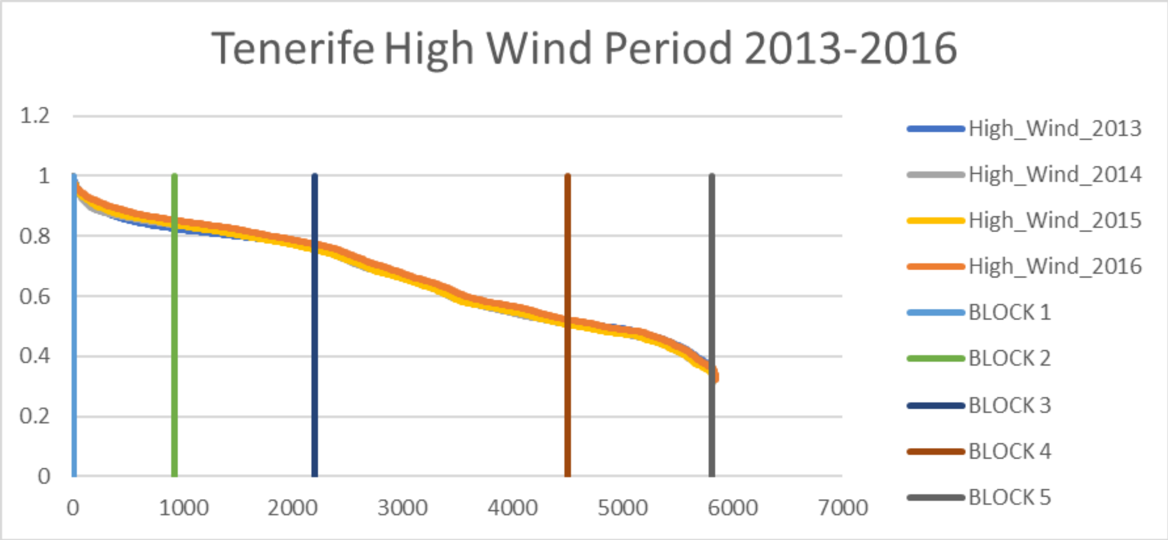

Figure 36 Monotone Curve Normalized for Tenerife in its period of low demand

The figure above shows the normalized monotone curve for Tenerife in its High Wind Season. This monotone has been divided into different blocks to identify the periods of super-peak, valley, etc.

The logic behind the determination of each block is to find the points where the tendency in the demand patterns changes. By doing this we can identify different demand blocks.

The number of hours corresponding to each block are presented in the table below and its average level of demand with respect to the peak.

BLOCK	HOURS	Demand with respect to the maximum (%)	Hours block/season (%)	Hours block/hours year (%)
Block 1	15	1.00	0.003	0.002
Block 2	915	0.86	0.157	0.105
Block 3	1270	0.79	0.218	0.146
Block 4	2300	0.58	0.394	0.264
Block 5	1320	0.45	0.226	0.152
Block 6	11	0.32	0.002	0.001

Table 6 Number of hours, demand (%),etc corresponding to each block for Tenerife in High Wind Period

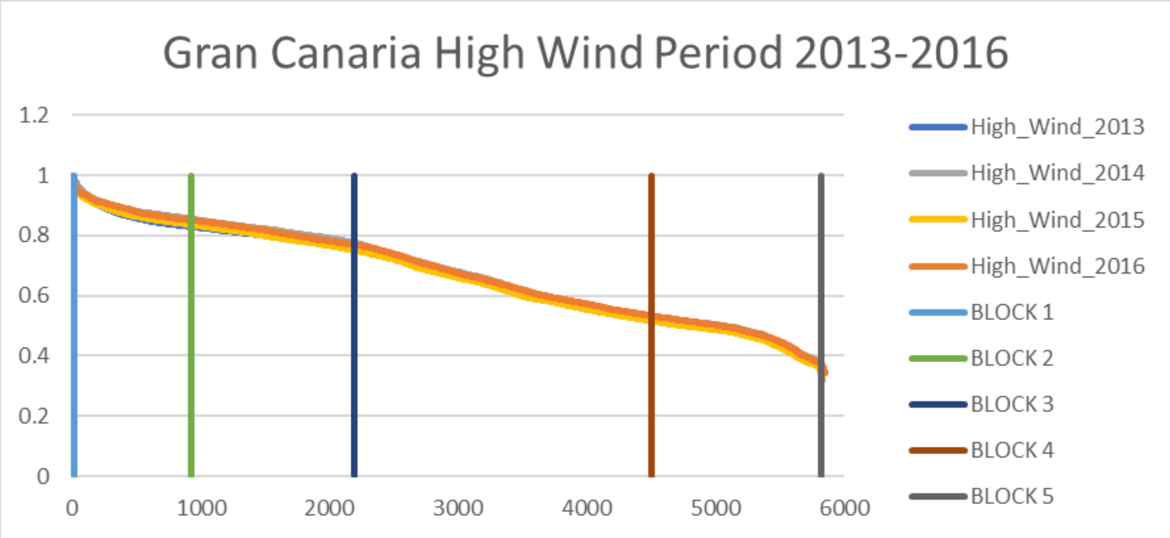

Figure 37 Monotone Curve Normalized for Gran Canaria in its period of low demand

The figure above shows the normalized monotone curve for Gran Canaria in its High Wind Season. This monotone has been divided into different blocks to identify the periods of super-peak, valley, etc.

The logic behind the determination of each block is to find the points where the tendency in the demand patterns changes. By doing this we can identify different demand blocks.

The number of hours corresponding to each block are presented in the table below and also its average level of demand with respect to the peak.

BLOCK	HOURS	Demand with respect to the maximum (%)	Hours block/season (%)	Hours block/hours year (%)
Block 1	15	1.00	0.003	0.002
Block 2	915	0.86	0.157	0.105
Block 3	1270	0.80	0.218	0.146
Block 4	2300	0.61	0.394	0.264
Block 5	1320	0.46	0.226	0.152
Block 6	11	0.32	0.002	0.001

Table 7 Number of hours, demand (%),etc corresponding to each block for Gran Canaria in High Wind Period

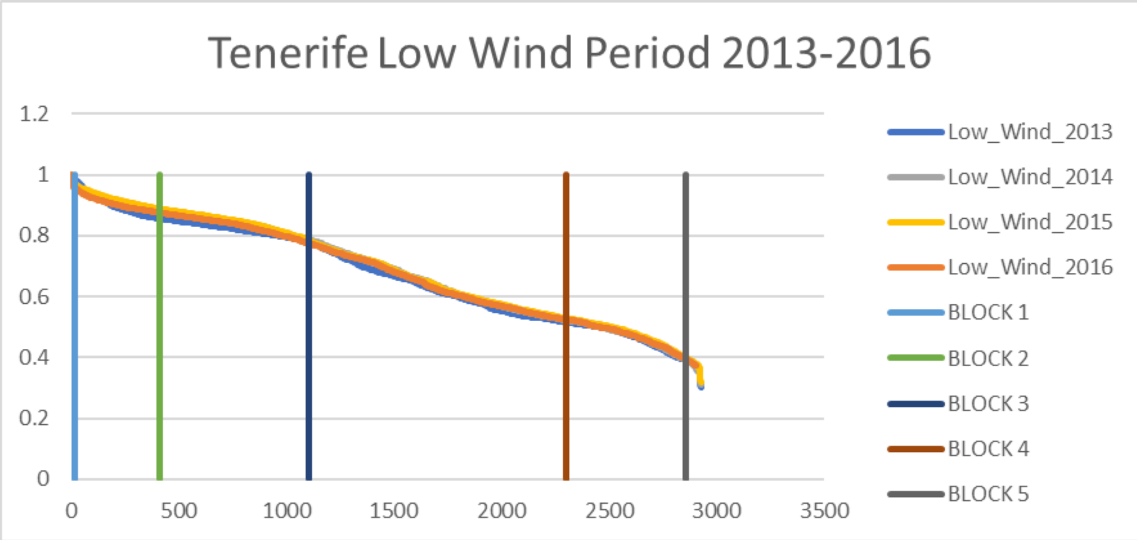

Figure 38 Monotone Curve Normalized for Tenerife in its period of high demand

The figure above shows the normalized monotone curve for Tenerife in its Low Wind Season. This monotone has been divided into different blocks to identify the periods of super-peak, valley, etc.

The logic behind the determination of each block is to find the points where the tendency in the demand patterns changes. By doing this we can identify different demand blocks.

The number of hours corresponding to each block are presented in the table below and also its average level of demand with respect to the peak.

BLOCK	HOURS	Demand respect to the maximum (%)	Hours block/season (%)	Hours block/hours year (%)
Block 1	15	1.00	0.005	0.002
Block 2	398	0.91	0.138	0.046
Block 3	693	0.85	0.241	0.080
Block 4	1194	0.62	0.415	0.137
Block 5	560	0.47	0.195	0.064
Block 6	15	0.34	0.005	0.002

Table 8 Number of hours, demand (%),etc corresponding to each block for Tenerife in Low Wind Period

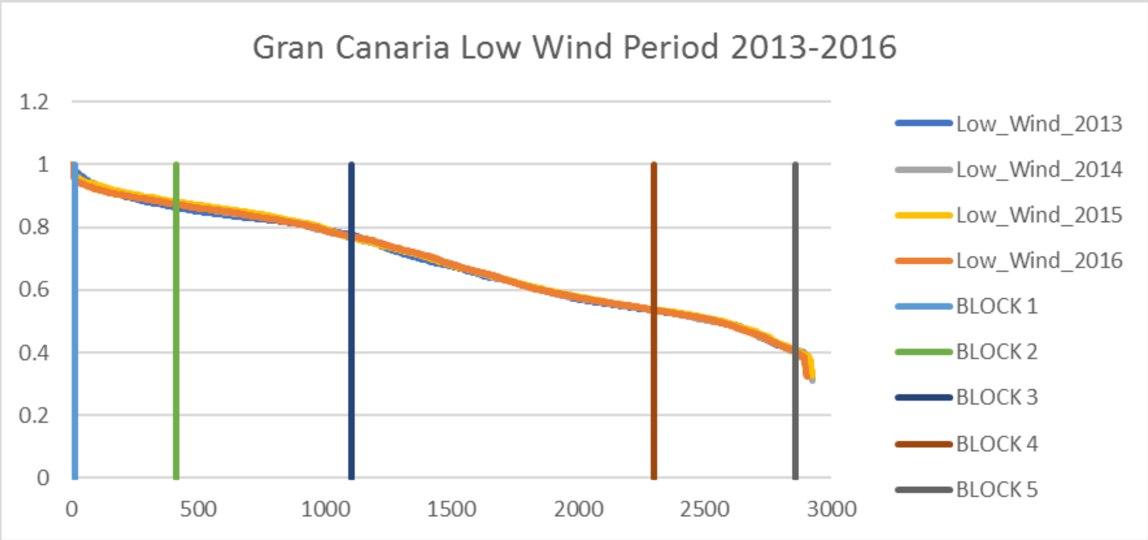

Figure 39 Monotone Curve Normalized for Gran Canaria in its period of high demand

The figure above shows the normalized monotone curve for Gran Canaria in its Low Wind Season. This monotone has been divided into different blocks to identify the periods of super-peak, valley, etc.

The logic behind the determination of each block is to find the points where the tendency in the demand patterns changes. By doing this we can identify different demand blocks.

The number of hours corresponding to each block are presented in the table below and also its average level of demand with respect to the peak.

BLOCK	HOURS	Demand respect to the maximum (%)	Hours block/season (%)	Hours block/hours year (%)
Block 1	15	1.00	0.005	0.002
Block 2	398	0.91	0.138	0.046
Block 3	693	0.84	0.241	0.080
Block 4	1194	0.62	0.415	0.137
Block 5	560	0.48	0.195	0.064
Block 6	15	0.34	0.005	0.002

Table 9 Number of hours, demand (%),etc corresponding to each block for Gran Canaria in Low Wind Period

3.2.- Determining the level of RES generation corresponding to each block

Once the demand has been sorted in blocks, each of them corresponding with some number of hours and with a level of demand, it must be found whether there is any kind of relationship between the blocks in each period and the level of production coming from RES within the hours of each block. This means the different situations of demand may be related with a level of production. This consideration makes sense because one of the main drivers of demand are the weather conditions, and the weather conditions affects the production of wind and solar facilities.

For instance, peak block in winter must correspond with the coldest days in the year. There is expected to exist a correlation between this meteorological phenomenon and the production coming from wind. The coldest day may correspond to the impact of cold wind currents on the islands.

On the other hand, the highest demand on summer may correspond to days with high solar radiation but almost no wind.

It is important to remember that to plan the grid two kind of scenarios have special interest, mean scenarios and critical scenarios. The main characteristics of these scenarios are:

- Mean scenarios:
    - Considers the mean demand and RES generation in each block.
    - It represents the normal average status of the grid.
    - Not very demanding
    - It is the representative situation of a hi
- Critical scenarios:
    - Mean demand on each block.
    - High production coming from RES.
    - They represent only a few number of hours, that is why normally they are associated with a probability of happening.

      The probability of the scenario determines whether it is worthy to invest on the possible reinforcements on the lines needed or to explore other possible ways to handle the situation (interruptible demand, non-served energy, etc.)

To identify this relationship the following methodology is going to be used. Firstly, having the number of hours corresponding to each block allows to identify the specific hour of a specific day belonging to this block. This means, knowing that the Block 1 for the low demand period is formed by the 15 hours with the highest production, it is easy to identify this hours. Identifying this hours means to assign Block 1 specific days and hours in a year.

Therefore, it can be known that Block 1 of the low demand period correspond, for instance, to the following dates of the year 2013: 03/01/2013 22:00h, 22/01/2013 21:00, etc. (these dates are random and just used for an illustrative purpose).

A point to be clarified is that for each year, the days and hours of each block are different. They are the days and hours corresponding to each block for every year. The demand considered for grouping the data is the corrected one, considering the calendar effect.

Secondly, once the exact dates and hours corresponding with each block are identified, it can be easy to identify the level of RES production corresponding with that dates, just by looking to the measurements collected by Red Eléctrica de España for the year 2013-2016

Thirdly, having the sample of the level of RES production coming from RES a statistical analysis will be carried out. Two kinds of studies will be done, one for each type of study needed: the mean scenario study and the critical scenario study.

The study needed for the mean scenario is quite straight forward. Because just the average RES production for each block has to be obtained.

The statistical analysis for the critical scenario is as follows:

- Wind: for wind energy production, it will be considered the Percentile 95 and Percentile 05 of the sample as the representative scenarios to study. This means, that from the sample obtain for each block those will be the level of RES production considered. Hence, it will be obtained a scenario of high and low production.

The percentile 95 means that just for 5% of the hours in each block the demand has exceeded that level of production. The percentile 05 means that the production has been a 95% of the time above that limit.

These are representative levels for critical scenarios, since they have already happened and the grid must cope with them

- Solar PV: solar is a much stable source of energy than wind. This means that its production is highly stable during the different periods of the year. Solar will be studied together with wind, in order not to loss simultaneity.

  For the levels above the Percentile 95 of wind production, it will be considered the average production of solar in those hours. By doing this it is sure that the production of solar is refer to the same hours of wind under study. The stability of solar also allows this assumption, because not a great volatility is expected.

Finally, in the next page it will be shown the results for both studies.

MEAN SCENARIOS

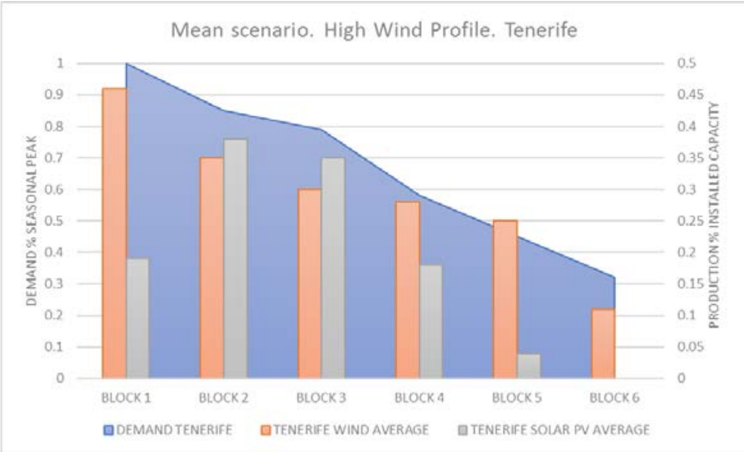

Figure 40 Mean scenario. High Wind Profile. Tenerife

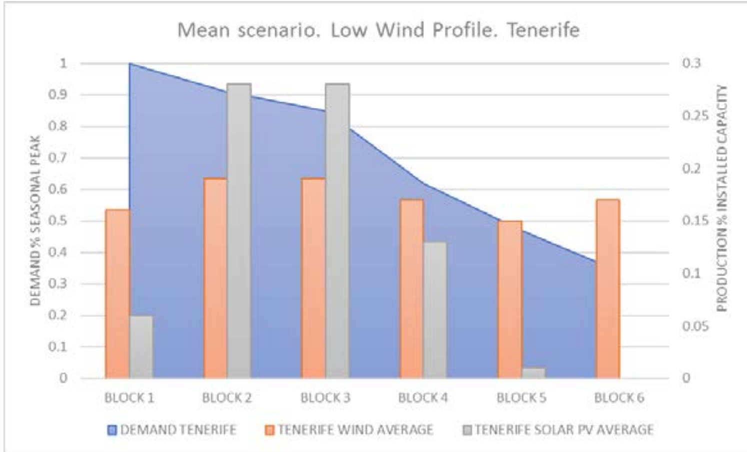

Figure 41 Mean scenario. Low Wind Profile. Tenerife

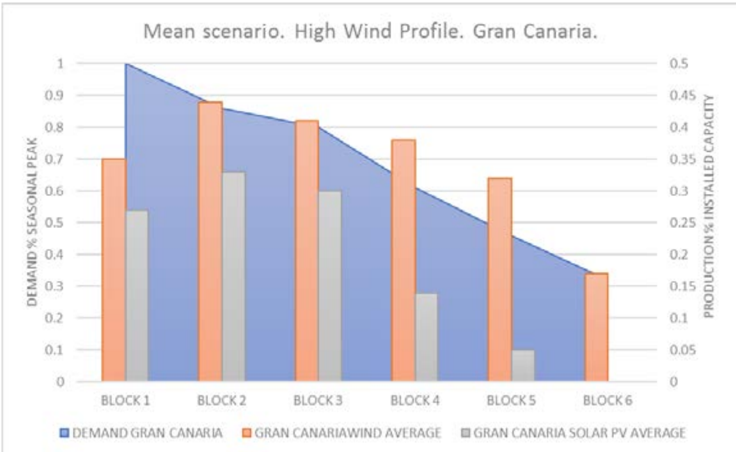

Figure 42 Mean scenario. High Wind Profile. Gran Canaria

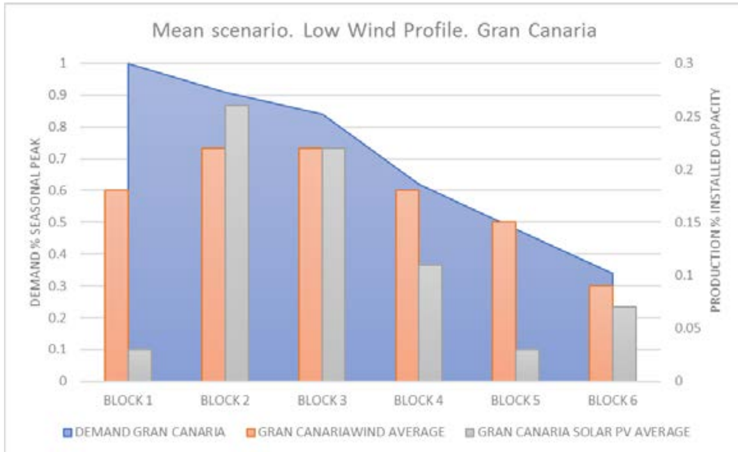

Figure 43 Mean scenario. Low Wind Profile. Gran Canaria

CRITICAL SCENARIOS

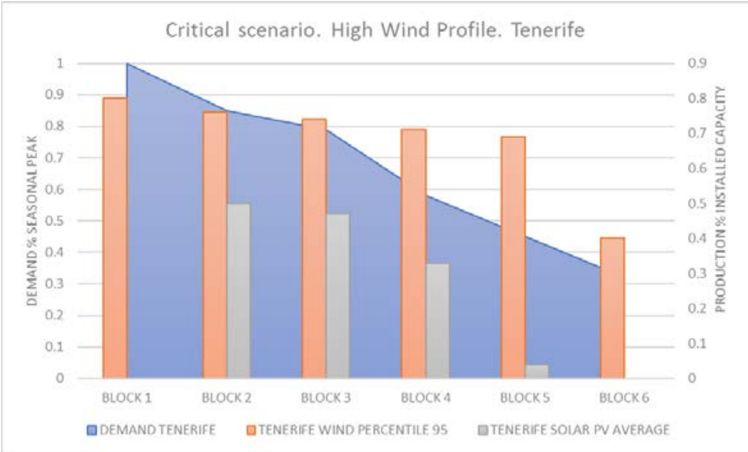

Figure 44 Critical scenario. High Wind Profile. Tenerife

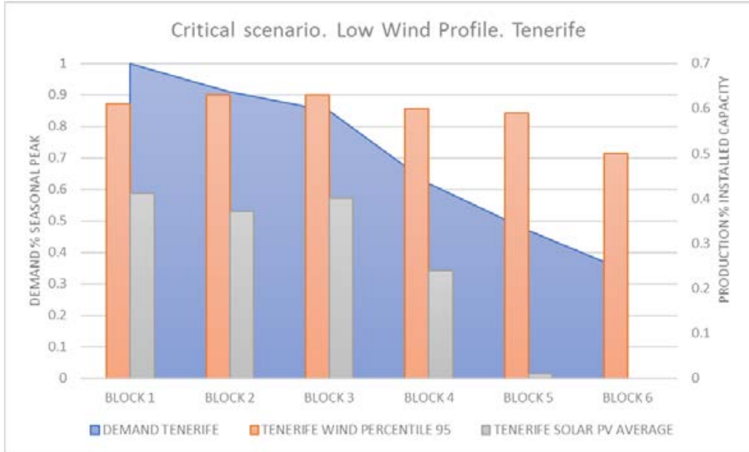

Figure 45 Critical scenario. Low Wind Profile. Tenerife

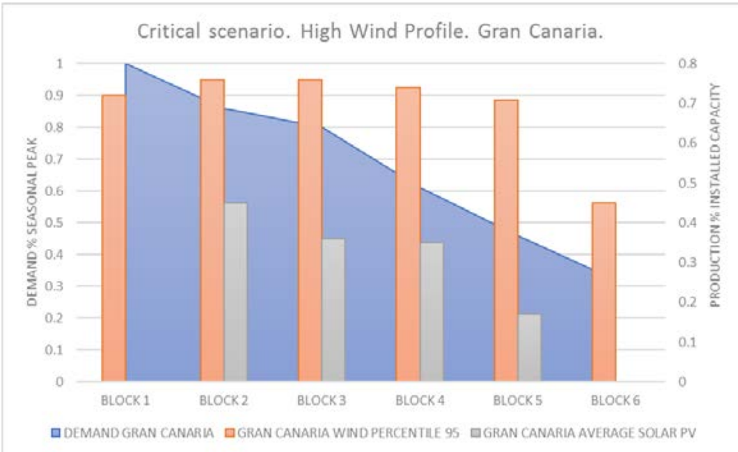

Figure 46 Critical scenario. High Wind Profile. Gran Canaria

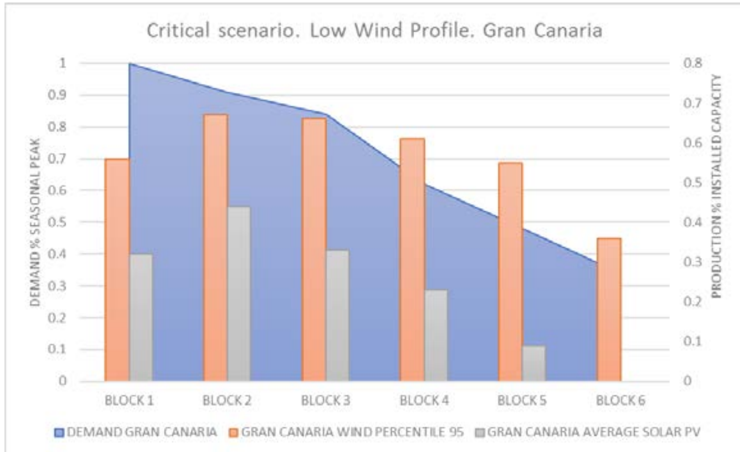

Figure 47 Critical scenario. Low Wind Profile. Gran Canaria

- For mean scenarios
    - It is seen how the level of production does not go beyond 50% of the installed capacity in any block.
    - In months with a low wind profile the average wind production is lower than in months with high wind profile.
    - It can also be observed that the level of wind production generally decreases from block to block. This confirms the relationship between demand and RES production. This means that climate conditions that lead to a higher demand of electricity also make RES facilities generate more.
    - The level of production of solar PV in block 1 is lower than in blocks 2,3. This means that demand in block 1 must include more hours of night peaks that midday peaks, and that is why the average production of solar is lower.
    - The level of production of solar PV is higher in blocks 2 & 3 than in block 1 this must mean that there is a greater proportion of midday hours in these blocks than in block 1.
    - The production of solar PV in the other blocks is lower because valley hours must include more night hours with no sun.
- Critical scenarios
    - The level of production in these scenarios is more stable than the level of production in mean scenarios. Wind production shows that the peaks in production are most or less equal not mattering which block is compared, but block 6. Nevertheless, critical production is higher in months corresponding to a high wind profile.
    - In the scenario of high wind profile in block 1 for both islands the level of production of solar PV is zero. This means that high wind profiles correspond to the entrance of cold fronts for peak demand at night and no sun. Block 1 for low wind profile may correspond to cold days in and the midday peak, that is why solar PV is producing.
    - In block 6 the wind production is the lowest in all cases, this means that in warm nights the level of wind production is low.

CHAPTER 5.- RESULTS

1.- Peninsula

The results are just commented because two mean reasons.

1. The results are too extensive to be present in this Master's Thesis and they exceed the limits of its purpose.
2. Due to data protection, neither the detailed scenarios nor the results can be present.

Nevertheless, the general results obtained are going to be commented.

To evaluate the results in the horizon 2020 with the grid already planned and approved by the government, 32 scenarios have been simulated.

These 32 scenarios are composed by the blocks 1 and 2 in winter and summer, because they are the most important blocks to assess the necessities of new investments or reinforcements in the lines, transformers, etc. The scenarios include, apart from these 2 blocks in summer and winter, the possibility to be importing/exporting and high/low profiles of wind and solar PV production.

The simulations are computed for two alternatives. One of them is the Alternative A that has been used regularly for the grid planning using the old coefficients for wind and solar PV. The Alternative B with the new coefficients of wind and solar PV obtained in this Master's Thesis.

The results show that in the Alternative B the average wind generation is a 6% greater whilst the solar PV considered is a 15% lower.

The average charge in the Alternative B is 2,5 % higher than in Alternative A, a 15% higher in the 400 kV lines and a 2% lower in the 220 kV lines.

2.- Canary Islands

The results have been presented during the study. The most important result to pay attention to are the seasonal characterization based mainly on wind production, the level of demand assigned to each block, the number of hours of the block, and the level of production assigned to each block in the mean and critic scenario.

CHAPTER 6.- CONCLUSIONS

1.- Conclusions

The conclusions are different depending which system is considered. That is why they are going to be commented separately.

1.1.- Conclusions for the Peninsular system

The analysis in such a large system as the Iberic is difficult. There are temporal and geographical relations between the different demand and the level of RES generation that makes the study more complicated.

The solution proposed to study this system is believed to be an accurate one. Nevertheless, it could be improved by computing for each block for each region and for the most probable geographical relationships between regions the Load Flow (LF). This means to simulate each block when the production in each region is high to obtain the most demanding geographical configuration for each block.

However, this study requires a much more complex analysis that requires to develop many more scenarios to assess statistically geographical relationship in every region of the Peninsular system.

On the other hand, the study done is more complete that the previous studies developed. This means that more realistic scenarios have been computed that consider not only the relationship of demand and generation but the relationship between regions.

Also, the simulation done seems to be accurate. It provides results that are more demanding for the grid than the original Horizon studies.

1.1.1.- Further studies. UPLAN.

To improve the characterization of the grid further studies could be done. One of them is to simulate the system using UPLAN.

UPLAN is a software that simulates both the electricity market and the network transmission model. This is done for a yearly basis and therefore the curve of wind and solar PV production must be characterized including peaks in generation.

The most relevant feature of this software is that it allows to simulate hour by hour the whole system, obtaining an economical representation of both the market and the network. Therefore, the total costs can be simulated and assigned to each agent.

This study is going to be developed from the results arrive in this Master's Thesis.

1.1.2.- Further studies. Capacity studies.

Capacity studies are the ones that simulate the grid when it is subject to the most congested situations. This means that from the planning studies, already done, it is interesting to simulate the grid in situations where the capacity of the lines is almost exceeded to know the real limits of the system.

These studies are complementary to the planning studies and most of the data used in those studies could be re-used. For example, the division of the regions, the values of RES generation assigned to each province the geographical relationship, the temporal relationship with the demand could be re-used in this kind of studies.

The maximum capacity of renewable power is an important input for the agents and producers when they must evaluate the convenience of any investment in new capacity. REE publish is his website this data for each node of the grid and for all Regions of Spain.

This studies are going to be develop from the results of this Master's Thesis.

1.1.3.- Conclusions for the Canary Islands

From the analysis done a series of possible scenarios in the islands have been obtained. These scenarios are characterized by simultaneous levels in demand and RES generation and their probability of occurrence that would allow to compute future necessities of the grid in a more complete manner.

The most relevant conclusions from the analysis of the data and the scenarios calculations are:

- There is a clear relationship between demand, climate conditions and tourism.
- The seasonal patterns in demand and wind generation are not the same and they do not follow the same trend.

- From the simultaneities in demand and RES generation it could be said that some relevant cases have been found. It is interesting to remark that contrary from the most logical first approach blocks 1 are not the most demanding scenarios for studying the grid. In fact, these more demanding scenarios are blocks 2 and 3, corresponding with what it is known as peak and shoulder blocks. The reason behind this is because in these scenarios wind and solar PV will be producing.
  This is more relevant in Tenerife where there is solar PV has more weight in the installed mix.

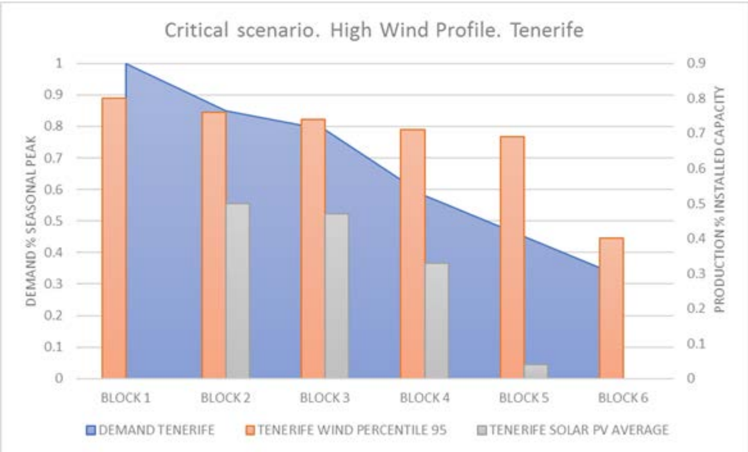

Figure 48 Critical scenario in Tenerife for the High Wind Profile.

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