UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

Assessment of the Firmness of the Wind Technology

Author: **Iván Garrido Yuste**

Supervisor: **Plácido Ostos Nieto**

Co-Supervisor:

Madrid, 07/2016

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SUMMARY

The electricity sector is facing an unprecedented transition. In the past, the power sector used to have the certainty about the availability of the sufficient resources in the system by attracting investors through economic signals that involved low risk investments and stable incomes. However, this traditional framework has been modified in the last decade. First, the liberalization of the traditional framework modified the investors' risk that until that time the agents used to face; and after, the disruption of the traditional generation mix, by the arrival of the renewable technologies with low variable cost, that reduce the income of the traditional agents involved

The establishment of this new paradigm involves facing new challenges that allow achieving the new model without a sharp break with the traditional model. Thus, the regulators and the responsible agents of each system try to implement different solutions that allow to evolve the system in a softly way. One of the main challenges that the regulators face is related with the current concern about the firmness of the system. Therefore in the last years different mechanisms have been established in order to guarantee the desired level of firmness in the system whereas economic signals are sent to the investors, in order to attract them to provide the service.

The main objective of this project is to determine a methodology that evaluate the contribution of the different technologies to the firmness of the power system in order to allow all of them to participate in the remuneration mechanism already established by the regulators to tackle with the reliability problem.

The methodology has been assessed with the Wind Technology because is one of the technologies that has been more developed in the last years, presents a decoupling between installed and firm capacity and also because in some countries its participation is not allowed due to some vague arguments against its variability.

CHAPTER 1

INTRODUCTION

CHAPTER 1: INTRODUCTION

1.1 Motivation of the Project

The electricity sector is facing an unprecedented transition. In the past, the power sector used to have the certainty about the availability of the sufficient resources in the system by attracting investors through economic signals that involved low risk investments and stables incomes [IEA_14]. However, this traditional framework has been modified in the last decade. First, the liberalization of the traditional framework modified the investors' risk that until that time the agents used to face; and after, the disruption of the traditional generation mix, by the arrival of the renewable technologies with low variable cost, that reduce the income of the traditional agents involve.

There is total unanimity about the relevance of reliability of electricity supply, and therefore in the need of guaranteeing the availability of this essential service in all time horizons. Traditionally the reliability problem has been separated into three different dimensions: security, firmness and adequacy [ARRI07].

- Security is defined by the NERC as the "ability of the electrical system to support unexpected disturbances such as electrical short circuits. Typically is associated with the operating reserves available to guarantee the providing of the services" [NER97].
- Firmness "is defined as the short-term generation availability that partly results from operation planning activities of the already installed capacity" [REGP12].
- Adequacy is associated with the existence of enough available capacity, both installed and expected, to meet the demand, (a long-term issue) [REGP12].

In the centralized context, the reliability problem in its firmness and adequacy dimension, was tackled by a central entity which through investment signal based on the guaranteeing of stable incomes for the future used to attract a sufficient level of resources in the system to tackle the problem. However, in a liberalize context there is no longer that institutional figure which take the decision to invest in the system and the decision is in the hands' of the investors which attracted by the economical signal of the markets decide to invest or not.

In a competitive market with a demand's elasticity and with an absence of economies of scale in generation, the market price is a right economic signal to attract investors because it would be sufficient to remunerate the total cost of those generating units whose investment is well adapted to the existing demand. However, this basic principle of the market theory does not apply for the electricity market because two main reasons [REGP12]:

- There are economies of scale in generation activities, therefore there is a clear trend to over dimension the size of the plants.
- The theory of the competitive market perfectly matches with some periods of scarcity of supply that allows the peak units to recover their investment cost. However, due to the essential of the service, there is no country that can allow themselves to have periods of scarcity and therefore there is a clear trend to attract investors to install more capacity than what the theory suggest.

These points lead the power sector to a situation where there is more installed capacity than needed, due to the aversion to the scarcity periods that impact in the different agents involved; investors facing a lot of uncertainty to recover their stranded cost, more significantly those agents that produce in peak hours, and in the meantime regulators that are afraid of those generators leaving the mix, with the reliability problem associated and also trying to send an economic to attract investors.

Additionally, the already mentioned disruption of the renewable technologies in the power sector, supported by a clear political intention to decarbonize the sector in order to fulfill with the international environmental treaties, has contributed to distort the already blur economic signal from the power market. This distortion, roughly speaking has been caused because there are new technologies that have not been facing the market risk, but have been participating in the electricity market reducing the market price and therefore affecting the market signal.

The direct consequence of this problem is that the agents involved in the generation business do not react to market signals and the regulators in the power system are glimpsing a reliability of supply problem for the short and medium term due to the aging of the existing plants and the lack of incentive to invest. Therefore, in order to mitigate the negative impact of the economic signals the regulators have established additional mechanisms to correct weak long-term signals. The most common approach is the capacity remuneration mechanism, which consists roughly speaking on remunerating the agents involved based on their contribution to the firmness of the power system.

Regarding the firmness' concern in the power sector, the objective of the regulators policies are oriented to create mechanisms that contribute to solve the problem. These mechanisms already implemented consist on defining products that reflect the system needs while at the same time is reinforcing an investment signal.

However in some of the mechanisms implemented these technologies are not allowed to participate in the capacity remuneration mechanism mainly because there is no clear assessment of their contribution and as a consequence the new mechanism that has been conceived to correct the distorted signal from the energy market is creating a distorted signal too.

1.2 Objectives

The main objective of this project is to determine a methodology that evaluate the contribution of the different technologies to the firmness of the power system in order to allow all of them to participate in the remuneration mechanism already established by the regulators to tackle with the reliability problem.

The methodology will be assessed with the Wind Technology because is one of the technologies that has been more developed in the last years and also because in some countries its participation is not allowed due to some vague arguments.

Additional objectives will be tackled in the project:

- Description of the main Wind Technology characteristics in order to have a clear view of the problematic associated with its participation in the capacity remuneration mechanism.
- Description of the different mechanism already developed by the regulators in order to tackle with the reliability problem.
- Clear description of the current reliability problem associated with the disruption of Wind Technology.

CHAPTER 2

STATE OF THE ART

CHAPTER 2: STATE OR THE ART

2.1 Introduction

Electricity is an asset which modern society has come to depend upon entirely. The repercussions of lack of electricity stretch deep into the social, economic and political domains of any country. Hence it is of primordial importance for politicians, system regulators and operators that power systems function correctly, avoiding emergency situations or blackouts.

In a liberalized electric market framework, the generation activity is decentralized leaving the investment decisions in players' hands. Therefore the decision of installing capacity in a power system has been since the beginning of the deregulation process a permanent issue for the regulator's entities in order to guarantee the sufficient level of capacity to meet the energy requirements all the times.

The aim of this chapter is to provide a general view about one of the problems associated with the reliability of supply, Therefore an analysis of this concept is explained in the first part of the chapter, to continue with some methods used to assess the confidence of the system in the short term and afterwards conclude with some mechanism already implemented in international power systems to achieve a certain level of reliability.

2.2 The reliability of supply concern

Modern society depends critically on the availability of electricity. The consequences of a lack of supply are known to affect regions and countries profoundly in their social, economic and political dimensions. Progress is without any doubt linked with the availability of sufficient electricity. For that reason the security of supply has been a major issue for the regulators in order to guarantee a certain level quality standards.

The reliability of supply issue is a question that is associated with the four activities of the power sector: generation, transmission, distribution and supply, however with the current liberalized framework the main issues, considering a well function and remunerated monopolistic activities, are in those activities that have been liberalized in order to introduce competition (generation and retail), since the decision of investing in new generation plants are driven by agents whose interests are not necessarily guaranteeing the energy needs of the power system.

Prior to the liberalization of the generation activities, in a centralized scenario, the generation's investments were responsibility of the central agent which used to take the "necessary" decisions in order to achieve an acceptable level of reliability. Therefore the reliability of supply problem used to be solved in a simpler way than nowadays, at least theoretically, however. Now, the reliability of the system depends in somehow the market interactions between consumers and generators, which does not necessarily guarantee enough generation resources in order to maintain a certain level of supply in the generation side, or at least the desirable level sought by the regulators, which are permanently looking for market base approach to cope with this issue Moreover, the arrival of renewable technologies and their steady development within the generation mix has modified the vision of the problem mainly due to the uncertainty associated with the generation of these technologies.

The traditional approach to the problem is based on breaking the security of supply question down into its major components in order to identify the main issues and the regulatory measures to put in practice. Several classifications of these components are in use, however in this particular topic, the components of the problem usually make reference to the time periods involved, the known as time dimensions.

The four dimensions of the security of supply

The four dimensions of the security of supply problem are explained before in broad terms [RODI10]:

- Security: is the ability of the electric system to support unexpected disturbances such as electrical short circuits or unexpected loss of components of the system or sudden disconnections.
- Firmness: a short to mid-term subject, can be defined as the ability of the facilities already installed to respond to actual requirements of the system to meet the demand.
- Adequacy: a long-term requirement refers to the existence of enough available generation and network capacity, either installed or expected to be installed, to efficiently meet the demand in the long term.

- Strategic expansion policy: concern a very long-term policy related with the availability of energy resources and infrastructures. This dimension usually entails diversifying fuel supply and the generation mix technology, together with long-term network planning, and it is frequently associated to other aspects of energy policy, in particular environmental concerns.

2.3 Firmness of the Power System

The aim of this project is to analyze the firmness of the Wind Generation to assess the real contribution of this technology to the firmness of the Spanish Power System. Therefore, prior to the assessment of the firmness is necessary to address the different calculation methods to determine the firm capacity of a technology. The best definition of firmness is the amount of capacity (MW) that is available to generate when needed, during a defined interval of time. Based on the latter definition is noticeable that the determination of that firm capacity of each generator will be strongly linked with the definition of the system needs. The most common approach associated to the definition of the system's needs is in those periods where the system is considered being stressed, i.e. there is more probability of not covering the energy needs. The consideration of these needs is relevant to compute the firmness of each technology to contribute to the system firmness. Moreover, the methodology used to evaluate the firmness play an important role for the determination of the problem. For instance the firm capacity of a generator plant will not be that same in case it is computed based on the historical data, (heuristic procedures) of availability of the plants, rather than if is calculated based on the production when there is a high risk of scarcity of supply characterized by high prices in the wholesale market. The other methodology used to determine the firmness is based on convolution techniques.

2.3.1 Methods based on heuristic procedures

These methods have the advantage of being simple to calculate, and mainly defined as a function of the each generator's maximum power output, determine by the nominal capacity and its outage rate defined by the technical availability of the generating plant. Examples of these methods are the firm capacity in the PJM capacity market which is defined as functions of generator's maximum power output and its outage rate. [PJM_14]

Thermal units:

$$Firm\ Capacity = p_{max} \cdot (1 - FOR) \qquad \text{(Eq 2.1)}$$

2.3.2 Methods based on convolution techniques

The advantage of these methods in comparison with the previous one is that they take the full power system int o account when calculating individual generator contribution.

In these methods the load duration is convoluted, followed by the convolution of each of the system's generators. In this manner all the generators are dispatched depending on their nature (thermal, hydro, etc.). Then each of the generators is removed from the system by deconvolution, either individually or in different combination with other generators from the system. The absence of each generator will leave an amount of non-served energy in the system and the firm capacity is defined as the power equivalent necessary to cover the non-served energy remaining after each individual deconvolution.

2.4 Tackling with the firmness in a liberalize context

Regarding with this subject many papers have been released pointing out the necessity of modifying the traditional approached regarding with the security of supply issues. As it was explained before within the liberalize context the investment decision is on the hands on the different agents and ideally the market solve the problem. However as it has been pointed out in some publications the market presents imperfections and the behaviour of the agents introduce modifications that lead the market not to be enough to deal with the firmness problem. The principle drivers that cause the market not to be a sufficient mechanism to face the firmness problems are [RODI10]:

- Risk aversion of the investors and regulators.
- Low elasticity of the demand in the short term to determine the likelihood of the scarcity times.
- Imperfect regulation such as Price Cap.

The problems addressed before in the energy only market create long-term distortions that lead to underinvestment in generation capacity and do not guarantee the desirable level of firmness neither in the short nor the long run. Therefore the regulatory concerns in this subject going through establishing a mechanism that send economic signal to the investors in order to attract them to invest in firm capacity in the system. Said that, the following point of the chapter will be devoted in addressing some of the mechanism implemented so far, to overcome the uncertainty associated with the security of supply.

2.4.1 Security of supply mechanism to meet firmness requirements

The own definition of firm capacity as the amount of capacity (MW) that is available to generate when needed during a defined interval of time, left the computation of the firm capacity as a not straightforward subject. For that reason when implemented mechanisms to increment the firmness of the system the definition of the firm supply can be adapted according to the necessities and the characteristics of the power system and also as the time frame considered.

2.4.2 Regulatory attempts to increase the security of supply

There are many examples about different mechanisms already implemented by regulation entities in order to achieve the desirable firmness level. Some of them have been implemented in a centralized approach like the case of the Spanish Power System, but the trend in this subject is going through achievingthe desire level base on market approaches. Therefore, the most common procedure to implement a market approach is roughly speaking based on the designing of a product that could be perfectly identified by the agents involved to afterwards create a market with the product. This mechanism, in a simplified approach involved the definition of the two main components:

- Definition of the firm supply.
- Time frame considered

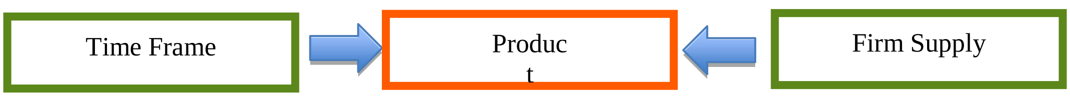

Figure 2.1: Scheme the definition of a reliability product

These 2 aspects are basically what form the products defined by the regulators in order to achieve a satisfactory level of firmness when they need it. The definition of each particular product depends on the nature of the power system, the demand pattern or generation mix.

There are several examples of mechanisms implemented in different power systems where the regulators define certain reliability product for a time frame in order to meet a satisfactory level of reliability. Those mechanisms can be classified basically on the objective of the regulator, to ensure a certain quantity of the product or to set a price for the product:

- Price mechanism: the regulator basically simplifies the firmness problem to the introduction of installed capacity in the power system. Therefore the regulator promotes generation capacity investment by providing payments to generation units as a reward of the addition of firm capacity. In addition to the firm's expected.
- Quantity mechanism: as the previous one the regulator defines a product and an amount of quantity required to achieve the reliability requirements. Under this scheme the money does not flow directly to the agents but it is traded between the providers of the product and the regulators in behalf of the demand.

In the following point of the chapter a general overview of the different international experiences implemented so far will be displayed, according with classification of the different mechanism explained before. The explanation will be devoted mainly in the definition of the reliability supply product and the time frame considered among other considerations.

2.4.3 International examples of reliability of supply mechanism

There are several examples about the different mechanisms implemented so far to ensure the firmness requirement of the system operator. They can be classified according to whether they are a volume based or price based. As a result of the classification five different types of capacity remuneration mechanisms can be defined, presented in the following Figure 2.2 [ACER13].

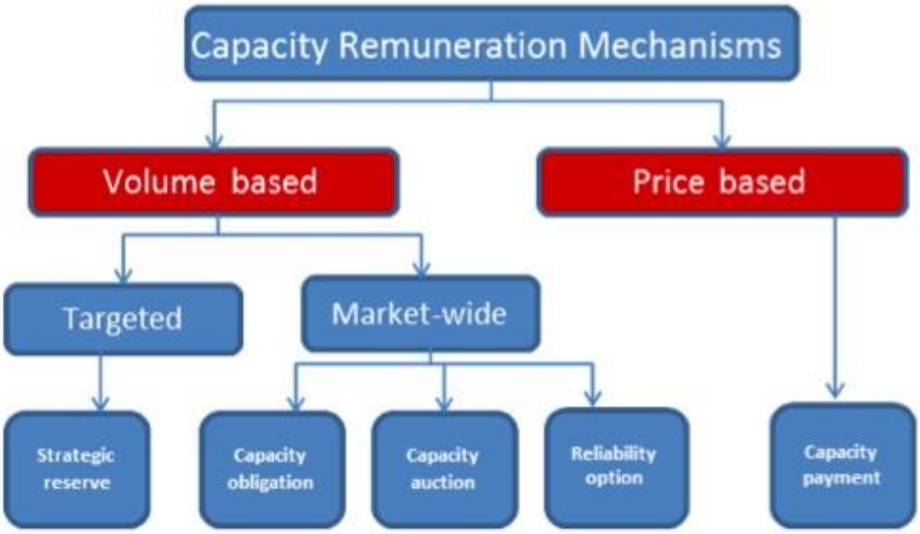

Figure 2.2: Scheme of Capacity Remuneration mechanisms. Source: ACER

PRICE MECHANISM

A. Spanish Capacity Payments

Capacity payments mechanism implemented in 1997, [BOE_07] with the aim to ensure a certain level of firmness in the stressed time frame of the system i.e. when the demand is highest in the power system. The mechanism consists in a payment to each generator that previously has committed its firm capacity or part of it to be available in these periods of maximum demand. In this case the reliability product defined to this capacity mechanism is the firm capacity previously defined by the regulator according with the availability of the generators in those periods of maximum demand.

The procedure to determine the firm capacity of each plant is based on heuristic method to determine the expected availability of the generator to supply in those periods of maximum demand. The definition of firm capacity for a thermal plant is defined as follows, where the FOR (Forced Outage Rate) is the probability of not being able to supply for technical reasons and on average historical production for hydro units.

The provision of the service is remunerated in terms of the firm capacity [€/MW] available to the system operator in those periods of maximum demand previously defined. The firm capacity is defined as net amount of power that is available to the system operator multiple by the historical availability of the technology in those hours of maximum demand. However, this mechanism is far from being considered a market approach because only CCGTs and coal plants were allowed to participate claiming that there were a risk that they leave the market because of the reduction of operating hours and as a consequence the income. Therefore this mechanism in at least in the Spanish implementation is not considered a well example.

QUANTITY BASED MECHANISMS

A. Nordic Countries, Strategic reserve

Also called peak load Reserves. In a Strategic Reserve scheme, some generation capacity, firm capacity, is set aside to ensure security of supply in exceptional circumstances, which can be signalled by prices in the day ahead, intra-day or balancing markets increasing above a certain threshold level. The system operator determines the amount of capacity to be set aside to achieve the desired degree of adequacy and dispatches it whenever due. The capacity to be set-aside is procured and the payments to this capacity determine through a typically year ahead tender [ENER15].

For the Denmark case the system operator's requirement to provide the service is that the resources participating in the reserves must be at disposal 24 hours per day for the entire duration of the contract. This condition makes something unfeasible the participation of the Wind Generation in this service.

B. France, Capacity Obligations

A Capacity obligation scheme is a decentralised scheme where obligations are imposed on large consumers and on load serving entities, to contract a certain level of capacity linked to their self-assessed future, between one to three years ahead, consumption or supply obligations. Contracted generators and consumers are required to make the contracted capacity available to the market in periods of shortages previously defined or by market prices rising above a threshold level. The firm capacity is determined by the regulators, which firstly compute a Contribution Coefficient based on the technologies and past records of their producible energy at peak. In the following table are presented the values of the contribution coefficients of the intermittent generation [RTE_14]:

	Technology		
	Hydro	Wind	Solar
Contribution Coefficient (%)	85	70	25

Table 2.1: Contribution Coefficient (%)

In the following graph is presented the effective power of Wind Generation for the year 2011 with a different range of number of hours of peak demand.

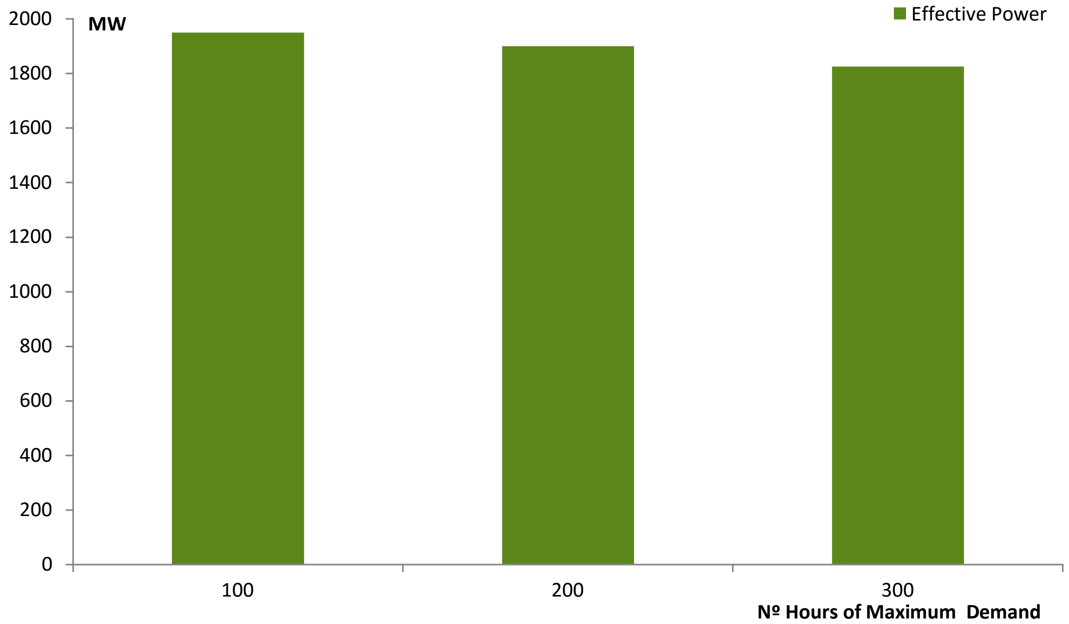

Figure 2.3: Effective Power of Wind technology in France

C. PJM, Capacity Auctions

This capacity remuneration mechanism so far has been used for the adequacy problem; time frame larger than one year, not for the firmness problem, due to that it will not be explained.

In the PJM power system determine the time frame of firmness scarcity as the period between June through August. The firm capacity is defined as the UCAP (UNforced CAPacity) and is defined as follow [PJM_12]:

$$UCAP_{Thermal\ Plants} = ICAP\ .(1 - FOR) \quad \text{(Eq 2.2)}$$

$$UCAP_{Intermittent\ GEN} = \frac{\sum_{h=1}^{2208} Output_h}{2208} \quad \text{(Eq 2.3)}$$

Being ICAP is the nameplate capability of a generating unit.

For the intermittent generation the FOR is not applicable and the UCAP is based on average of June through August peak hour output over three year calendar.

D. Italy, Reliability Options

Reliability Options (ROs) are an instrument similar to call options, where generators, capacity providers are required to pay the difference between the wholesale market price and the strike price(pre-set reference), whenever the difference is positive, i.e. the option exercised. In exchange they receive a fixed fee benefiting from a more stable and predictable income steam [AUTO15]. Under this scheme, the incentive for the contracted generator to be available (at times of scarcity) arises from the high market prices and from the fact that, if not available and therefore not dispatched, it will have to meet the payments under the RO without receiving any revenue from the market. The generators commit their firm capacity or part of it in order to provide the service in periods of high prices.

Under this scheme there is no need to evaluate the firm capacity of each generator administratively, as each generator bids the amount and it considers balancing the loss of revenues and the risk of penalization with the stable revenue of the contract premium.

2.5 Conclusions

The liberalization of the generation sector has introduced more uncertainty in the reliability of supply problem; moreover the current penetration level of renewable technologies in the power system has modified the traditional approach to tackle the problem driving the regulators to deal with a more complex problem. Therefore new mechanisms have been adopted to ensure the desired level of reliability and at the same time the assessment of the firmness of renewable technologies is still being a an open subject to discuss about it.

2.6 Motivation of the project

Nowadays the power system is immersed in a transformation towards a more sustainable and efficient sector. The establishment of this new paradigm involves facing new challenges that allow achieving the new model without a sharp break with the traditional model. Thus, the regulators and the responsible agents of each system try to implement different solutions that allow to evolve the system in a softly way. One of the main challenges that the regulators face is related with the current concern about the firmness of the system. Therefore in the last years different mechanisms have been established in order to guarantee the desired level of firmness in the system whereas economic signals are sent to the investors, in order to attract them to provide the service. In this chapter it has been shown different mechanisms already implemented, based in some cases, on the system needs to guarantee a certain level of firmness. Therefore the consideration taken into account for the definition of the mechanism is crucial to the signal that the agents perceive. For instance in the case of Spain, the current Wind's firmness is 7% of the installed capacity. However if other assumptions were considered the value would change notably. For example if the firmness was determined based on the annual contribution to the system needs in terms of energy this 7%, would increase up to 20%. Thus, this project comes up to analyse and suggest an accurate assessment of the definition of the product, in order to open the capacity remuneration to all the technologies.

CHAPTER 3

PROBLEM DESCRIPTION

CHAPTER 3: PROBLEM DESCRIPTION

3.1 Introduction

The aim of this chapter is to tackle the problem associated with the determination of the firmness of the Wind Generation not as an individual technology but within a Power System. To state the framework associated with the problem the chapter is divided in three principal points. Firstly, there is a presentation about the different perspectives about the firmness of the wind generation and the impact that a significant penetration level of this technology produces in the traditional framework of the power system explaining the principal aspects that affect the firmness problem. Secondly, the chapter continues presenting some characteristics of the wind generation within the Spanish Power System subject to be crucial in the assessment of its firmness.

3.2 Is the Wind Generation a Reliably Technology in terms of supply?

This doubt is the principal drawback against the wind generations supported by those who are looking at the technology from the point of view of a traditional thermal plant or others who have additional interests to overturn this technology. In this Master Thesis the aim is to be the most objective as possible explaining the facts associated with the firmness of the Wind Generation no matter if they are pros or cons, if they support the results or turn them into a more indecipherable scenario.

The traditional thermal plants are characterized for being dispatchable units, easily manageable with an almost permanent availability of the resource to produce electricity. From this point of view the Wind Generation cannot be considered manageable and dispatchable at least in the sense of the thermal units and therefore in some cases is considered as a source of uncertainty and uncontrollability. However, despite this uncertainty the Wind Technology is a clear provider of energy and it is not a problem is part of the solution.

This is a question that utilities are looking into closely now that wind energy has emerged as a mainstream option for new power generation. The fact is, any energy technology has its special characteristics, and so utility and transmission system managers have always adapted to accommodate them. For example, when nuclear power was introduced, system managers had to adjust operations to ease the integration of a large, non-dispatchable, single source of electricity that could suddenly trip off-line;

in fact, even today, they typically set their "reserve margin" at the level of the largest nuclear plant on their system. Moreover, nuclear and coal plants can generate a lot of power on a continuing basis, but cannot be easily ramped down or up to meet variable demand. They need to be supplemented with dispatchable technologies like natural gas. And while natural gas and oil power plants are flexible and easy to use, their fuel cost is volatile and increasingly high, so they are best used for "peaking" and designed to remain idle if not needed, sometimes for long periods of time. As for wind power, it is not typically used to meet peak electric loads but it makes a large contribution to the amount of electricity that is generated and consumed over time: wind's benefit is in providing energy, diversifying supply, saving fuel, and reducing carbon and other emissions. The fact that the output from wind farms is variable does not mean that wind farms need dedicated "back-up" or "storage" -- the power system already has reserves and typically only a modest amount of additional reserves may be needed to handle wind. In the case of the Spanish Power system the demand share typically covered by the Wind Generation in annual basis is above the 20%, with days that overcome the 50% of the needs and others that barely reach the 5%.

This framework previously presented, do not clarify the perception about the behavior of the Wind Generation in terms of firmness, at least not in terms of an isolated technology. However, to analyze the real impact of the wind generation in terms of reliability needs to be done in within a Power System. In the case of this Thesis will be done in the Spanish Power system, one of the pioneers in the introduction of Wind Generation in its generation mix.

3.2.1 Traditional Status Quo of the Spanish System

Traditionally the Spanish system demand has been met by three types of technologies: Nuclear, Thermal and Hydroelectric plants, which in terms of operation are characterized by dispatchable units easily manageable according to the requests of the system subject to the availability of the resource to produce the electricity. Under this scenario the analysis of the reliability of the system used to be very straight forward mainly because the generating units presented a nominal capacity available to produce, subject to the technical problems and operations of maintenance, that reduce their availability, that usually presented a high level of firmness, *defined as the availability of a generating units when is needed*.

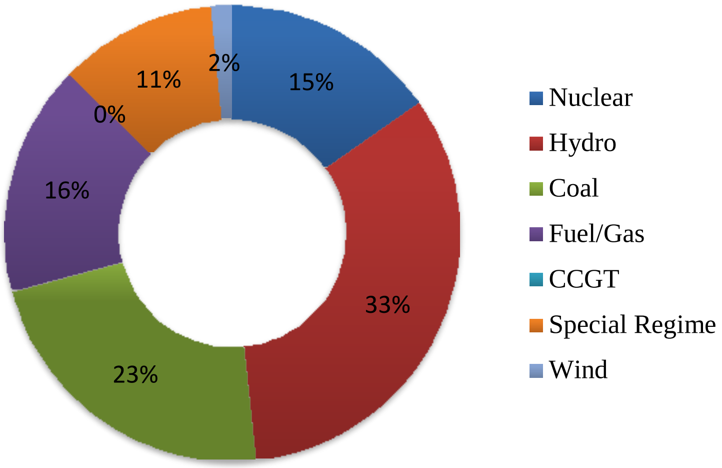

Figure 3.1: Installed Capacity in Spanish Power System 1998. Source: REE

Under this scenario coping with the reliability problem in the short and long term roughly speaking used to consist in having enough capacity, characterized with a probability of availability to cover the most stress situation of the system, defined mainly by the evolution of the demand. However during the first years of the previous decade different technologies disrupted turning the traditional status quo into another different one [REE_00] [REE_15].

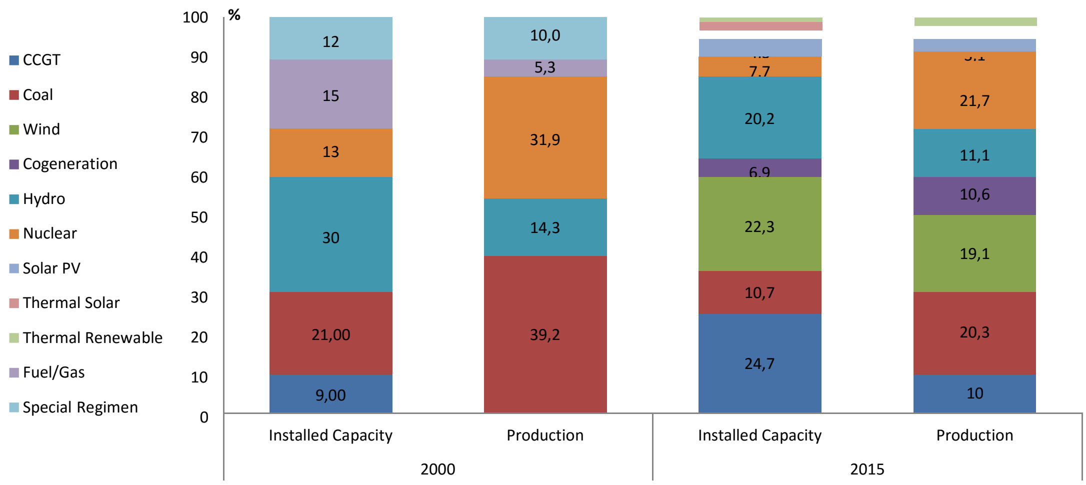

Figure 3.2: Evolution of the Installed Capacity and Demand Share (2000-2010). Source: REE

As it can be noticed in *Figure 3.2* the disruption was originated principally by the entrance in the system of Combined Cycle Gas Turbine (CCGT) and Wind generation, the first adding 25 GW of capacity and the latter with another 20 GW additionally another Renewable Technologies were introduced such us PV panels or Thermosolar [14].

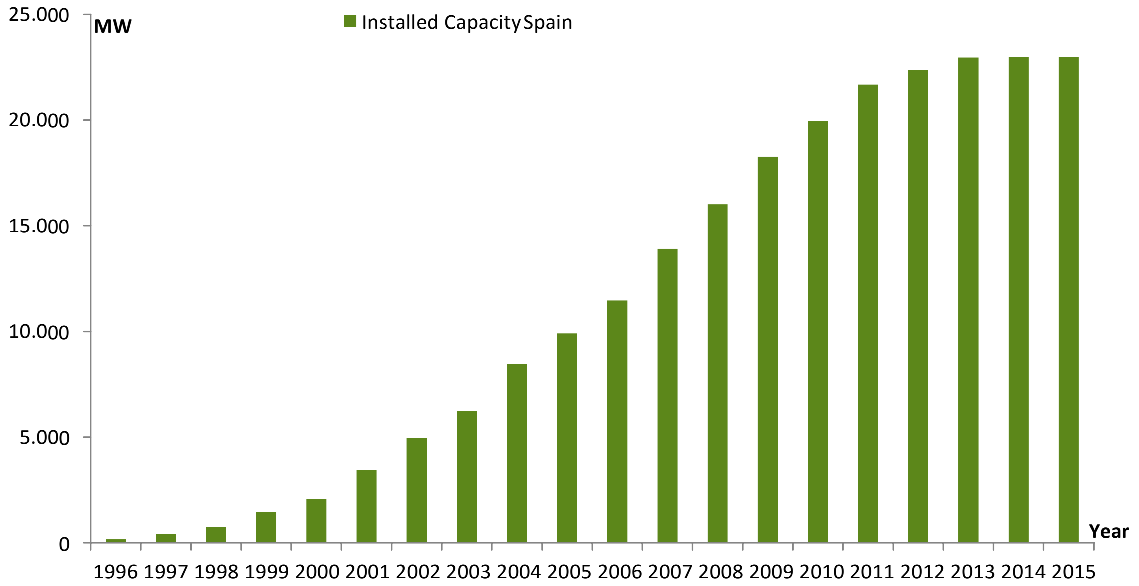

Figure 3.3: Historical Evolution of Wind Installed Capacity in Spain

3.2.3 The new status quo, redefinition of the reliability concept

The disruption of renewable technologies, characterized by their non-dispatchability, in the power systems, has impacted the traditional way to tackle with the reliability problem. The reason that has caused it has been the appearance of technologies characterized by a decoupling between firm and installed capacity. Traditionally the installed capacity, with certain exceptions and considerations, used to be considered as a reference of their firm capacity. Therefore the traditional way to guarantee a certain level of firm power in the system used to consist in having enough installed capacity in the system. Therefore, due the appearance of technologies characterized by a decoupling between firm and installed capacity this previous proxy was no longer accurate and as a consequence an assessment of the firmness of the new technologies is needed.

Another reason that has modified the traditional assessment of the reliability problem has been as a consequence of the liberalization process that has wondering the capabilities of this new model to attract investors in order to guarantee sufficient resources in order to avoid reliability problems. Traditionally, the products provided by generating agents to cover the system needs have been:

Firm Capacity

Is the capacity provided by generating agents that is available to the system needs whenever it needed with a certain level of probability.

Energy:

Energy is a measure of power provided over time, calculated by multiplying the amount of power consumed or generated by the time it was used or generated. Traditionally the energy produced by a thermal unit was determined by the installed capacity of the plant and the needs of the system. However, the Wind Generation's output does not only depend on those two inputs, but is also associated with the availability of the resource and therefore the energy produced by a windmill cannot be only associated with the demand capacity and the system demands.

Flexibility:

Is the ability of a power facility to modify their output to balance the variation the demand in the real time.

Traditionally these three products have been provided to the system though different ways:

- Energy has been supplied by the different power plants that were dispatch on the wholesale market.
- The flexibility has been acquired through the participation of the generating agents in the ancillary services.

Regarding the provision of the firmness, it has always been neglected i.e. there was no need to worry about it, roughly speaking because the system did not present a problem of firmness. However, the appearance of RES technology has reduced significantly the price in the wholesale market and as a consequence some of the agents involved have faced a notable reduction of their incomes. Thus, these agents affected, characterized by being firmness' provider, have clearly shown their intention to leave the mix provoking a lack of firmness in the system. Therefore, the regulators have realized that there is a problem (not existing in the past, but a problem nowadays) and they look for a solution, which is usually a new product or a market. The aim of this new product is to guarantee the needs of the system while the economic signal is reinforced. In the past the economic signal from those products was the sum of the energy plus flexibility while there was no need of firmness signal. Once the new product is created, the new signal is formed by energy, flexibility and the firmness.

3.2.4 Definition of the Needs of the system

The definition of firmness as the availability of a plant to produce when is needed is insufficient or at least incomplete due to the decoupling between firm and installed capacity and therefore the definition of the needs of the system will drive the assessment of the firmness from one way or another.

Each Power System presents their own particularities that make themselves different from the others, i.e. there are hydraulic systems, like Brazil or Colombia, characterized for covering their power needs through hydro power plants and as a consequence making them exposed to the variability of the rains and therefore the most risky period would be in times of drought. However, although there is no power system equal to the others, all of them share a common driver to determine the criticality of the system, which is the demand. It is obvious that the demand is one of the most important driver to lead the system to a stress situation, i.e. when the demand present a medium-low level is clear that a well-designed power system is able to meet its energy needs from an stable position, and on the contrary , when the demand is high, the situation is different; the system is more stressed and some possible variations or failures in any active units may drive the system to collapse. Therefore the demand is widespread along the power sector and has always been used as a reference for the system planner to determine the system needs.

3.3 Characterization of the Wind Generation

3.3.1 Variable Output

Wind technology is characterized by its variability and as a consequence accused of being responsible to introduce more uncertainty in the system [OSTO12]. Nevertheless, the generation-demand problem since the very beginning has been defined by its uncertainty and variability, therefore the Wind generation is responsible for adding variability and uncertainty within a system that by nature presents certain level of variability and uncertainty. Furthermore, the wind generation technology contribute to cover the system energy requirements and have to be seen as a technology part of the solution with characteristics that need to be tackled from another perspective.

The variability of wind needs to be examined in the wider context of the power system, rather than at the individual wind farm or wind turbine level. The wind does not blow continuously at any particular site, but there is little overall impact if the wind stops blowing in a certain area, as it is always blowing elsewhere. This lack of correlation means that at system level, wind can be considered to provide stable output regardless of the fact that wind is not available all the time at any particular site. So in terms of overall power supply, it is largely irrelevant to consider the case when a wind power plant produce zero power for a time, due to the local wind conditions.

This level of stability of wind generation can be better understood in *Figure 3.4*which shows the load duration curve of Wind Generation in the Spanish power system for the year 2015 that even though the variability of the Wind Generation is clear the level of generation never goes below 500 MW, minimum output level of the year [ESIO16].

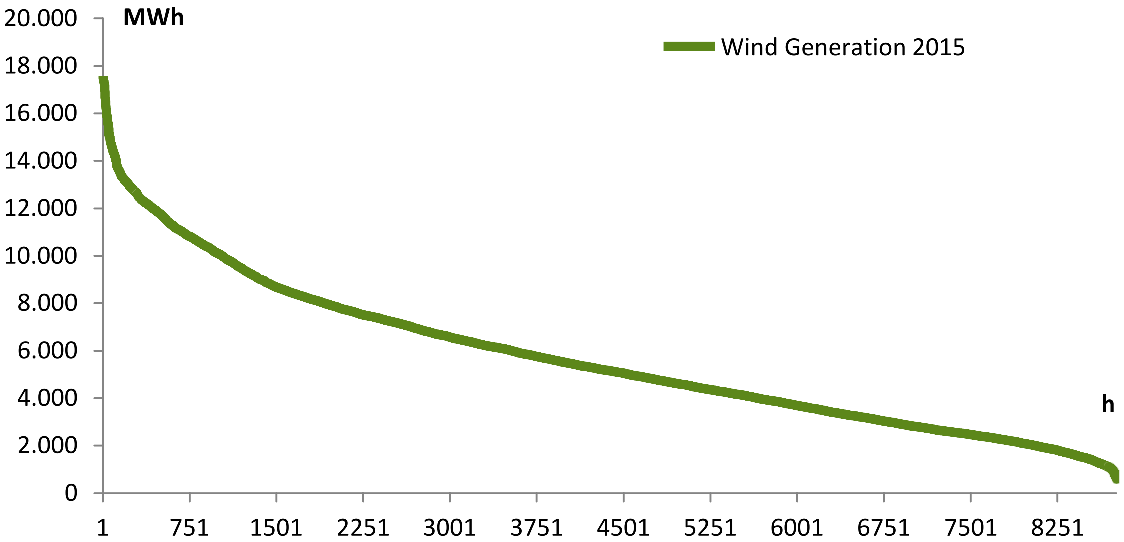

Figure 3.4: Load Duration Curve of Wind Technology in Spain, 2015. Source:REE

In the chapter 3 some methodologies were explained about the representation of the Load Duration Curve allows comprehending that although the Wind generation is variable there is not intermittency associated. It is clear that the output of each individual wind turbine is variable, but as was said before the Wind Generation within a Power System can be seen as the aggregation of the individual wind turbines and when it is done there is no single hour where the wind stops its generation.

3.3.2 Seasonal output variation

Wind Generation presents a seasonal component, i.e. the production is not the same during winter and summer because during the coldest months basically because the wind blows with more intensity. This difference between cold and hot months is presented in Figure 3.5 that yields that during the 50% of the hours the generation output in winter is 20% larger than in summer, indicative that the production is linked to the season of the year. This seasonal behavior can be easily considered as a drawback against the firmness of the wind generation. This result shows that although the wind produces less electricity in summer the percentage of demand share cover in those hours is rather stable [ESIO16].

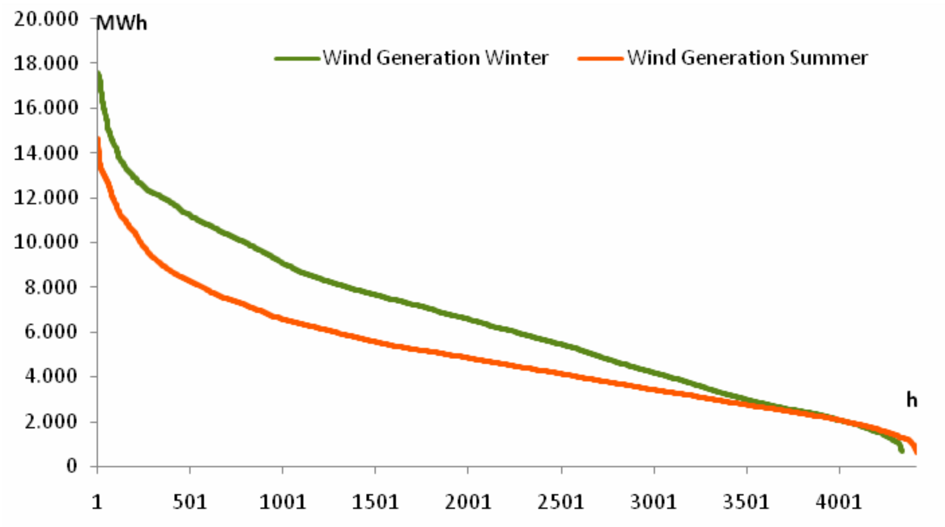

Figure 3.5: Seasonal Load Duration Curve of Wind Technology, 2015. Source: REE

Nevertheless, to a better evaluation of this seasonality the demand is plot and shown that the in summer the peak demand is lower than in winter which involves that although the decrease in the wind generation's output is clear the impact that have in the demand cover is lower that a priory may be thought.

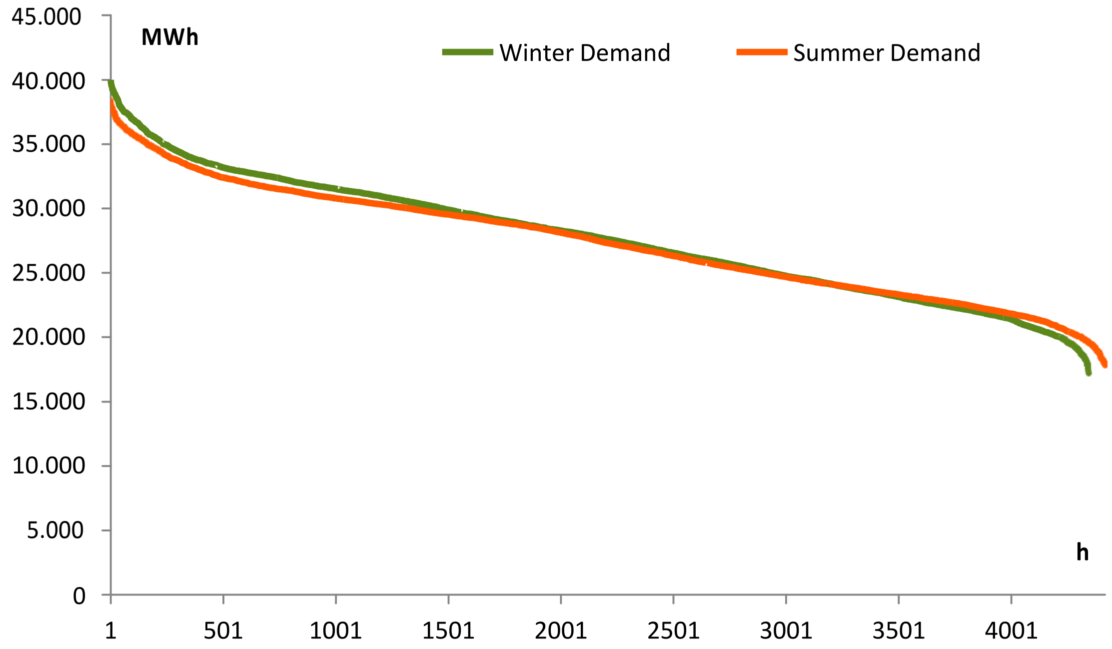

Figure 3.6: Seasonal Demand Curve in Spain, 2015. Source: REE

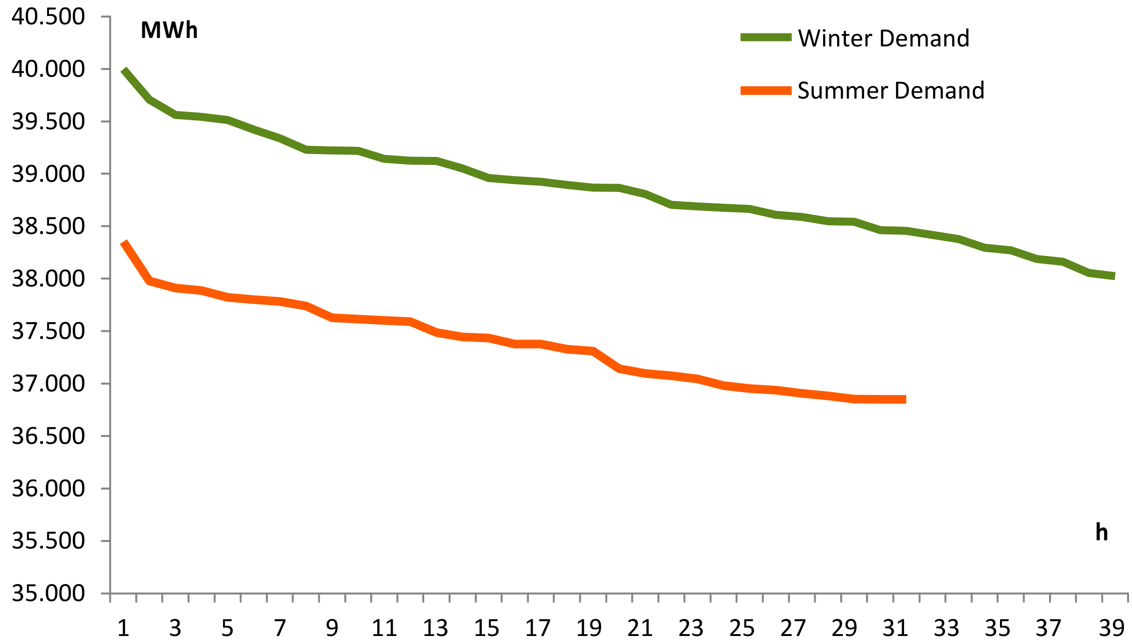

Figure 3.7: Seasonal Peak Demand Curve, 2015. Source:REE

Aggregated Probability of the Wind Generation

Once is has been addressed that the intermittency associated to the Wind generation of a Power system tend to be low compared with a single windmill; the next step in this characterization consist in determining the probability associated to each level of output. The probability for a certain range of output is defined as the number of hours that the wind output is within that range divided by the total number of hours of the period considered.

This definition of probability drives the *Figure 3.8*where the frequency the each range of 200 MW is presented for the year 2015 with the accumulated probability for all the hours of the year.

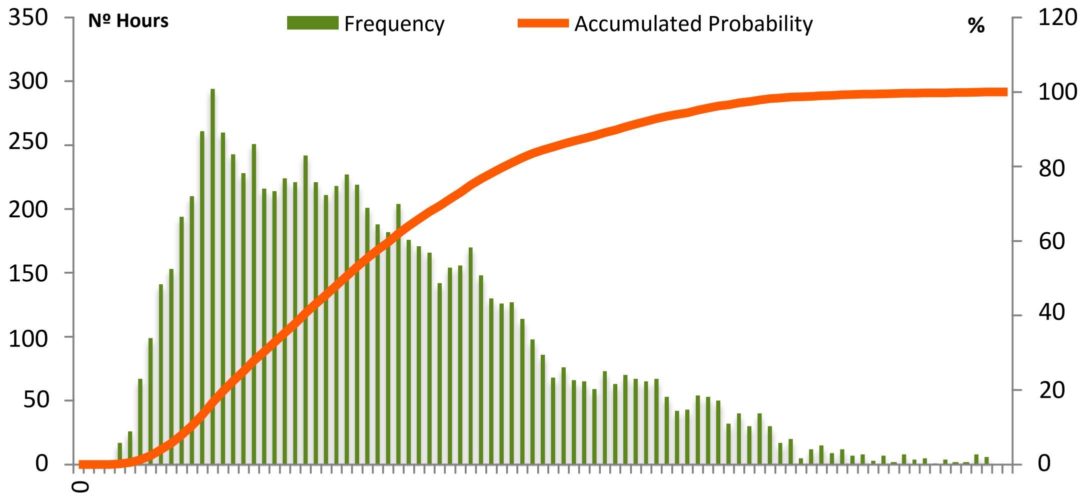

Figure 3.8: Histogram of Wind Technology in Spain, 2015. Source:REE, Own Elaboration

Some results can be obtained from the previous graph:

- The mean value of the wind's output corresponds with a generation range between 2600 and 2800 MW.
- The generation output is above 1800 MW with a probability above 95%. This means that in more than 8250 hours the wind blows strongly enough, no matter in which site of the country, to ensure a level of capacity above 1800 MW.

3.4 Conclusions

The penetration of Windmills in the traditional generation mix has driven the traditional definition of firmness towards a new review in order to have a common tool to assess the capacity of all the generation technologies in the same way. In this scenario the concept of installed capacity is no longer valid a parameter to evaluate the reliability of a generator in the short term. Therefore, the valuation of the firmness goes to first, define a critical period subject to be used as a reference to determine the needs of the system. Secondly, the analysis going to determine firmness in that period not only through the installed capacity, but also through the capacity of the technology to help the system to meet the demand. It also has been shown that although wind generation presents a clear variability in hourly basis the wind is always there and the aggregated production can be evaluated in order to compute its firmness based on its contribution to cover the system needs.

CHAPTER 4: PROBLEM DESCRIPTION

CHAPTER 4: PROPOSED METHOD

4.1 Introduction

The aim of this chapter is to explain the methodology used to evaluate the firmness of the Wind technology in the Spanish Power System. The chapter is structured in three main parts. Firstly, there is an assessment about some of the relevant characteristics of the Wind Generation subject to be considered for the purpose of the Thesis. In the second part, there is an overall explanation about the methodology used by the Spanish system operator in order to compute the firmness of the Wind Technology. The chapter ends with a detailed explanation about the methodology used to compute the firmness in this project and the assumptions consider.

4.2 Characteristics of the Wind Generation in the Spanish Power System

The state that Wind Generation is variable even if aggregated generation is considered is to be evidence. It is also true that wind presents a grade of uncertain, (although thanks to the improvements in forecasting is reducing year after year), because it is not possible to fully predict Wind generation. The consequence of this characteristics of the Wind Technology impacts in a different way according with the level of penetration in the power system; when the share of wind power in a power system is small, these quantities only have a minor impact on the short-term energy balance of the power system. However, if the penetration in the power system is larger, like the case of the Spanish Power System, the role that the wind generation plays on the system requirements increase and therefore the associated variation and uncertainty starts to overshadow the existing variation and uncertainty of the system.

It is clear that the output of the wind generation is determined by the availability of the resource and it presents a variability minute after minute, even stopping the generation in many cases. This intermittence can be mitigated if all the generation windmills are aggregated, therefore in those cases the intermittence of the technology tends to a low value because if in one part of the country there is no wind in other will likely blow and as a consequence the aggregated generation will be greater than zero. In *Table 4.1* is presented the lowest level of the Wind Generation for the last three years, showing this mentioned effect that there is no hour when the generation in the whole system is zero [ESIO16].

	2013	2014	2015
Minimum Level of Output (MW)	70,4	97,4	586,1

Table 4.1: Minimum Wind Generation in Spain

Due to its variability, Wind Generation introduces more uncertainty in the demand balance problem adding another concern to the system operators. This characteristic has been widely used a negative argument against the Wind Technology obviating the nature of the problematic associated to the balancing of the demand problem, which is defined by a great level of uncertainty and variability. The experience so far has demonstrated that this property can be perfectly managed by the System operators and cases like the Spanish Power are clear example of success (when in the latest step forward Wind Generation is able to participate in the Ancillary Service Market).

The adaptation of the Wind technology to the generation mix and its contribution to meet the demand has demonstrated that despite its variability can be perfectly managed to be part of the solution and not the problem. It is obvious that each technology presents its own characteristics different from the others, which some of them will fit better for some scenarios than for others. This is intrinsic to each technology, for instance the nuclear are great provider of energy but not fit properly to follow the demand, and however nobody criticize them for it. The reality is that a well-developed and diversified generation mix provides more resources to the operation of the system and eases the managing of the problem. Moreover, when the system is well developed and stable, the addition of any facility does not imply a bigger problem. It may imply a non-optimal solution, if that new facility is not needed, but not a bigger or worse problem, which is only covering the demand [OMIE16].

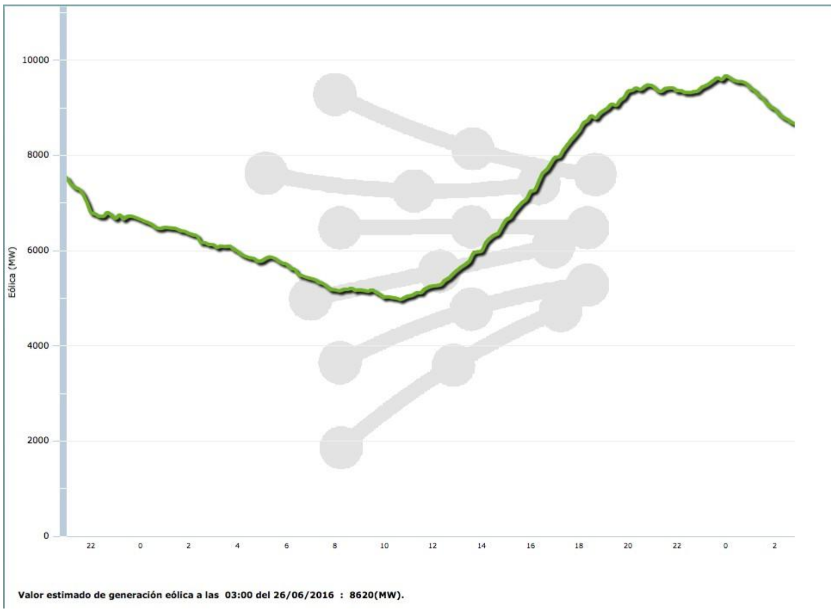

Figure 4.1: Variability of Wind Generation. Source: OMIE

The fact that Wind Generation is part of the solution and not the problem is reinforced with the contribution that provides to cover the system energy requirement. Looking at the figures of the last year 2015 in the Spanish power System, Wind Generation is ranking in the third position in terms of the demand share. Furthermore, this contribution is more significant in days where the demand is highest, being in most of days the principal agent in covering the energy needs. Both these facts can be shown in the following figure that corresponds to the Spanish Power System for the year 2015 [REE_15].

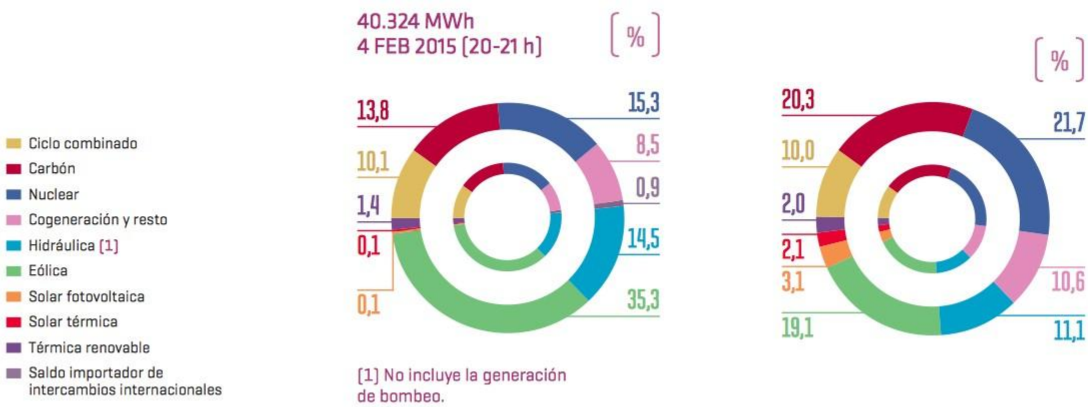

Figure 4.2: Wind Generation demand Share. Source: REE

*Figure 4.3*shows how in some cases the Wind Generation is able to cover a demand share around 60% [REE_16].

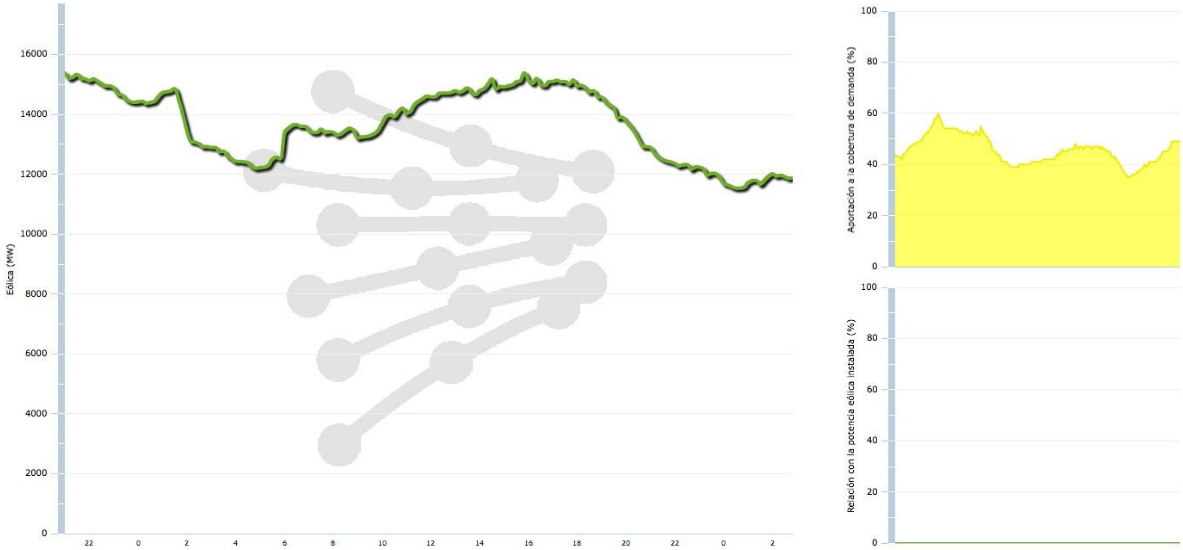

Figure 4.3: Daily production and demand share of Wind Technology: Source:REE

4.3 Current Wind Generation Firmness in the Spanish Power

As it was explained in the previous point Wind's production changes a lot from one hour to the other, however this technology, despite of the variability, is a provider of energy that contributes to meet the energy requirements of the system, diminishing the demand load curve that the system have to meet and as a consequence the contribution of others technologies. This effect is shown in the *Figure 4.4* that presents the chronological evolution of the demand and the residual demand that the system have to cover after the Wind's contribution.

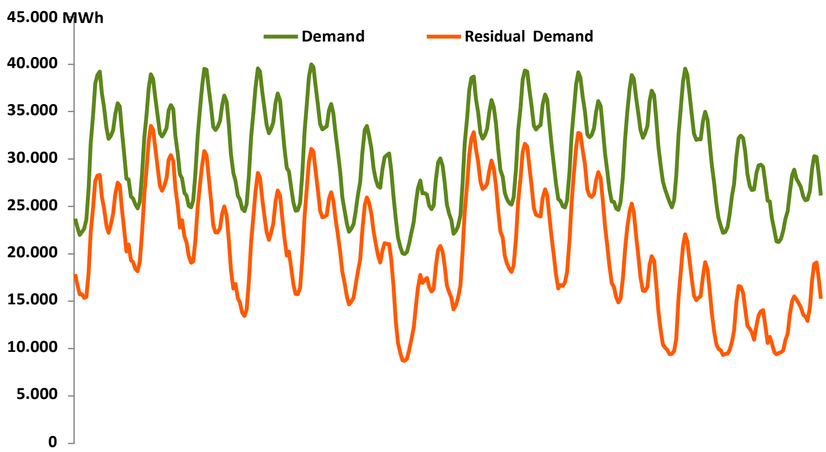

Figure 4.4: Chronological curve of the demand and Wind Generation. Source: REE

This contribution can be seen from another perspective looking at the load duration curve which traditionally is used to identify the long term optimum technology mix, the one that fits better to the system needs, and the residual demand curved, which is the load duration curve minus the wind contribution. *Figure 4.5* shows this relationship for the year 2015.

The results show that the effect of the wind in the load is statistically similar to the effect produced by a base load technology despite the known variability. The main difference between a wind and traditional base load technologies is that peak and Off Peak hours may end not being the same hours. Therefore the energy contribution to the system demand's requirements is a fact because the wind is always there, it may blow later or sooner, may cover a higher or lower level of demand share but it is a reliable provider of energy in annual basis. In fact a superficial analysis of the wind generation of the year 2015 shown that in average terms cover a percentage above a 20% of the demand share and with a net equivalent hours greater than 2150 hours.

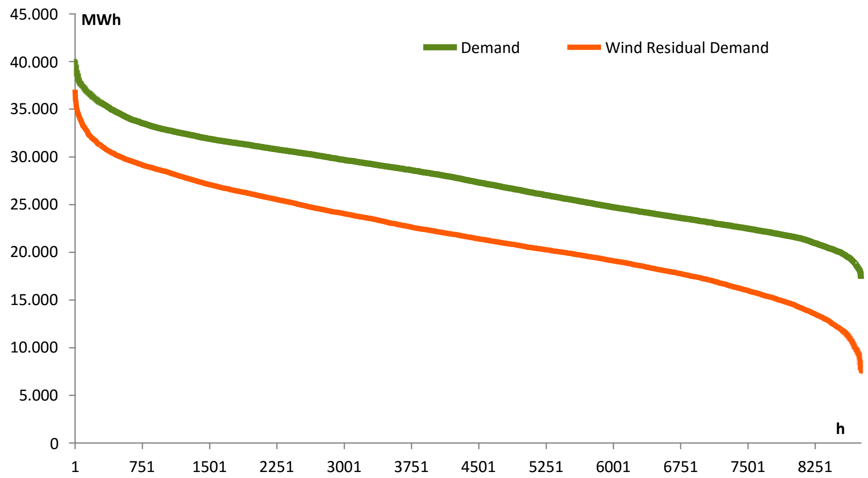

Figure 4.5: Load Duration and Residual Demand Curve. Source: REE

Therefore the Wind technology is variable and present a level of uncertainty, nevertheless is a reliable provider of energy in annual basis and consequently the Spanish System operator considers this technology for reliability purpose. Therefore the System operator evaluates the Wind Technology in order to compute its firmness. The methodology used for that purpose, roughly speaking consists in determine the firmness through a historical analysis of the capacity factor in the 95% of the total hours of the year. The result of this computation ends up with a firmness value of 7% of the capacity factor that corresponds, in terms of capacity, with a value of 1600 MW above an installed capacity of 23000 MW [REE_16] [BOE_11].

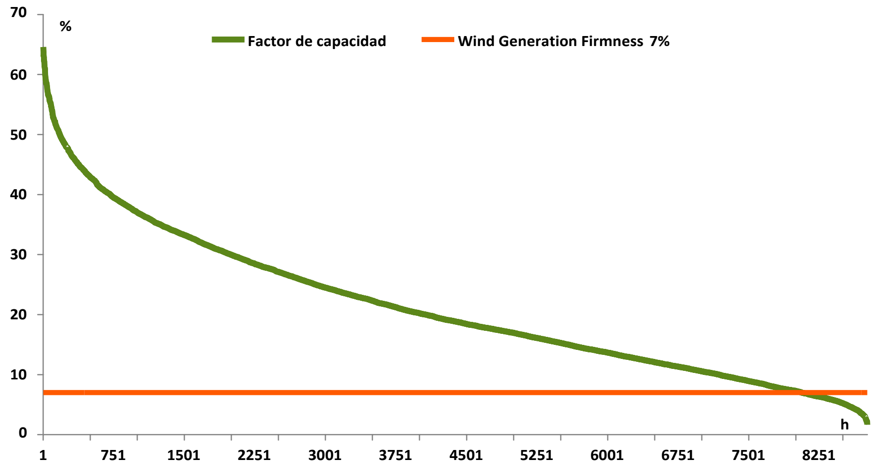

Figure 4.6: Determination of Wind Technology Firmness in the Spanish Power System. Source: REE

4.4 Methodology implemented in the project

The assessment of the wind firmness has been realized for the years 2013, 2014 and 2015 based on a probabilistic method of the peak hours. The reason of analyzing the peak hours is due to the definition of the firmness that is defined as "The available capacity to produce when is needed" and the own definition that the Spanish System operator make to define the availability product the "La cobertura de las horas pico en el Sistema para promover y mantener las condiciones en que se basa la seguridad del suministro en el corto y medio plazo" (*Coverage of the peak hours in the system to promote and maintain the conditions that underpin security of supply in the short and medium term)*[BOE_07]. Therefore, due to these two considerations the analysis is carried out in the peak when the system is likely to be more stressed. It is a fact that there are other scenarios where the system may be stressed, such as a case of drought when the hydro production is low, but for the sake of simplicity the analysis is considering the demand as the only driver to determine the stressed situation of the system. Moreover, before the analysis of the Peak Hours the same methodology has been used to determine the "firmness" of the Wind Technology associated to different levels of the demand.

The methodology is a probabilistic method that consists on determining the Wind Technology firmness through its contribution to cover the system needs subject to a level of probability that allows being confident to the results obtained. The steps carried out to obtain a value are explained in the point 4.4.2, but before explaining the methodology there is an explanation about the assumptions considered for the implemented methodology.

4.4.1 Assumptions

- There is no variation in Wind installed capacity during the years 2013, 2014 and 2015.
- The peak hours are determined as the number of hours within the range formed by maximum demand value of the 3 years and the 95% of that value.
- The demand has been divided in intervals of 1.000 MW for sake of simplicity.
- The demand below 20.000 MWh has been gathered in the first demand interval for sake of simplicity too.
- There are other scenarios where the system is subject to be stressed but for this analysis the demand is considered the only driver.

4.4.2 Steps of the process

1º Access to the historical data

The Spanish System operator publishes in its website www.esios.es among much other information in the settlement files the historical data of the Wind Generation and demand. Therefore for the aim of the thesis the data corresponding to the years 2013, 2014 and 2015 are downloaded.

2º Analysis of the firmness in all the hours of the year

This first step consists on characterizing the output of Wind Generation in all the hours of the year according to the level of demand in the system. The objective is to determine the Wind technology firmness for each level of the demand based on the probability of each scenario previously defined. The construction of the scenarios is based on the intervals of the Wind Generation output and the level of the demand. To ease the analysis the different scenarios are constructed based on demand intervals of 1.000 MW, and the same for the Wind generation output. The detailed process to compute the firmness is explained below:

1. Construction of a matrix that define the different scenarios that will be evaluated. Each scenario relates Wind generation output with a different level of

demand in such a way that a matrix likes *Figure 4.7* is obtained. In the columns are shown the different intervals associated to the demand while in the rows the intervals of wind generation. Each scenario is determined by the intersection of a level of the demand and a level of wind generation output. Notice again that the load ranges cover all the spectrum of the demand but for simplicity purpose all the values below 20.000MWh are aggregated in that scenario and in the case of Wind Generation output the different levels along the year are explicitly shown, from zero to the maximum level of output that is lower for all the cases than 18.000 MWh.

Wind Generation Output	Level Of Demand																				
0	20000	21000	22000	23000	24000	25000	26000	27000	28000	29000	30000	31000	32000	33000	34000	35000	36000	37000	38000	39000	40000
500																					
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Figure 4.7: Matrix of the Scenarios

2º Once the matrix is compute the next step is to determine the number of hours that each scenario takes places in the year in such a way that at the end a matrix like *Figure 4.8* is obtained with all the hours of the year are distributed among the scenarios.

Wind Generation Output	Level of Demand (MWh)																				
0	20.000	21.000	22.000	23.000	24.000	25.000	26.000	27.000	28.000	29.000	30.000	31.000	32.000	33.000	34.000	35.000	36.000	37.000	38.000	39.000	40.000
500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.000	0	0	2	0	3	0	3	2	6	1	2	5	6	4	3	0	3	2	2	0	0
1.500	1	12	16	13	11	10	9	9	16	16	20	29	30	13	15	5	0	2	3	0	0
2.000	3	7	16	28	33	30	35	19	36	33	24	57	36	25	12	12	10	7	1	0	0
2.500	17	12	33	50	46	44	41	31	37	37	42	56	62	33	25	4	13	12	8	0	0
3.000	22	33	38	51	61	57	44	40	43	40	42	45	49	28	26	20	14	8	3	1	0
3.500	12	21	37	51	48	43	33	45	42	33	46	42	35	39	22	14	9	3	4	1	0
4.000	16	18	30	49	53	48	40	29	36	41	46	41	35	27	14	10	8	5	5	2	0
4.500	22	20	25	43	50	49	36	38	27	45	44	36	45	30	20	14	8	14	3	0	0
5.000	12	20	24	38	33	47	41	49	40	35	38	40	38	33	16	15	13	5	6	1	0
5.500	16	23	19	42	39	30	50	39	32	45	47	42	50	26	16	9	12	5	1	2	0
6.000	12	15	19	33	35	37	28	20	40	31	38	41	41	35	15	16	7	5	2	2	0
6.500	18	26	25	40	32	31	27	28	21	33	35	49	32	36	14	12	4	5	1	1	1
7.000	21	23	13	28	21	26	24	31	28	37	37	26	18	22	11	9	5	4	3	1	0
7.500	25	14	30	34	32	32	31	25	32	24	28	29	27	10	5	18	6	4	3	1	0
8.000	11	13	20	31	25	28	24	21	19	26	31	25	23	18	14	13	2	1	0	1	2
8.500	3	5	27	26	28	29	21	21	15	33	30	17	20	14	6	10	5	3	2	0	0
9.000	7	8	11	16	15	18	26	19	9	28	24	15	10	8	12	1	2	1	1	2	2
9.500	0	5	5	12	8	18	9	6	11	13	19	14	18	4	17	3	5	0	3	0	3
10.000	0	3	10	14	17	8	12	12	13	18	12	7	8	11	4	4	3	2	0	2	1
10.500	2	8	9	11	20	8	16	8	8	9	10	15	16	9	8	4	1	5	5	0	0
11.000	0	7	7	10	10	14	9	11	7	14	14	12	6	13	14	3	5	4	2	3	1
11.500	1	5	9	6	15	7	8	9	8	17	9	13	13	4	8	1	3	3	2	0	2
12.000	4	3	5	6	11	13	4	11	3	9	7	5	16	4	3	3	4	5	0	0	0
12.500	1	1	4	3	6	10	5	11	8	11	8	14	14	8	11	1	0	4	5	0	0
13.000	0	1	2	12	1	3	2	4	9	6	1	9	6	8	5	1	4	2	4	0	0
13.500	0	0	0	2	5	4	1	5	3	13	5	7	4	8	5	2	4	4	4	2	0
14.000	0	0	3	0	1	2	0	5	2	1	4	2	2	5	1	1	1	1	2	1	0
14.500	0	0	0	2	0	1	1	1	1	1	3	2	1	7	7	1	3	2	0	1	0
15.000	0	0	0	0	2	2	3	1	0	2	1	0	1	3	0	1	2	3	0	0	0
15.500	0	0	0	0	0	1	1	2	3	1	2	1	0	2	0	1	0	0	0	0	0
16.000	0	0	0	0	0	0	2	1	1	2	2	0	1	2	1	2	0	0	0	0	0
16.500	0	0	0	0	0	0	1	1	1	3	0	0	0	2	0	1	0	0	0	0	0
17.000	0	0	0	0	0	0	0	1	0	0	0	1	0	4	1	0	0	0	0	0	0
17.500	0	0	0	0	0	0	0	0	1	1	1	0	1	2	0	2	1	2	1	1	1
18.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0

Figure 4.8: Number of hours of each scenario

3º Once the number of hours of each scenario is defined, the next step is to compute the probability of each scenario for each level of the demand. The probability is defined as the number of hours of each scenario divided by the number of hours of the year. The matrix obtained is shown in *Figure 4.9*.

Wind Generation Output	Level of Demand (MWh)																				
0	20.000	21.000	22.000	23.000	24.000	25.000	26.000	27.000	28.000	29.000	30.000	31.000	32.000	33.000	34.000	35.000	36.000	37.000	38.000	39.000	40.000
500	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
1.000	0,0	0,0	0,5	0,0	0,5	0,0	0,5	0,4	1,1	0,2	0,3	0,7	0,9	0,8	0,9	0,0	1,9	1,6	2,6	0,0	0,0
1.500	0,4	4,0	3,6	2,0	1,7	1,5	1,5	1,6	2,9	2,4	3,0	4,2	4,5	2,6	4,5	2,3	0,0	1,6	3,9	0,0	0,0
2.000	1,3	2,3	3,6	4,3	5,0	4,6	6,0	3,4	6,5	5,0	3,6	8,2	5,4	5,0	3,6	5,6	6,4	5,6	1,3	0,0	0,0
2.500	7,5	4,0	7,5	7,7	7,0	6,8	7,0	5,6	6,6	5,6	6,3	8,0	9,3	6,6	7,6	1,9	8,3	9,7	10,5	0,0	0,0
3.000	9,7	10,9	8,7	7,8	9,2	8,8	7,5	7,2	7,7	6,1	6,3	6,5	7,4	5,6	7,9	9,4	8,9	6,5	3,9	3,8	0,0
3.500	5,3	6,9	8,4	7,8	7,3	6,6	5,6	8,1	7,5	5,0	6,8	6,0	5,3	7,8	6,6	6,6	5,7	2,4	5,3	3,8	0,0
4.000	7,1	5,9	6,8	7,5	8,0	7,4	6,8	5,2	6,5	6,2	6,8	5,9	5,3	5,4	4,2	4,7	5,1	4,0	6,6	7,7	0,0
4.500	9,7	6,6	5,7	6,6	7,6	7,5	6,1	6,8	4,8	6,8	6,5	5,2	6,8	6,0	6,0	6,6	5,1	11,3	3,9	0,0	0,0
5.000	5,3	6,6	5,5	5,8	5,0	7,2	7,0	8,8	7,2	5,3	5,7	5,7	5,7	6,6	4,8	7,0	8,3	4,0	7,9	3,8	0,0
5.500	7,1	7,6	4,3	6,5	5,9	4,6	8,5	7,0	5,7	6,8	7,0	6,0	7,5	5,2	4,8	4,2	7,6	4,0	1,3	7,7	0,0
6.000	5,3	5,0	4,3	5,1	5,3	5,7	4,8	3,6	7,2	4,7	5,7	5,9	6,2	7,0	4,5	7,5	4,5	4,0	2,6	7,7	0,0
6.500	8,0	8,6	5,7	6,1	4,8	4,8	4,6	5,0	3,8	5,0	5,2	7,0	4,8	7,2	4,2	5,6	2,5	4,0	1,3	3,8	7,7
7.000	9,3	7,6	3,0	4,3	3,2	4,0	4,1	5,6	5,0	5,6	5,5	3,7	2,7	4,4	3,3	4,2	3,2	3,2	3,9	3,8	0,0
7.500	11,1	4,6	6,8	5,2	4,8	4,9	5,3	4,5	5,7	3,6	4,2	4,2	4,1	2,0	1,5	8,5	3,8	3,2	3,9	3,8	0,0
8.000	4,9	4,3	4,6	4,8	3,8	4,3	4,1	3,8	3,4	3,9	4,6	3,6	3,5	3,6	4,2	6,1	1,3	0,8	0,0	3,8	15,4
8.500	1,3	1,7	6,2	4,0	4,2	4,5	3,6	3,8	2,7	5,0	4,5	2,4	3,0	2,8	1,8	4,7	3,2	2,4	2,6	0,0	0,0
9.000	3,1	2,6	2,5	2,5	2,3	2,8	4,4	3,4	1,6	4,2	3,6	2,2	1,5	1,6	3,6	0,5	1,3	0,8	1,3	7,7	15,4
9.500	0,0	1,7	1,1	1,8	1,2	2,8	1,5	1,1	2,0	2,0	2,8	2,0	2,7	0,8	5,1	1,4	3,2	0,0	3,9	0,0	23,1
10.000	0,0	1,0	2,3	2,2	2,6	1,2	2,0	2,2	2,3	2,7	1,8	1,0	1,2	2,2	1,2	1,9	1,9	1,6	0,0	7,7	7,7
10.500	0,9	2,6	2,1	1,7	3,0	1,2	2,7	1,4	1,4	1,4	1,5	2,2	2,4	1,8	2,4	1,9	0,6	4,0	6,6	0,0	0,0
11.000	0,0	2,3	1,6	1,5	1,5	2,2	1,5	2,0	1,3	2,1	2,1	1,7	0,9	2,6	4,2	1,4	3,2	3,2	2,6	11,5	7,7
11.500	0,4	1,7	2,1	0,9	2,3	1,1	1,4	1,6	1,4	2,6	1,3	1,9	2,0	0,8	2,4	0,5	1,9	2,4	2,6	0,0	15,4
12.000	1,8	1,0	1,1	0,9	1,7	2,0	0,7	2,0	0,5	1,4	1,0	0,7	2,4	0,8	0,9	1,4	2,5	4,0	0,0	0,0	0,0
12.500	0,4	0,3	0,9	0,5	0,9	1,5	0,9	2,0	1,4	1,7	1,2	2,0	2,1	1,6	3,3	0,5	0,0	3,2	6,6	0,0	0,0
13.000	0,0	0,3	0,5	1,8	0,2	0,5	0,3	0,7	1,6	0,9	0,1	1,3	0,9	1,6	1,5	0,5	2,5	1,6	5,3	0,0	0,0
13.500	0,0	0,0	0,0	0,3	0,8	0,6	0,2	0,9	0,5	2,0	0,7	1,0	0,6	1,6	1,5	0,9	2,5	3,2	5,3	7,7	0,0
14.000	0,0	0,0	0,7	0,0	0,2	0,3	0,0	0,9	0,4	0,2	0,6	0,3	0,3	1,0	0,3	0,5	0,6	0,8	2,6	3,8	0,0
14.500	0,0	0,0	0,0	0,3	0,0	0,2	0,2	0,2	0,2	0,2	0,4	0,3	0,2	1,4	2,1	0,5	1,9	1,6	0,0	3,8	0,0
15.000	0,0	0,0	0,0	0,0	0,3	0,3	0,5	0,2	0,0	0,3	0,1	0,0	0,2	0,6	0,0	0,5	1,3	2,4	0,0	0,0	0,0
15.500	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,4	0,5	0,2	0,3	0,1	0,0	0,4	0,0	0,5	0,0	0,0	0,0	0,0	0,0
16.000	0,0	0,0	0,0	0,0	0,0	0,0	0,3	0,2	0,2	0,3	0,3	0,0	0,2	0,4	0,3	0,9	0,0	0,0	0,0	0,0	0,0
16.500	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,2	0,5	0,0	0,0	0,0	0,4	0,0	0,5	0,0	0,0	0,0	0,0	0,0
17.000	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,0	0,0	0,0	0,1	0,0	0,8	0,3	0,0	0,0	0,0	0,0	0,0	0,0
17.500	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,1	0,0	0,2	0,4	0,0	0,9	0,6	1,6	1,3	3,8	7,7
18.000	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,8	0,0	3,8	0,0

Figure 4.9: Probability of each Scenario

4º Considering the probability obtained, the next step is to compute the aggregated probability for each level of Wind Generation and each level of the demand, in such a way that the probability of producing above 500MWh will be the sum of the probabilities of the other Wind generation level above this value. The probability of each column should be equal to 100%. An example of this step is shown in *Figure 4.10*.

Wind Generation Output	Level of Demand (MWh)																				
0	20.000	21.000	22.000	23.000	24.000	25.000	26.000	27.000	28.000	29.000	30.000	31.000	32.000	33.000	34.000	35.000	36.000	37.000	38.000	39.000	40.000
500	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0
1.000	100,0	100,0	99,5	100,0	99,5	100,0	99,5	99,6	98,9	99,8	99,9	99,3	99,1	99,2	99,1	100,0	98,1	98,4	97,4	100,0	100,0
1.500	99,6	96,0	95,9	98,0	97,9	98,5	98,0	98,0	96,1	97,4	97,0	95,1	94,6	96,6	94,6	97,7	98,1	96,8	93,4	100,0	100,0
2.000	98,2	93,7	92,3	93,7	92,9	93,8	92,0	94,6	89,6	92,4	93,3	86,9	89,2	91,5	90,9	92,0	91,7	91,1	92,1	100,0	100,0
2.500	90,7	89,8	84,7	86,0	85,9	87,1	85,0	89,0	83,0	86,8	87,1	78,9	79,8	84,9	83,4	90,1	83,4	81,5	81,6	100,0	100,0
3.000	81,0	78,9	76,1	78,2	76,7	78,5	77,5	81,8	75,3	80,7	80,8	72,5	72,4	79,3	75,5	80,8	74,5	75,0	77,6	96,2	100,0
3.500	75,7	71,9	67,7	70,4	69,4	71,7	71,9	73,7	67,7	75,7	74,0	66,4	67,2	71,4	68,9	74,2	68,8	72,6	72,4	92,3	100,0
4.000	68,6	66,0	60,8	62,8	61,4	64,3	65,1	68,5	61,3	69,5	67,1	60,5	61,9	66,0	64,7	69,5	63,7	68,5	65,8	84,6	100,0
4.500	58,8	59,4	55,1	56,2	53,9	56,8	58,9	61,6	56,5	62,7	60,6	55,4	55,1	60,0	58,6	62,9	58,6	57,3	61,8	84,6	100,0
5.000	53,5	52,8	49,7	50,4	48,9	49,5	52,0	52,8	49,3	57,4	54,9	49,6	49,4	53,3	53,8	55,9	50,3	53,2	53,9	80,8	100,0
5.500	46,5	45,2	45,3	43,9	43,0	44,9	43,4	45,8	43,5	50,5	47,9	43,6	41,9	48,1	48,9	51,6	42,7	49,2	52,6	73,1	100,0
6.000	41,2	40,3	41,0	38,9	37,7	39,2	38,7	42,2	36,4	45,8	42,3	37,7	35,7	41,0	44,4	44,1	38,2	45,2	50,0	65,4	100,0
6.500	33,2	31,7	35,3	32,7	32,8	34,5	34,1	37,1	32,6	40,8	37,1	30,7	30,9	33,8	40,2	38,5	35,7	41,1	48,7	61,5	92,3
7.000	23,9	24,1	32,3	28,4	29,7	30,5	30,0	31,5	27,6	35,2	31,4	27,0	28,2	29,4	36,9	34,3	32,5	37,9	44,7	57,7	92,3
7.500	12,8	19,5	25,5	23,2	24,8	25,5	24,7	27,0	21,9	31,6	27,2	22,8	24,1	27,4	35,3	25,8	28,7	34,7	40,8	53,8	92,3
8.000	8,0	15,2	21,0	18,4	21,0	21,2	20,6	23,2	18,5	27,6	22,6	19,2	20,6	23,7	31,1	19,7	27,4	33,9	40,8	50,0	76,9
8.500	6,6	13,5	14,8	14,4	16,8	16,8	17,0	19,5	15,8	22,6	18,2	16,8	17,6	20,9	29,3	15,0	24,2	31,5	38,2	50,0	76,9
9.000	3,5	10,9	12,3	12,0	14,5	14,0	12,6	16,0	14,2	18,4	14,6	14,6	16,1	19,3	25,7	14,6	22,9	30,6	36,8	42,3	61,5
9.500	3,5	9,2	11,2	10,1	13,3	11,2	11,1	15,0	12,2	16,4	11,8	12,6	13,4	18,5	20,5	13,1	19,7	30,6	32,9	42,3	38,5
10.000	3,5	8,3	8,9	8,0	10,7	10,0	9,0	12,8	9,9	13,7	10,0	11,6	12,2	16,3	19,3	11,3	17,8	29,0	32,9	34,6	30,8
10.500	2,7	5,6	6,8	6,3	7,7	8,8	6,3	11,4	8,4	12,3	8,5	9,5	9,8	14,5	16,9	9,4	17,2	25,0	26,3	34,6	30,8
11.000	2,7	3,3	5,2	4,8	6,2	6,6	4,8	9,4	7,2	10,2	6,4	7,7	8,9	11,9	12,7	8,0	14,0	21,8	23,7	23,1	23,1
11.500	2,2	1,7	3,2	3,8	3,9	5,5	3,4	7,7	5,7	7,6	5,1	5,9	6,9	11,1	10,3	7,5	12,1	19,4	21,1	23,1	7,7
12.000	0,4	0,7	2,1	2,9	2,3	3,5	2,7	5,8	5,2	6,2	4,0	5,2	4,5	10,3	9,4	6,1	9,6	15,3	21,1	23,1	7,7
12.500	0,0	0,3	1,1	2,5	1,4	2,0	1,9	3,8	3,8	4,6	2,8	3,2	2,4	8,7	6,0	5,6	9,6	12,1	14,5	23,1	7,7
13.000	0,0	0,0	0,7	0,6	1,2	1,5	1,5	3,1	2,2	3,6	2,7	1,9	1,5	7,0	4,5	5,2	7,0	10,5	9,2	23,1	7,7
13.500	0,0	0,0	0,7	0,3	0,5	0,9	1,4	2,2	1,6	1,7	1,9	0,9	0,9	5,4	3,0	4,2	4,5	7,3	3,9	15,4	7,7
14.000	0,0	0,0	0,0	0,3	0,3	0,6	1,4	1,3	1,3	1,5	1,3	0,6	0,6	4,4	2,7	3,8	3,8	6,5	1,3	11,5	7,7
14.500	0,0	0,0	0,0	0,0	0,3	0,5	1,2	1,1	1,1	1,4	0,9	0,3	0,5	3,0	0,6	3,3	1,9	4,8	1,3	7,7	7,7
15.000	0,0	0,0	0,0	0,0	0,0	0,2	0,7	0,9	1,1	1,1	0,7	0,3	0,3	2,4	0,6	2,8	0,6	2,4	1,3	7,7	7,7
15.500	0,0	0,0	0,0	0,0	0,0	0,0	0,5	0,5	0,5	0,9	0,4	0,1	0,3	2,0	0,6	2,3	0,6	2,4	1,3	7,7	7,7
16.000	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,4	0,4	0,6	0,1	0,1	0,2	1,6	0,3	1,4	0,6	2,4	1,3	7,7	7,7
16.500	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,2	0,1	0,1	0,2	1,2	0,3	0,9	0,6	2,4	1,3	7,7	7,7
17.000	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,2	0,2	0,1	0,0	0,2	0,4	0,0	0,9	0,6	2,4	1,3	7,7	7,7
17.500	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,8	0,0	3,8	0,0
18.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 4.10: Aggregated Probability for each Level of Wind Output

5º Determination of the Wind technology firmness for each level of demand from those Wind Generation scenarios where the probability is between, the values previously defined as the acceptable level of confidence, 90 and 95 %. The results of the stage are gathered in *Figure 4.11*.

	Wind Firmness	
Demand (GWh)	90%	95%
20	2000	1500
21	2000	1500
22	2000	1500
23	2000	1500
24	2000	1500
25	2000	1500
26	2000	1500
27	2000	1500
28	2000	1500
29	2000	1500
30	2000	1500
31	1500	1000
32	2000	1500
33	2500	2000
34	2000	1500
35	2500	2000
36	2000	1500
37	2000	1500
38	2000	1500
39	3500	3000
40	7500	6000

Figure 4.11: Wind Generation Firmness for each Level of the Demand

3º Assessment of the Wind technology in the peak hours

The assessment of the Wind Generation in the peak hours is carried out in a similar way as the valuation of the whole load curve. This procedure consists on analyzing the wind generation output in those hours considered peak hours.

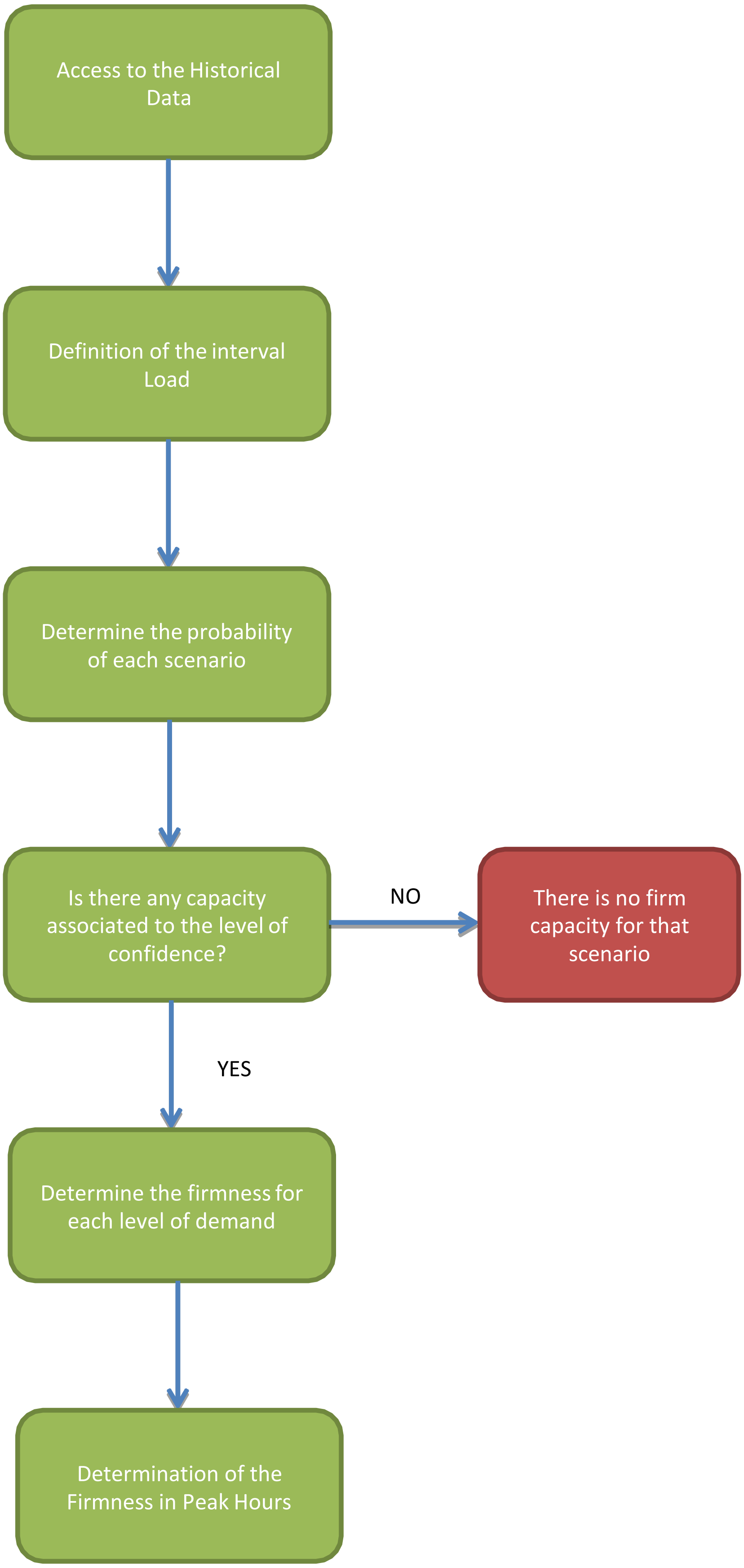

Figure 4.12: Flow Chart of the Methodology

4.5 Conclusions

This methodology implemented to determine the firmness of the Wind Generation evaluate the Wind firmness not along the whole year, but that is based on the definition of criticality of the System Operator to evaluate the contribution to the system needs. Furthermore, the methodology is based on statistically analysis of the historical data similar to the current method carried out by the system operator.

Because it has been considered that when the supply is tight, all capacities contribute to meeting all the demand, and there is no reason to evaluate the firmness in the periods of maximum demand analyzing the behavior along the whole year. Additionally, if there is a mechanism to reward the firmness of the technologies in the peak load periods, it is impossible to identify the power plants that contribute specifically to security of supply; there is no technical justification for a mechanism that does not reward all capacities.

CHAPTER 5:

Results

CHAPTER 5: RESULTS

5.1 Introduction

The aim of this chapter is to present the results obtained in the assessment of wind technology's firmness following the methodology explained in chapter 4. The chapter has been structured in three different parts. Firstly, it is shown the results of the analysis of the firmness in all the hours of the year. The second part shows the result obtained considering the seasonal influence in the wind technology's output. Finally, the chapter ends with the results of the analysis of the firmness in the peak hours of the three years considered.

5.2 Results of the assessment in all the hours of the year

The analysis has been carried out for the year 2013, 2014 and 2015 but for the purpose of simplicity the methodology is explained in detail for the year 2015 whereas for the other years only the results will be presented.

1º Results of the matrix's wind generation-demand scenario

The matrix relates the Wind Generation in each of the different levels of the demand. Each cell corresponds to different levels of demand and shows the number of times, hours, in which each scenario occurs throughout the year.

- The green tones of the cells show the most common scenarios that correspond with a medium-low level of demand and a generation between 2000 and 6000 MWh.
- The red cells correspond to scenarios that rarely/never happen.

W.G (MWh)	Level of Demand (MWh)																				
0	20.000	21.000	22.000	23.000	24.000	25.000	26.000	27.000	28.000	29.000	30.000	31.000	32.000	33.000	34.000	35.000	36.000	37.000	38.000	39.000	40.000
500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.000	0	0	2	0	3	0	3	2	6	1	2	5	6	4	3	0	3	2	2	0	0
1.500	1	12	16	13	11	10	9	9	16	16	20	29	30	13	15	5	0	2	3	0	0
2.000	3	7	16	28	33	30	35	19	36	33	24	57	36	25	12	12	10	7	1	0	0
2.500	17	12	33	50	46	44	41	31	37	37	42	56	62	33	25	4	13	12	8	0	0
3.000	22	33	38	51	61	57	44	40	43	40	42	45	49	28	26	20	14	8	3	1	0
3.500	12	21	37	51	48	43	33	45	42	33	46	42	35	39	22	14	9	3	4	1	0
4.000	16	18	30	49	53	48	40	29	36	41	46	41	35	27	14	10	8	5	5	2	0
4.500	22	20	25	43	50	49	36	38	27	45	44	36	45	30	20	14	8	14	3	0	0
5.000	12	20	24	38	33	47	41	49	40	35	38	40	38	33	16	15	13	5	6	1	0
5.500	16	23	19	42	39	30	50	39	32	45	47	42	50	26	16	9	12	5	1	2	0
6.000	12	15	19	33	35	37	28	20	40	31	38	41	41	35	15	16	7	5	2	2	0
6.500	18	26	25	40	32	31	27	28	21	33	35	49	32	36	14	12	4	5	1	1	1
7.000	21	23	13	28	21	26	24	31	28	37	37	26	18	22	11	9	5	4	3	1	0
7.500	25	14	30	34	32	32	31	25	32	24	28	29	27	10	5	18	6	4	3	1	0
8.000	11	13	20	31	25	28	24	21	19	26	31	25	23	18	14	13	2	1	0	1	2
8.500	3	5	27	26	28	29	21	21	15	33	30	17	20	14	6	10	5	3	2	0	0
9.000	7	8	11	16	15	18	26	19	9	28	24	15	10	8	12	1	2	1	1	2	2
9.500	0	5	5	12	8	18	9	6	11	13	19	14	18	4	17	3	5	0	3	0	3
10.000	0	3	10	14	17	8	12	12	13	18	12	7	8	11	4	4	3	2	0	2	1
10.500	2	8	9	11	20	8	16	8	8	9	10	15	16	9	8	4	1	5	5	0	0
11.000	0	7	7	10	10	14	9	11	7	14	14	12	6	13	14	3	5	4	2	3	1
11.500	1	5	9	6	15	7	8	9	8	17	9	13	13	4	8	1	3	3	2	0	2
12.000	4	3	5	6	11	13	4	11	3	9	7	5	16	4	3	3	4	5	0	0	0
12.500	1	1	4	3	6	10	5	11	8	11	8	14	14	8	11	1	0	4	5	0	0
13.000	0	1	2	12	1	3	2	4	9	6	1	9	6	8	5	1	4	2	4	0	0
13.500	0	0	0	2	5	4	1	5	3	13	5	7	4	8	5	2	4	4	4	2	0
14.000	0	0	3	0	1	2	0	5	2	1	4	2	2	5	1	1	1	1	2	1	0
14.500	0	0	0	2	0	1	1	1	1	1	3	2	1	7	7	1	3	2	0	1	0
15.000	0	0	0	0	2	2	3	1	0	2	1	0	1	3	0	1	2	3	0	0	0
15.500	0	0	0	0	0	1	1	2	3	1	2	1	0	2	0	1	0	0	0	0	0
16.000	0	0	0	0	0	0	2	1	1	2	2	0	1	2	1	2	0	0	0	0	0
16.500	0	0	0	0	0	0	1	1	1	3	0	0	0	2	0	1	0	0	0	0	0
17.000	0	0	0	0	0	0	0	1	0	0	0	1	0	4	1	0	0	0	0	0	0
17.500	0	0	0	0	0	0	0	0	1	1	1	0	1	2	0	2	1	2	1	1	1
18.000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0

Figure 5.1: Number of Hours of each Scenario, 2015

2º Probability of each scenario

This matrix is similar to the previous one but in this case each the results are presented in probabilistic terms.

W.G (MWh)	Probability of each scenario (%)																				
0	20.000	21.000	22.000	23.000	24.000	25.000	26.000	27.000	28.000	29.000	30.000	31.000	32.000	33.000	34.000	35.000	36.000	37.000	38.000	39.000	40.000
500	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
1.000	0,00	0,00	0,02	0,00	0,03	0,00	0,03	0,02	0,07	0,01	0,02	0,06	0,07	0,05	0,03	0,00	0,03	0,02	0,02	0,00	0,00
1.500	0,01	0,14	0,18	0,15	0,13	0,11	0,10	0,10	0,18	0,18	0,23	0,33	0,34	0,15	0,17	0,06	0,00		0,03	0,00	0,00
2.000	0,03	0,08	0,18	0,32	0,38	0,34	0,40	0,22	0,41	0,38	0,27	0,65	0,41	0,29	0,14	0,14	0,11	0,08	0,01	0,00	0,00
2.500	0,19	0,14	0,38	0,57	0,53	0,50	0,47	0,35	0,42	0,42	0,48	0,64	0,71	0,38	0,29	0,05	0,15	0,14	0,09	0,00	0,00
3.000	0,25	0,38	0,43	0,58	0,70	0,65	0,50	0,46	0,49	0,46	0,48	0,51	0,56	0,32	0,30	0,23	0,16	0,09	0,03	0,01	0,00
3.500	0,14	0,24	0,42	0,58	0,55	0,49	0,38	0,51	0,48	0,38	0,53	0,48	0,40	0,45	0,25	0,16	0,10	0,03	0,05	0,01	0,00
4.000	0,18	0,21	0,34	0,56	0,61	0,55	0,46	0,33	0,41	0,47	0,53	0,47	0,40	0,31	0,16	0,11	0,09	0,06	0,06	0,02	0,00
4.500	0,25	0,23	0,29	0,49	0,57	0,56	0,41	0,43	0,31	0,51	0,50	0,41	0,51	0,34	0,23	0,16	0,09	0,16	0,03	0,00	0,00
5.000	0,14	0,23	0,27	0,43	0,38	0,54	0,47	0,56	0,46	0,40	0,43	0,46	0,43	0,38	0,18	0,17	0,15	0,06	0,07	0,01	0,00
5.500	0,18	0,26	0,22	0,48	0,45	0,34	0,57	0,45	0,37	0,51	0,54	0,48	0,57	0,30	0,18	0,10	0,14	0,06	0,01	0,02	0,00
6.000	0,14	0,17	0,22	0,38	0,40	0,42	0,32	0,23	0,46	0,35	0,43	0,47	0,47	0,40	0,17	0,18	0,08	0,06	0,02	0,02	0,00
6.500	0,21	0,30	0,29	0,46	0,37	0,35	0,31	0,32	0,24	0,38	0,40	0,56		0,41	0,16	0,14	0,05	0,06	0,01	0,01	0,01
7.000	0,24	0,26	0,15	0,32	0,24	0,30	0,27	0,35	0,32	0,42	0,42	0,30	0,21	0,25	0,13	0,10	0,06	0,05	0,03	0,01	0,00
7.500	0,29	0,16	0,34	0,39	0,37	0,37	0,35	0,29	0,37	0,27	0,32	0,33	0,31	0,11	0,06	0,21	0,07	0,05	0,03	0,01	0,00
8.000	0,13	0,15	0,23	0,35	0,29	0,32	0,27	0,24	0,22	0,30	0,35	0,29	0,26	0,21	0,16	0,15	0,02	0,01	0,00	0,01	0,02
8.500	0,03	0,06	0,31	0,30	0,32	0,33	0,24	0,24	0,17	0,38	0,34	0,19	0,23	0,16	0,07	0,11	0,06	0,03	0,02	0,00	0,00
9.000	0,08	0,09	0,13	0,18	0,17	0,21	0,30	0,22	0,10	0,32	0,27	0,17	0,11	0,09	0,14	0,01	0,02	0,01	0,01	0,02	0,02
9.500	0,00	0,06	0,06	0,14	0,09	0,21	0,10	0,07	0,13	0,15	0,22	0,16	0,21	0,05	0,19	0,03	0,06	0,00	0,03	0,00	0,03
10.000	0,00	0,03	0,11	0,16	0,19	0,09	0,14	0,14	0,15	0,21	0,14	0,08	0,09	0,13	0,05	0,05	0,03	0,02	0,00	0,02	0,01
10.500	0,02	0,09	0,10	0,13	0,23	0,09	0,18	0,09	0,09	0,10	0,11	0,17	0,18	0,10	0,09	0,05	0,01	0,06	0,06	0,00	0,00
11.000	0,00	0,08	0,08	0,11	0,11	0,16	0,10	0,13	0,08	0,16	0,16	0,14	0,07	0,15	0,16	0,03	0,06	0,05	0,02	0,03	0,01
11.500	0,01	0,06	0,10	0,07	0,17	0,08	0,09	0,10	0,09	0,19	0,10	0,15	0,15	0,05	0,09	0,01	0,03	0,03	0,02	0,00	0,02
12.000	0,05	0,03	0,06	0,07	0,13	0,15	0,05	0,13	0,03	0,10	0,08	0,06	0,18	0,05	0,03	0,03	0,05	0,06	0,00	0,00	0,00
12.500	0,01	0,01	0,05	0,03	0,07	0,11	0,06	0,13	0,09	0,13	0,09	0,16	0,16	0,09	0,13	0,01	0,00	0,05	0,06	0,00	0,00
13.000	0,00	0,01	0,02	0,14	0,01	0,03	0,02	0,05	0,10	0,07	0,01	0,10	0,07	0,09	0,06	0,01	0,05	0,02	0,05	0,00	0,00
13.500	0,00	0,00	0,00	0,02	0,06	0,05	0,01	0,06	0,03	0,15	0,06	0,08	0,05	0,09	0,06	0,02	0,05	0,05	0,05	0,02	0,00
14.000	0,00	0,00	0,03	0,00	0,01	0,02	0,00	0,06	0,02	0,01	0,05	0,02	0,02	0,06	0,01	0,01	0,01	0,01	0,02	0,01	0,00
14.500	0,00	0,00	0,00	0,02	0,00	0,01	0,01	0,01	0,01	0,01	0,03	0,02	0,01	0,08	0,08	0,01	0,03	0,02	0,00	0,01	0,00
15.000	0,00	0,00	0,00	0,00	0,02	0,02	0,03	0,01	0,00	0,02	0,01	0,00	0,01	0,03	0,00	0,01	0,02	0,03	0,00	0,00	0,00
15.500	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,02	0,03	0,01	0,02	0,01	0,00	0,02	0,00	0,01	0,00	0,00	0,00	0,00	0,00
16.000	0,00	0,00	0,00	0,00	0,00	0,00	0,02	0,01	0,01	0,02	0,02	0,00	0,01	0,02	0,01	0,02	0,00	0,00	0,00	0,00	0,00
16.500	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,01	0,03	0,00	0,00	0,00	0,02	0,00	0,01	0,00	0,00	0,00	0,00	0,00
17.000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,00	0,00	0,01	0,00	0,05	0,01	0,00	0,00	0,00	0,00	0,00	0,00
17.500	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,01	0,01	0,00	0,01	0,02	0,00	0,02	0,01	0,02	0,01	0,01	0,01
18.000	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,00	0,01	0,00

Figure 5.2: Probability of each Scenario, 2015

3º Aggregated probability of each level of Wind Generation for each demand's scenario

The matrix shows that as the Wind Generation level increased the probability of each ascending scenario decreases. In other words, it would be more probable to expect a wind generation output above 1.000MWh rather than 10.000 MWh.

However, analyzing in detail the results, they show that the Wind Generation associated with the level of confidence between 90 and 95% does not vary from one level of demand to the other. It remains more and less stable for medium-low level of the demand. However, it is seen that when the demand reaches peak values, the level of production associated with the confidence interval increases, being more significant with the highest value of the demand.

0	20000	21000	22000	23000	24000	25000	26000	27000	28000	29000	30000	31000	32000	33000	34000	35000	36000	37000	38000	39000	40000
500	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
1000	100	100	99,54	100	99,55	100	99,49	99,64	98,92	99,85	99,85	99,28	99,1	99,2	99,09	100	98,09	98,39	97,37	100	100
1500	99,56	96,04	95,9	98	97,88	98,46	97,96	98,02	96,06	97,42	97,02	95,12	94,58	96,58	94,56	97,65	98,09	96,77	93,42	100	100
2000	98,23	93,73	92,26	93,7	92,89	93,85	91,99	94,59	89,61	92,41	93,3	86,94	89,16	91,55	90,94	92,02	91,72	91,13	92,11	100	100
2500	90,71	89,77	84,74	86,02	85,93	87,08	85,01	89,01	82,97	86,8	87,05	78,91	79,82	84,91	83,38	90,14	83,44	81,45	81,58	100	100
3000	80,97	78,88	76,08	78,19	76,7	78,46	77,51	81,8	75,27	80,73	80,8	72,45	72,44	79,28	75,53	80,75	74,52	75	77,63	96,15	100
3500	75,66	71,95	67,65	70,35	69,44	71,69	71,89	73,69	67,74	75,72	73,96	66,43	67,17	71,43	68,88	74,18	68,79	72,58	72,37	92,31	100
4000	68,58	66,01	60,82	62,83	61,42	64,31	65,08	68,47	61,29	69,5	67,11	60,55	61,9	66	64,65	69,48	63,69	68,55	65,79	84,62	100
4500	58,85	59,41	55,13	56,22	53,86	56,77	58,94	61,62	56,45	62,67	60,57	55,38	55,12	59,96	58,61	62,91	58,6	57,26	61,84	84,62	100
5000	53,54	52,81	49,66	50,38	48,87	49,54	51,96	52,79	49,28	57,36	54,91	49,64	49,4	53,32	53,78	55,87	50,32	53,23	53,95	80,77	100
5500	46,46	45,21	45,33	43,93	42,97	44,92	43,44	45,77	43,55	50,53	47,92	43,62	41,87	48,09	48,94	51,64	42,68	49,19	52,63	73,08	100
6000	41,15	40,26	41	38,86	37,67	39,23	38,67	42,16	36,38	45,83	42,26	37,73	35,69	41,05	44,41	44,13	38,22	45,16	50	65,38	100
6500	33,19	31,68	35,31	32,72	32,83	34,46	34,07	37,12	32,62	40,82	37,05	30,7	30,87	33,8	40,18	38,5	35,67	41,13	48,68	61,54	92,31
7000	23,89	24,09	32,35	28,42	29,65	30,46	29,98	31,53	27,6	35,2	31,4	26,97	28,16	29,38	36,86	34,27	32,48	37,9	44,74	57,69	92,31
7500	12,83	19,47	25,51	23,2	24,81	25,54	24,7	27,03	21,86	31,56	27,23	22,81	24,1	27,36	35,35	25,82	28,66	34,68	40,79	53,85	92,31
8000	7,965	15,18	20,96	18,43	21,03	21,23	20,61	23,24	18,46	27,62	22,62	19,23	20,63	23,74	31,12	19,72	27,39	33,87	40,79	50	76,92
8500	6,637	13,53	14,81	14,44	16,79	16,77	17,04	19,46	15,77	22,61	18,15	16,79	17,62	20,93	29,31	15,02	24,2	31,45	38,16	50	76,92
9000	3,54	10,89	12,3	11,98	14,52	14	12,61	16,04	14,16	18,36	14,58	14,63	16,11	19,32	25,68	14,55	22,93	30,65	36,84	42,31	61,54
9500	3,54	9,241	11,16	10,14	13,31	11,23	11,07	14,95	12,19	16,39	11,76	12,63	13,4	18,51	20,54	13,15	19,75	30,65	32,89	42,31	38,46
10000	3,54	8,251	8,884	7,988	10,74	10	9,029	12,79	9,857	13,66	9,97	11,62	12,2	16,3	19,34	11,27	17,83	29,03	32,89	34,62	30,77
10500	2,655	5,611	6,834	6,298	7,716	8,769	6,303	11,35	8,423	12,29	8,482	9,469	9,789	14,49	16,92	9,39	17,2	25	26,32	34,62	30,77
11000	2,655	3,3	5,239	4,762	6,203	6,615	4,77	9,369	7,168	10,17	6,399	7,747	8,886	11,87	12,69	7,981	14,01	21,77	23,68	23,08	23,08
11500	2,212	1,65	3,189	3,84	3,933	5,538	3,407	7,748	5,735	7,587	5,06	5,882	6,928	11,07	10,27	7,512	12,1	19,35	21,05	23,08	7,692
12000	0,442	0,66	2,05	2,919	2,269	3,538	2,726	5,766	5,197	6,222	4,018	5,165	4,518	10,26	9,366	6,103	9,554	15,32	21,05	23,08	7,692
12500	0	0,33	1,139	2,458	1,362	2	1,874	3,784	3,763	4,552	2,827	3,156	2,41	8,652	6,042	5,634	9,554	12,1	14,47	23,08	7,692
13000	0	0	0,683	0,614	1,21	1,538	1,533	3,063	2,151	3,642	2,679	1,865	1,506	7,042	4,532	5,164	7,006	10,48	9,211	23,08	7,692
13500	0	0	0,683	0,307	0,454	0,923	1,363	2,162	1,613	1,669	1,935	0,861	0,904	5,433	3,021	4,225	4,459	7,258	3,947	15,38	7,692
14000	0	0	0	0,307	0,303	0,615	1,363	1,261	1,254	1,517	1,339	0,574	0,602	4,427	2,719	3,756	3,822	6,452	1,316	11,54	7,692
14500	0	0	0	0	0,303	0,462	1,193	1,081	1,075	1,366	0,893	0,287	0,452	3,018	0,604	3,286	1,911	4,839	1,316	7,692	7,692
15000	0	0	0	0	0	0,154	0,681	0,901	1,075	1,062	0,744	0,287	0,301	2,414	0,604	2,817	0,637	2,419	1,316	7,692	7,692
15500	0	0	0	0	0	0	0,511	0,541	0,538	0,91	0,446	0,143	0,301	2,012	0,604	2,347	0,637	2,419	1,316	7,692	7,692
16000	0	0	0	0	0	0	0,17	0,36	0,358	0,607	0,149	0,143	0,151	1,61	0,302	1,408	0,637	2,419	1,316	7,692	7,692
16500	0	0	0	0	0	0	0	0,18	0,179	0,152	0,149	0,143	0,151	1,207	0,302	0,939	0,637	2,419	1,316	7,692	7,692
17000	0	0	0	0	0	0	0	0	0,179	0,152	0,149	0	0,151	0,402	0	0,939	0,637	2,419	1,316	7,692	7,692
17500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0,806	0	3,846	0
18000	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 5.3: Aggregated Probability for each Level of Wind Generation and Demand Level, 2015

4º Determination of wind generation firmness for each level of the demand

The firmness value of wind generation for each level of demand is computed considering those scenarios where the probability is between 90 and 95 %, take into consideration that the value of the firmness correspond to the Wind Generation level considered in this thesis and therefore in a proxy. The results for each level of demand are presented in the *Figure 5.3*and can be conclude that:

- The firmness of wind generation is stable for demand's level below 31 GWh, with a value between 1500 and 2000 MW.
- The firmness varies for levels of the demand between 31 and 38 GWh around 2.000 MW.
- In the peak hours, demand requirements above 38 GWh the firmness of the wind generation increases notably and achieves its maximum contribution with the highest values of the demand with a value between 7000 and 7500 MWh.

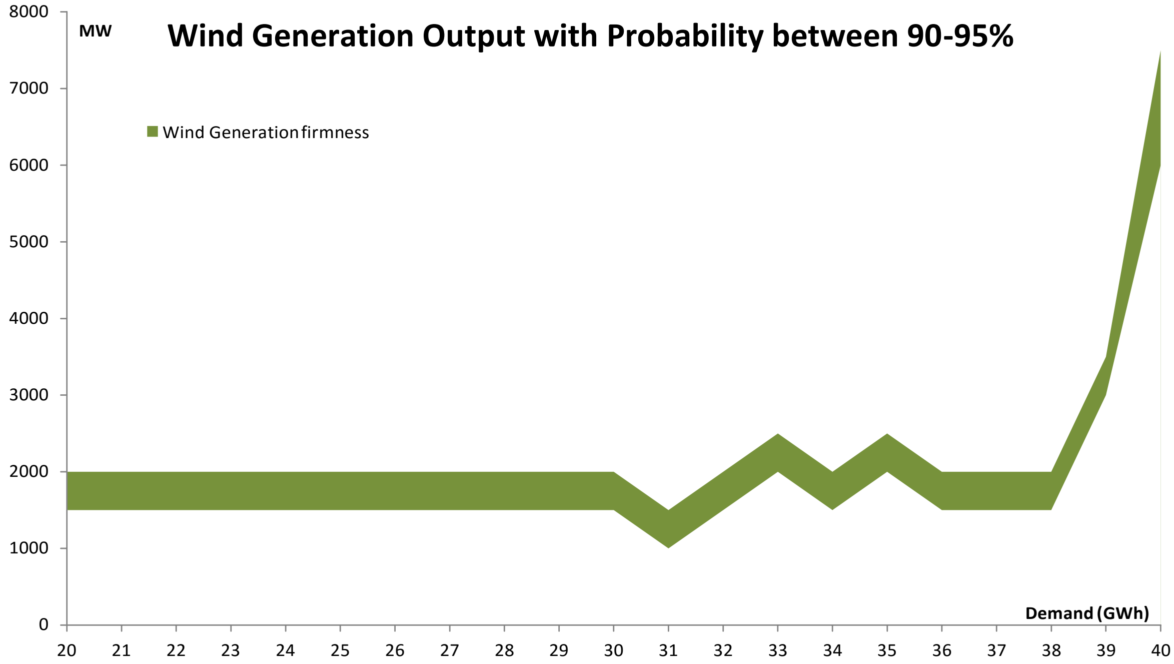

Figure 5.4: Results of Wind Generation Firmness, 2015

Results for the years 2013 and 2014

2013

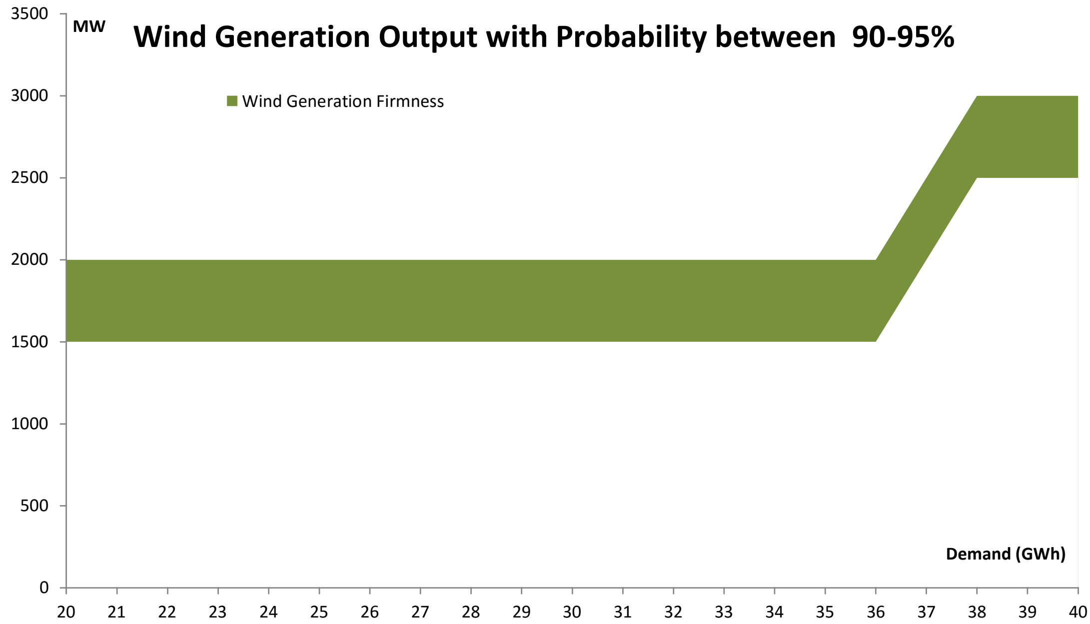

Figure 5.5: Results of Wind Generation Firmness, 2013

2014

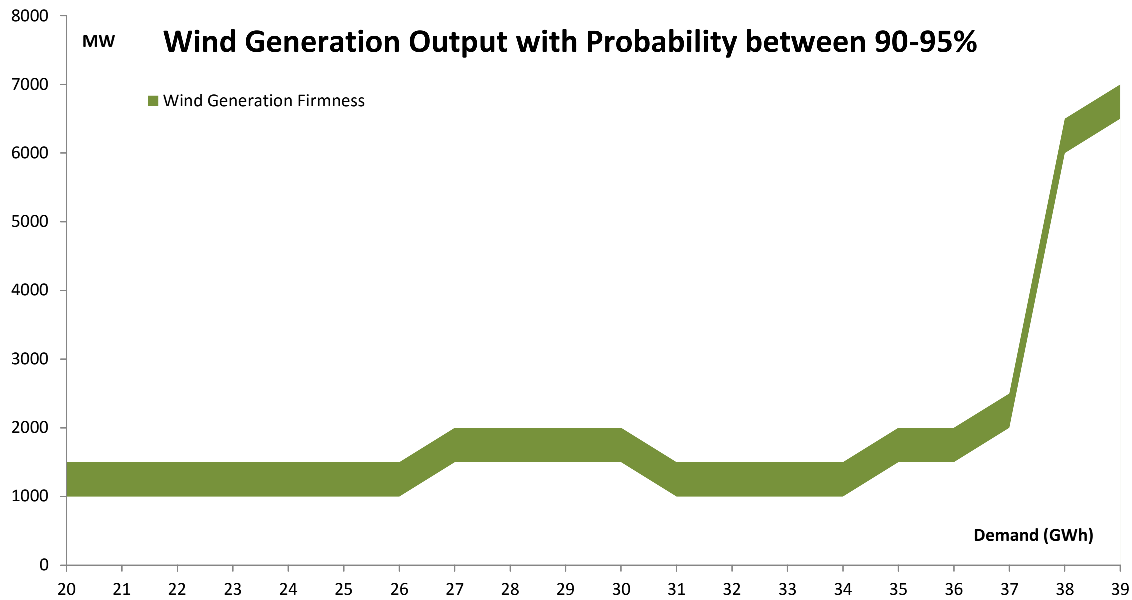

Figure 5.6: Results of Wind Generation Firmness, 2014

In the next table are presented all the results for the 3 years.

	Wind Generation Firmness					
	2013		2014		2015	
Demand(GWh)	90%	95%	90%	95%	90%	95%
20	2000	1500	1500	1000	2000	1500
21	2000	1500	1500	1000	2000	1500
22	2000	1500	1500	1000	2000	1500
23	2000	1500	1500	1000	2000	1500
24	2000	1500	1500	1000	2000	1500
25	2000	1500	1500	1000	2000	1500
26	2000	1500	1500	1000	2000	1500
27	2000	1500	2000	1500	2000	1500
28	2000	1500	2000	1500	2000	1500
29	2000	1500	2000	1500	2000	1500
30	2000	1500	2000	1500	2000	1500
31	2000	1500	1500	1000	1500	1000
32	2000	1500	1500	1000	2000	1500
33	2000	1500	1500	1000	2500	2000
34	2000	1500	1500	1000	2000	1500
35	2000	1500	2000	1500	2500	2000
36	2000	1500	2000	1500	2000	1500
37	2500	2000	2500	2000	2000	1500
38	3000	2500	6500	6000	2000	1500
39	3000	2500	7000	6500	3500	3000
40	3000	2500	NA	NA	7500	6000

Figure 5.7: Summary of the computation of Wind technology Firmness

The results obtained from the analysis of the 3 years are:

- Although independent variables, there is a correlation between the highest values of the demand and the firmness provides by Wind Generation.
- This contribution in peak hours is not stable in the three years, being more significant in years 2014 and 2015.
- The correlation between the demand and Wind Generation can be explained through the thermal sensation, due to the fact that when the wind blows in winter the cold feeling increases and as a consequence the demand is higher.

5.3 Seasonal influence over Wind Generation Firmness

Firstly, the annual evolution of the Wind Generation is presented in order to find the months where the blow is lower in order to evaluate the seasonal impact in the later analysis of influence in the firmness.

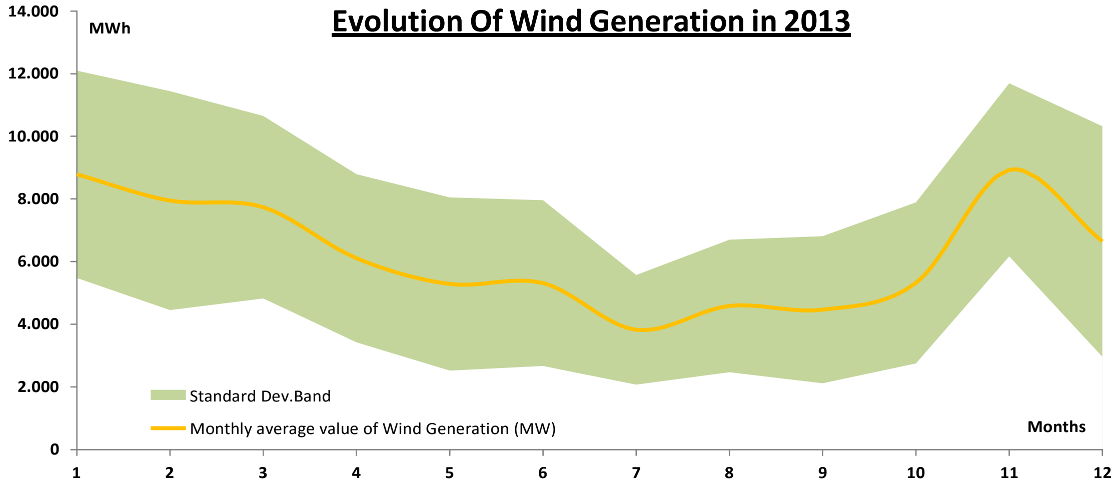

Figure 5.8: Evolution of Wind Generation, 2013

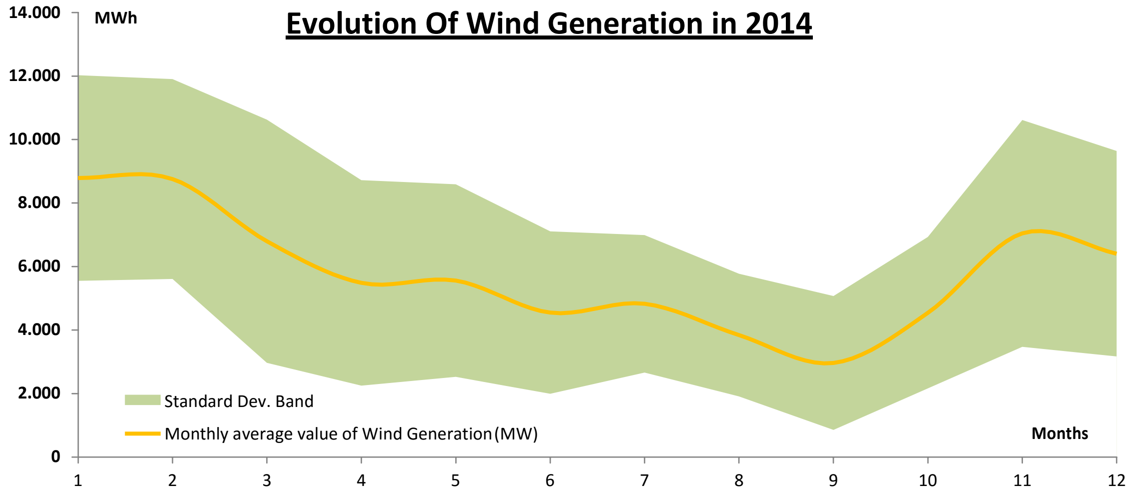

Figure 5.9: Evolution of Wind Generation, 2014

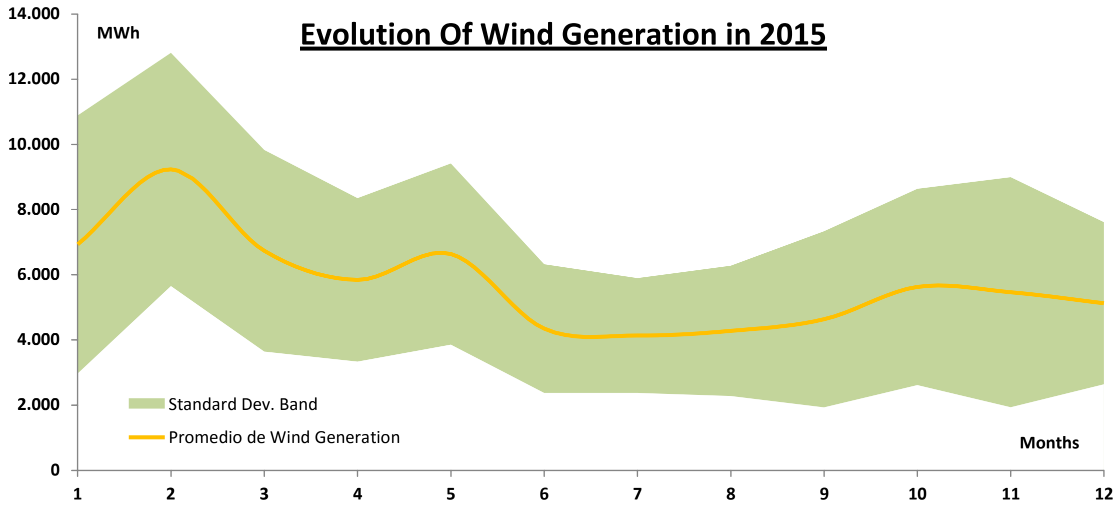

Figure 5.10: Evolution of Wind Generation, 2015

The results of the annual evolution of the Wind Generation show that:

- The lowest level of Wind Generation takes place in the months of June, July and August.
- The standard deviation in the summer months is lower comparing with the winter months where the Wind Generation is more variable.

The seasonal behavior will be carried out with the summer months (June, July and August) and with the winter months (January, February and December). The result of the 3 years analysis is shown in *Figure 5.11*.

	2015				2014				2013			
	Summer		Winter		Summer		Winter		Summer		Winter	
Demand (GWh)	90%	95%	90%	95%	90%	95%	90%	95%	90%	95%	90%	95%
20	500	500	500	500	500	500	500	500	500	500	500	500
21	1.500	1.000	2.500	2.000	1.500	1.000	2.500	2.000	1.500	2.000	5.000	4.500
22	2.000	1.500	2.000	1.500	2.000	1.500	3.500	3.000	2.000	1.500	2.000	1.500
23	2.000	1.500	2.000	1.500	2.000	1.500	2.000	1.500	2.000	1.500	2.000	1.500
24	2.000	1.500	2.500	2.000	2.000	1.500	3.500	3.000	2.000	1.500	3.500	3.000
25	2.000	1.500	2.000	1.500	2.000	1.500	3.500	3.000	2.000	1.500	3.500	3.000
26	2.000	1.500	2.500	2.000	2.000	1.500	2.500	2.000	2.000	1.500	2.500	2.000
27	2.000	1.500	2.500	2.000	2.000	1.500	3.000	2.500	1.500	1.000	3.000	2.500
28	2.000	1.500	2.500	2.000	2.000	1.500	2.500	2.000	2.000	1.500	3.000	2.500
29	2.000	1.500	2.500	2.000	2.000	1.500	3.000	2.500	2.000	1.500	1.000	500
30	2.000	1.500	2.500	2.000	1.500	1.000	2.500	2.000	2.000	1.500	2.500	2.000
31	2.000	1.500	2.000	1.500	2.000	1.500	2.500	2.000	1.500	1.000	1.000	500
32	2.000	1.500	2.000	1.500	1.500	1.000	3.000	2.500	1.500	1.000	2.500	2.000
33	2.000	1.500	2.500	2.000	1.000	1.000	2.500	2.000	1.500	1.000	1.500	1.000
34	1.500	1.000	2.500	2.000	1.000	1.000	3.500	3.000	1.500	1.000	2.500	2.000
35	1.500	1.000	3.000	2.500	1.500	1.000	3.500	3.000	1.000	500	2.500	2.000
36	1.500	1.000	2.500	2.000	1.000	1.000	3.500	3.000	1.000	500	3.000	2.500
37	1.500	1.000	4.000	3.500	2.000	1.500	5.500	5.000	1.000	500	3.000	2.500
38	1.500	1.000	3.000	2.500	NA	NA	6.500	6.000	2.000	1.500	2.500	2.000
39	3.500	3.000	3.500	3.000	NA	NA	7.000	6.500	NA	NA	2.500	2.000
40	NA	NA	7.500	7.000	NA	NA			NA	NA	2.500	2.000

Figure 5.11: Seasonal comparative of the Firmness

The Seasonal analysis shows that:

- In winter months the demand is larger than in summer.

- The firmness in cold months is equal or larger that in summer months for all the levels of the demand. Moreover, the difference between both periods is more significant in the peak hours than in other levels of the demand.

Another analysis that can be made is the difference in the firmness between the winter months and the general assessment in the whole year. The results are presented in *Figure 5.12*.

	2015				2014				2013			
	Winter		Year		Winter		Year		Winter		Year	
Demand (GWh)	90%	95%	90%	95%	90%	95%	90%	95%	90%	95%	90%	95%
20	500	500	2000	1500	500	500	1500	1000	500	500	2000	1500
21	2500	2000	2000	1500	2500	2000	1500	1000	5000	4500	2000	1500
22	2000	1500	2000	1500	3500	3000	1500	1000	2000	1500	2000	1500
23	2000	1500	2000	1500	2000	1500	1500	1000	2000	1500	2000	1500
24	2500	2000	2000	1500	3500	3000	1500	1000	3500	3000	2000	1500
25	2000	1500	2000	1500	3500	3000	1500	1000	3500	3000	2000	1500
26	2500	2000	2000	1500	2500	2000	1500	1000	2500	2000	2000	1500
27	2500	2000	2000	1500	3000	2500	2000	1500	3000	2500	2000	1500
28	2500	2000	2000	1500	2500	2000	2000	1500	3000	2500	2000	1500
29	2500	2000	2000	1500	3000	2500	2000	1500	1000	500	2000	1500
30	2500	2000	2000	1500	2500	2000	2000	1500	2500	2000	2000	1500
31	2000	1500	1500	1000	2500	2000	1500	1000	1000	500	2000	1500
32	2000	1500	2000	1500	3000	2500	1500	1000	2500	2000	2000	1500
33	2500	2000	2500	2000	2500	2000	1500	1000	1500	1000	2000	1500
34	2500	2000	2000	1500	3500	3000	1500	1000	2500	2000	2000	1500
35	3000	2500	2500	2000	3500	3000	2000	1500	2500	2000	2000	1500
36	2500	2000	2000	1500	3500	3000	2000	1500	3000	2500	2000	1500
37	4000	3500	2000	1500	5500	5000	2500	2000	3000	2500	2500	2000
38	3000	2500	2000	1500	6500	6000	6500	6000	2500	2000	3000	2500
39	3500	3000	3500	3000	7000	6500	7000	6500	2500	2000	3000	2500
40	7500	7000	7500	6000					2500	2000	3000	2500

Figure 5.12: Winter and Year comparative of the Firmness

In winter months, as it was expected, due to the higher value of Wind, the firmness in overall terms increases comparing with the yearly analysis. By the contrary in the peak values of the demand there is no significant variation between winter and yearly analysis.

	2015				2014				2013			
	Summer		Year		Summer		Year		Summer		Year	
Demand (GWh)	90%	95%	90%	95%	90%	95%	90%	95%	90%	95%	90%	95%
20	500	500	2000	1500	500	500	1500	1000	500	500	2000	1500
21	1500	1000	2000	1500	1500	1000	1500	1000	1500	2000	2000	1500
22	2000	1500	2000	1500	2000	1500	1500	1000	2000	1500	2000	1500
23	2000	1500	2000	1500	2000	1500	1500	1000	2000	1500	2000	1500
24	2000	1500	2000	1500	2000	1500	1500	1000	2000	1500	2000	1500
25	2000	1500	2000	1500	2000	1500	1500	1000	2000	1500	2000	1500
26	2000	1500	2000	1500	2000	1500	1500	1000	2000	1500	2000	1500
27	2000	1500	2000	1500	2000	1500	2000	1500	1500	1000	2000	1500
28	2000	1500	2000	1500	2000	1500	2000	1500	2000	1500	2000	1500
29	2000	1500	2000	1500	2000	1500	2000	1500	2000	1500	2000	1500
30	2000	1500	2000	1500	1500	1000	2000	1500	2000	1500	2000	1500
31	2000	1500	1500	1000	2000	1500	1500	1000	1500	1000	2000	1500
32	2000	1500	2000	1500	1500	1000	1500	1000	1500	1000	2000	1500
33	2000	1500	2500	2000	1000	1000	1500	1000	1500	1000	2000	1500
34	1500	1000	2000	1500	1000	1000	1500	1000	1500	1000	2000	1500
35	1500	1000	2500	2000	1500	1000	2000	1500	1000	500	2000	1500
36	1500	1000	2000	1500	1000	1000	2000	1500	1000	500	2000	1500
37	1500	1000	2000	1500	2000	1500	2500	2000	1000	500	2500	2000
38	1500	1000	2000	1500	NA	NA	6500	6000	2000	1500	3000	2500
39	3500	3000	3500	3000	NA	NA	7000	6500	NA	NA	3000	2500
40	NA	NA	7500	6000	NA	NA			NA	NA	3000	2500

Figure 5.13: Summer and Year Comparative of the Firmness

The results of the summer months show that Wind Technology firmness decrease. Apparently this result may be considered that impact negatively in the reliability of the system. However, if the summer conditions are analyzed, it is noticeable that the system is less stress mainly because the drop of the demand too. Moreover, in summer the contribution of Solar Technology is higher and quite sure than in winter, especially in the peak hours and therefore the system is even less tight than in winter

Probability distribution:

Regarding the behavior in seasonal and yearly periods it is possible to obtain the distribution function in order to obtain additional results. Therefore, searching in the bibliography it is found that the random values of the Wind Generation can be associated with a Weibull distribution function [WIND12]. The distribution of the data correspond to the analyzed years are presented in *Figure 5.14*, *5.15* and *5.16*.

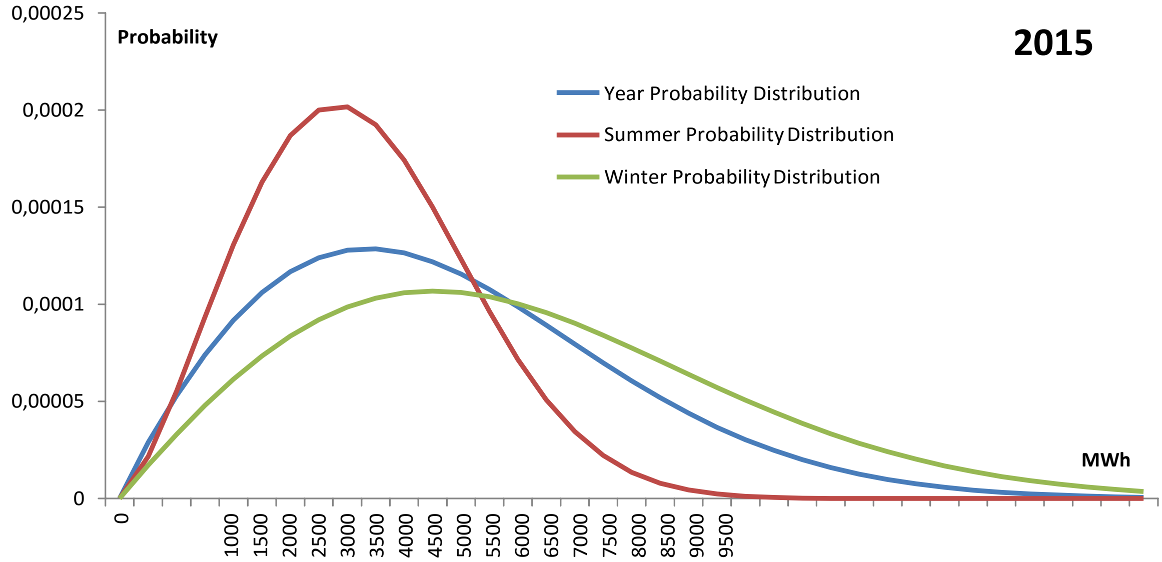

Figure 5.14: Weibull Distribution of Wind Generation year 2015

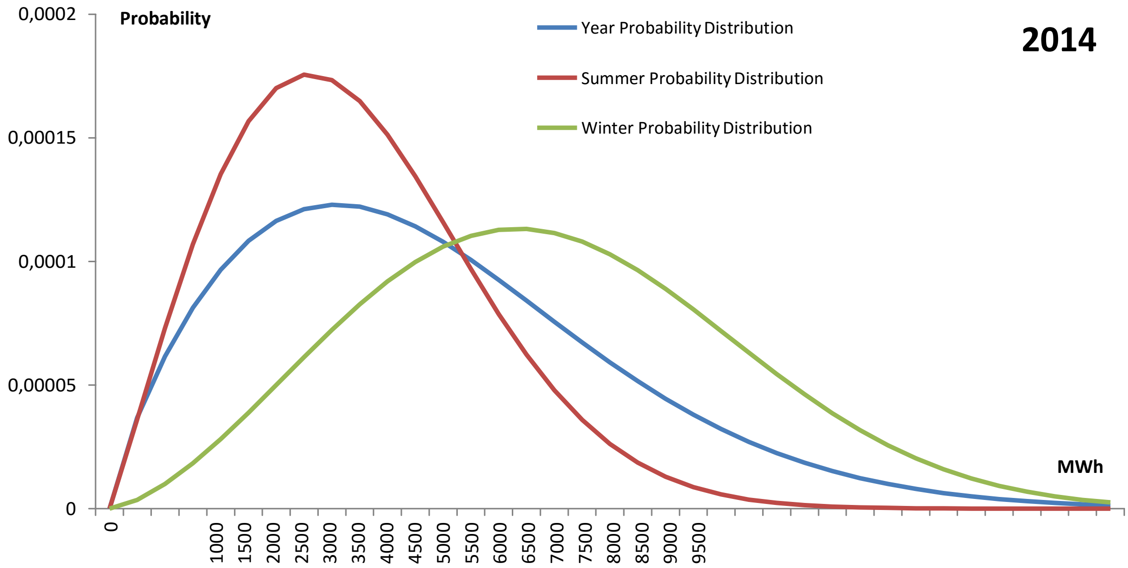

Figure 5.15: Weibull Distribution of Wind Generation year 2014

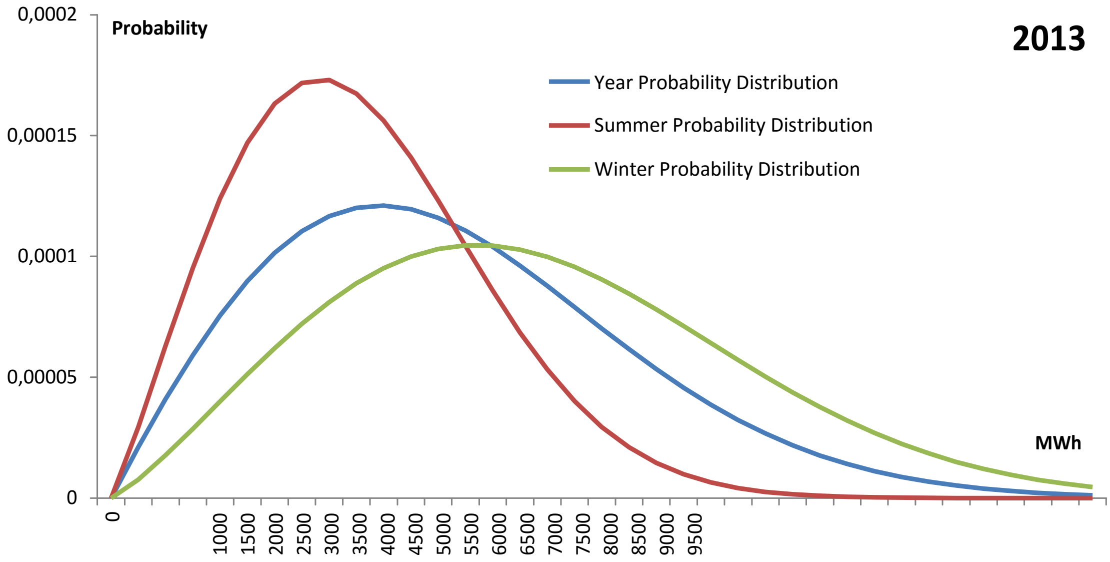

Figure 5.16: Weibull Distribution of Wind Generation year 2013

The results of the distribution functions are aligned with the results obtained in the firmness assessment. Furthermore, other results are extracted from its analysis:

- When the Wind Generation is lower, summer months, the probability distribution curve is more narrow and peaked; therefore the probability of a medium-low level of output is larger than in other periods. Moreover, the probability for outputs larger than 13.000 MWh tends to be zero.
- In winter periods the distribution function is shorter and wider comparing with summer. This result is aligned with the annual evolution of the wind generation in *Figure 5.11* that shows how the standard deviation is larger in cold months comparing with summer. Moreover, the top of the winter's curve is displaced to the right showing that the expected value of Wind Generation is higher than in summer. Finally, for highest value of Wind Generation the probability decrease but does not tend to be zero as it has been shown in the firmness assessment. Regarding with high levels of Wind Generation, it is seen that although the probability decreases it does not reach the zero.
- The annual probability distribution functions present a behavior in the middle between summer and winter curves, which matches with the firmness results.

5.4 Analysis of the peak hours

The final point of this chapter shows the results obtained in the analysis of the 3 years peak hours. The result of this analysis is the core of this master thesis and determines the firmness of the Wind Generation with the consideration that has been taken in this document.

Firstly, it is shown the probabilistic matrix to each scenario of demand and the different level of Wind Generation, *Figure 5.17*.

W.G(MWh)	Probability		
0	38000	39000	40000
500	100	100	100
1000	99,05	100	100
1500	97,63	100	100
2000	95,26	100	100
2500	89,57	96,15	100
3000	86,26	93,59	95,65
3500	82,46	91,03	95,65
4000	78,2	85,9	95,65
4500	76,78	84,62	95,65
5000	71,56	82,05	95,65
5500	69,67	78,21	91,3
6000	67,77	74,36	86,96
6500	66,35	71,79	82,61
7000	62,56	65,38	82,61
7500	58,77	53,85	78,26
8000	51,18	48,72	69,57
8500	44,08	41,03	69,57
9000	37,44	33,33	60,87
9500	33,65	28,21	34,78
10000	31,75	24,36	30,43
10500	28,44	23,08	26,09
11000	25,12	19,23	21,74
11500	19,91	17,95	4,348
12000	17,06	15,38	4,348
12500	13,74	12,82	4,348
13000	10,43	8,974	4,348
13500	7,583	6,41	4,348
14000	4,739	5,128	4,348
14500	3,791	2,564	4,348
15000	1,896	2,564	4,348
15500	0,474	2,564	4,348
16000	0,474	2,564	4,348
16500	0,474	2,564	4,348
17000	0,474	2,564	4,348
17500	0	1,282	0
18000	0	0	0

Figure 5.17: Wind Generation Firmness in Peak Hours of the three analyzed years

The results are aligned with those obtained in the yearly analysis. Therefore, if the firmness associated with each level of the demand is plot, the *Figure 5.18* is obtained.

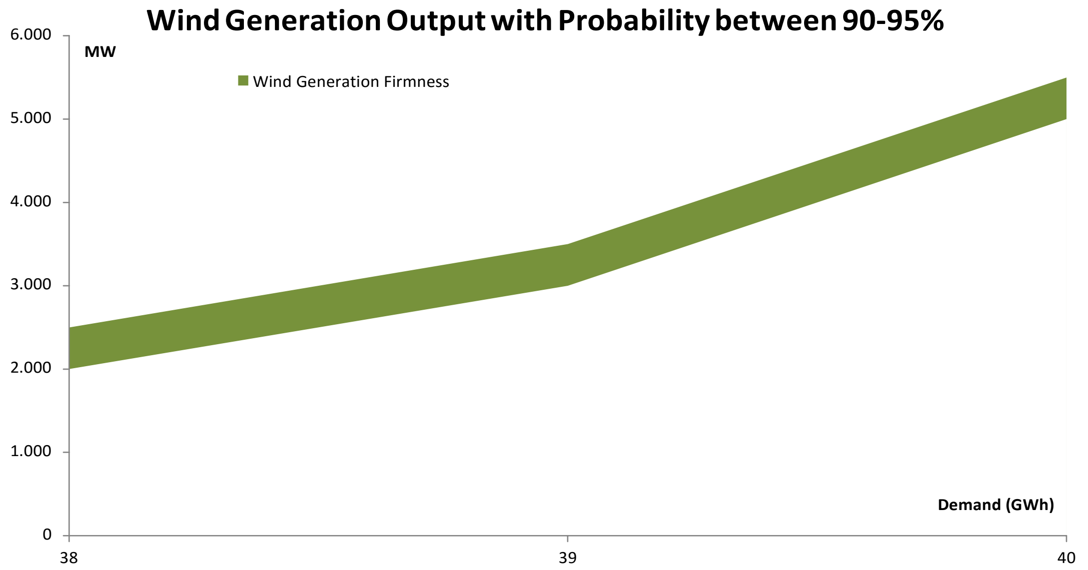

Figure 5.18: Relation of Wind Generation firmness against peak demand

The results show that the Wind Generation contribution to balance the demand increase as the value of the demand increase and as a consequence, with the considered assumptions, the firmness of Wind Generation increases.

Regarding the result, the determination of the final firmness value depends on the clear determination of the system needs in peak hours. In this project they were defined as critical hours where the demand is between the maximum value and the 95% of this value, therefore the Wind Generation firmness would be 2.000 MW with a 95% level of confidence. However the definition of the critical hours or the level of confidence considered can drive to other results:

- If the system operator accepts to deal with a lower level of confidence, 90%, the firmness increases until 2.500 MW.
- If the system operator considers that the critical hours are when the demand is close to 40 GWh the firmness of the Wind would be 5.000 MW with a level of confidence of 95% or 5.500 MW if the level of confidence is 90%.

5.5 Conclusions

The results of the assessment of the firmness of Wind technology has shown that:

- Although, in principle there is no correlation between the demand and the Wind Generation the results show that exists a relation between both variable more significant in the peak hours.

- The reasons to that relation can be explained through the thermal sensation in the windiest days, because in winter days when the wind blows the thermal feeling is lower and it makes that the demand increase. Therefore, can be concluded that the wind's blow in winter is a clear driver of the demand.
- The analysis of the seasonal Wind Generation firmness reinforces the previous result due to the reduction of demand in summer and also the decreasing in the firmness.
- The assessment of the firmness with this methodology has addressed that the contribution to the system needs of the Wind Generation can be considered larger than the current firmness value in the Spanish Power System.

CHAPTER 6: Conclusions

CHAPTER 6: CONCLUSIONS

6.1 Introduction

The aim of this chapter is to provide and overall assessment about the methodology implemented and the results obtained in this project. The chapter is structured in three main parts. First, there is an overall valuation about the results obtained in this project. Secondly, there is a valuation about the assumptions considered to end the chapter with guidelines about the future research in the topic.

6.2 Assessments of the results

The aim of this project has been to assess the firmness of the Wind Generation technology from a different point of view based on its contribution to cover the system needs. The methodology implemented in this project has led to results in which the firmness of the Wind Technology is larger than the current consideration in the Spanish Power system. However, neither the conclusion of the project nor the current assessment in the system is better than the other; both of them are computed from different perspectives of the same problem and perfectly valid for the purpose.

One of the objective of determining the firmness is the establishment of a capacity remuneration mechanism that contributes to increase the firmness in the system, (by the provision of the service by different agents) while at the same time send to the market an investment signal. Therefore, as important as the assessment of the firmness is the sending of the right economical signal to all the agents involve. Thus, the mechanism implemented should be neutral, stimulating the participation of all the technologies that complies with the requirements in order to not distort the signal and creating barrier.

The assumption of this project that considers peak hours as the periods of maximum stressed in the system allows to establish a mechanism open to all participants involved in the system because when the supply is tight all capacities contribute to meet the demand. Thus any mechanism that rewards some technologies and prevents others from participating, would be a clear example of distortive signal to the market and rarely would obtain the desired objective.

6.3 Assessments of the assumptions considered

The project has been developed based on the fact that in peak hours the system is more stressed than in the other hours. This is a common consideration that applied permanently to most of the Power Systems. However, demand is not the only driver that can lead the system to a stressed situation. There may be other scenarios in which the system is tight in resources availability and therefore can cause a difficult situation. A clear example of it could be a long period of drought that leads the reservoirs close to their minimum level making the hydro power plants unavailable. Therefore, all these considerations should be taken into account to a deeper analysis of the firmness.

The variability associated to Wind Generation impacts in different ways in the system. However, in this project the only consequence considered has been the one that affects the assessment of the firmness. Other impacts like the case of the ramps introduced in the system have not been considered due to the fact that they have to be evaluated from the right perspective. In the case of the ramps the analysis should be done from the flexibility point of view. Said that, it is crucial to identify the characteristics that each technology presents in order to evaluate them accurately and avoid general and wrong assessment.

. However, this second derivative of the variability do not affect in the firmness assessment because in that case it impacts in the flexibility of the system and the resources to manage it. Said that, it is crucial to identify the characteristics that each technology provides to the system and identify their impact in order to deal with the possible drawbacks and to remunerate their contribution.

Regarding the methodology implemented, the different scenarios of Wind Generation and demand have been set in intervals of 1.000 MWh taking into account that the behavior of the load and the Wind Generation output are very random and therefore there is no need to be extremely accurately.

The assessment of this project has been carried out in the last three years where the installed capacity of the Wind Technology in the Spanish Power has remained stable. Therefore, if this methodology was implemented to determine the firmness would necessary to a periodically review in case that the installed capacity increased in the system in order to maintain the firmness value updated [REE_15].

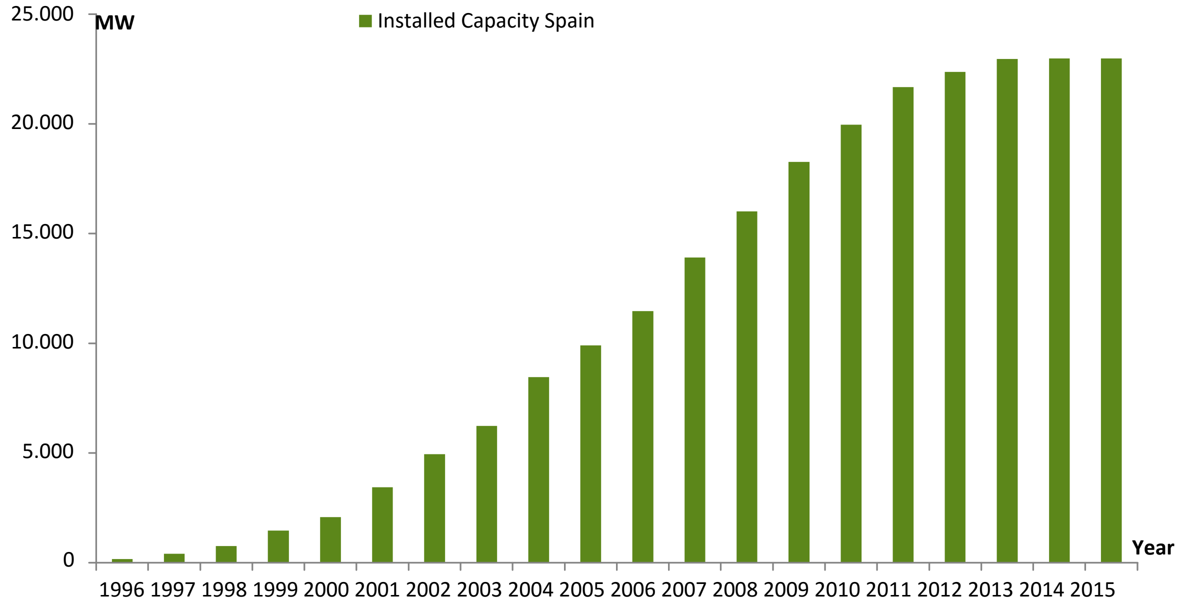

Figure 6.1: Historical Evolution of Wind Generation Installed Capacity in Spanish System

In this project there has not been previous studies about the historical behavior of the Wind, the only study was to determine the months where the wind blows stronger than the other. However, it would be interesting to determine some patrons that the wind may present. For instance the year 2013 presents a lower firmness than the year 2014 and 2015, with similar levels of the demand. Consequently, it may be thought that the demand share of 2013 was lower than 2014 and 2015. However, it did not, the demand share of the Wind Technology was higher than in years 2014 and 2015. Notice that with the project assessment the year 2013 presented a lower level of firmness and on the other hand with the current assessment of the System Operator the contribution will be higher [REE_15].

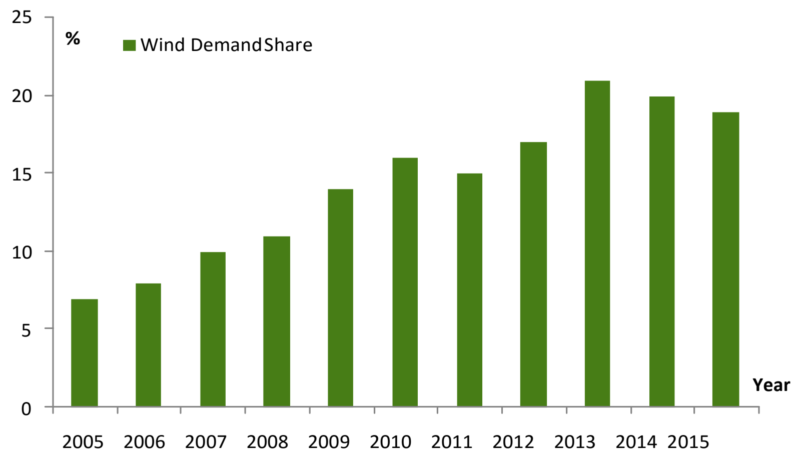

Figure 6.2: Historical evolution of the Spanish Wind Generation demand Share

The assessment of the firmness though a clear and common methodology that applied to all the technologies would simply the participation in the capacity remuneration mechanism because there would be a clear value of the capacity provided by each technology and thus the amount that they could sell. Moreover, allowing Wind Technology and others to participate in the mechanism would correct the possible distortion than may appear as a consequence of preventing some technologies from being participate of the services.

6.4 Future Research

The future lines of research after this Master Thesis can be drove to different aspects.

Economic Aspects

Assessment of the economic scenario that would establish in the case that Wind technology would be remunerated due its participation in the capacity remuneration markets. The analysis could be deeper if at the same time it was evaluated the possibility of reduction the current support mechanism to the Renewable technologies. This is could be an interesting analysis because nowadays the regulators of the systems are facing dilemmas between maintaining the policies to support the renewable, due to environmental reasons, or eliminating them for the amount of money that it costs and the distortive of the measure.

Assessment of firmness with storage solution

The possibility of using storage solution a large scale is a possibility that sooner or later will arrive in the power system. However, before that scenario it could be possible to use them in a small scale to increase the level of the Wind Technology firmness. This framework is another of the future line of research that can be done in order to evaluate:

- Increasing of the firmness.
- Economic viability of the solution in case Wind Technology were allowed to participated in the Capacity Remuneration mechanism, otherwise there would be no economic incentive to invest in storage solution.

Evaluation considering additional stress scenarios

In the point 6.2 of this chapter was detailed the reasons why in this project has only been considering the demand as the only driver of the stressed hours. Moreover, it was mentioned other scenarios that would cause a low level of firm capacity in the system. Therefore, a clear research would be repeated again the assessment considering all the scenarios and comparing the results between both scenarios.

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