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ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE ELECTRIC POWER INDUSTRY

Master's Thesis

ECONOMIC ASSESSMENT OF THE PARTICIPATION OF WIND GENERATION IN THE SPANISH ANCILLARY SERVICES MARKETS

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SUMMARY OF THE MASTER THESIS

In Spain renewable generation is not allowed to take part in ancillary services. However, the government is considering which should be the required tests to authorise renewable generation to participate in secondary and tertiary regulation, as well as deviations management mechanism. Therefore, it can be expected that wind farms will be allowed to participate in ancillary services in the near future.

The aim of this Master Thesis is the economic assessment of the participation of wind generation in the Spanish ancillary services markets. Firstly, a theoretical assessment of the most suitable circumstances for wind generation to participate in secondary and tertiary regulations and in the deviation management service has been carried out. According to this assessment, the tertiary regulation has been identified as the most interesting market for wind generation to participate in.

To estimate the economic impact for wind agents of their participation in tertiary regulation, three possible bidding strategies are proposed: a base strategy, an alternative strategy and a joint strategy. The base strategy aims to reduce the wind production deviations scheduling the latest production forecast in the tertiary regulation market, which is made closer to real time. The alternative strategy tries to detect trends in the system that imply a preference to provide upward or downward reserve. As any wind production forecast is made up of a mean value and an interval of confidence, it may result interesting to schedule the day-ahead in the confidence interval but not in the mean expected value in order to take advantage of the opportunity cost of providing reserves within the confidence interval for participating in tertiary regulation. The joint strategy combines the advantage of the base strategy of reducing the wind production deviations and the advantage of the alternative strategy of capturing additional profits modifying the current design of the bids submitted for the day-ahead market.

The joint strategy allows capturing the highest profits. With its implementation, it has been estimated that the wind sector would have increased its annual profits in more than 4 million € in the years 2012, 2013 and 2014. It also presents the highest number of hours in which the original profit would have growth. Nevertheless, the original profit would be also reduced in some hours. However, the percentage of these hours with respect to the total hours of the year is small (lower than 10% in the years studied).

The base strategy is desirable because its nature of reducing deviation implies no risks compared to the present situation, while obtaining higher annual profits. The joint strategy is preferable over the alternative strategy because it captures higher profits with lower risk. The choice between the joint strategy and the base strategy will depend on the risk aversion of wind agents. If the expected annual profits are prioritized, the joint strategy will be chosen. If wind agents want to prevent the reduction of the original profit in every hour; the base strategy will be more suitable for them.

In conclusion, a regulatory change that enables wind generation to provide tertiary regulation is desirable because only with the base strategy the costs of deviations for wind agents will be reduced; hence decreasing the cost of deviations of the system which implies reducing the costs for the consumers.

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Chapter 1 INTRODUCTION

In this chapter, an introduction to the Master Thesis will be carried out. In the first section, the motivation to develop the Master Thesis will be presented. In the section 1.2, the organization of the Spanish wholesale market will be described. The objectives of the Master Thesis will be explained in the section 1.3. Finally, how the document of the Master Thesis is organized will be explained in the section 1.4.

1.1 MOTIVATION

Wind power has been used for at least three thousand years. Until the early twentieth century, wind power was basically a mechanical power provider for pumping water or grinding grain (Ackerman, 2012).

In the early 1970s, with the first oil price shock, interest in wind power re-emerged. This time, however, the main focus was on wind power providing electrical energy instead of mechanical energy. In 1891, the Dane Poul la Cour built the first wind turbine that generated electricity. The technology was improved step by step enabling that wind energy re-emerged as one of the most important sustainable energy resources by the end of 1990s (Ackerman, 2012).

In the last decades, the increasing concern about the environment has promoted the development of renewable energies worldwide. As a sign of it, the objectives agreed in the EU Directive 2009/28/EC should be noted. By this Directive, known as ’20-20-20’, member states committed themselves to increase up to 20% the share of renewable energy in the primary energy mix for the whole Europe Union. Nowadays, the installed wind capacity in Spain is 22,8 GW, which represents 22,3% of total installed capacity (Red Eléctrica de España, 2014). It should be pointed out that Spanish wind production has reached 17,5 GW and during some hours it constitutes 60% of total generation (Red Eléctrica de España, 2013). Furthermore, in 2013 wind energy was the first technology in demand coverage in the country (Red Eléctrica de España, 2013).

Not only is wind energy one of the most relevant energy sources in Spain, but also worldwide. Wind energy has been the fastest growing energy technology since the 1990s, in terms of percentage of yearly growth of installed capacity per technology source. The growth of wind energy, however, has not been evenly distributed around the world. By the end of 2010, around 44% of the worldwide wind energy capacity was installed in Europe, a further 32% in the Asia Pacific, and 22% in North America (Ackerman, 2012). Figure 1 shows the evolution of the worldwide installed wind capacity during the last years. As it can be observed in the figure, at the end of 2014 the installed wind capacity amounted to 369,5 GW (GWEC, 2014). Although this figure is impressive, wind technology is still in its infancy. Currently, only 2,5% of global electricity is supplied by wind power (GWEC, 2015).

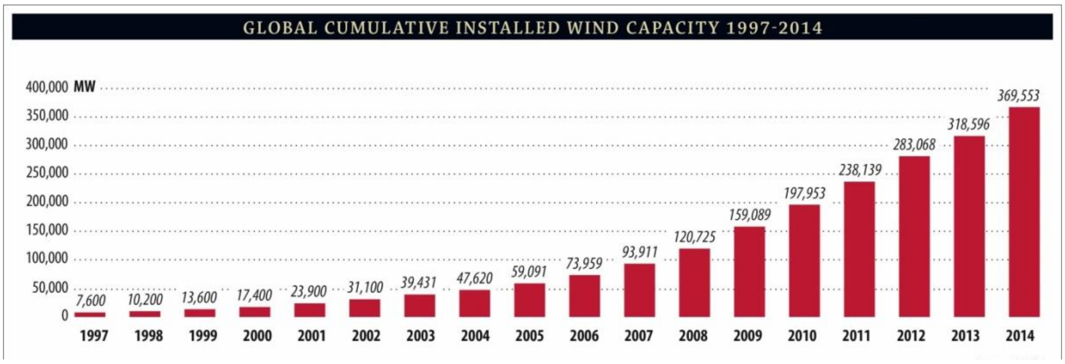

Figure 1: Global cumulative installed wind capacity 1997-2014(GWEC, 2014).

Within this worldwide and national framework, wind power poses increasing challenges to the planning and operation of power systems. Transmission System Operators (TSO) have often been cautious regarding massive penetration of wind energy into the grid arguing that wind power does not provide frequency and voltage control. However, current technology developments enable the design of operation and control strategies of wind turbines to provide such grid services (Sáiz-Marín et al., 13/01/2012).

Active power control includes primary, secondary (AGC) and tertiary regulation operating within different time scopes. Generators incur in an extra cost for providing frequency control that should be recovered. Within the Spanish system, primary regulation is considered a mandatory non-remunerated service, while secondary and tertiary regulations are driven by market-based mechanisms (Sáiz-Marín et al., 13/01/2012).

Despite the fact that renewable generation is currently not allowed to take part in ancillary services, the Spanish government is considering which should be the required tests to authorise renewable generation to participate in the secondary and tertiary regulation, as well as deviations management mechanism (Red Eléctrica de España, 2015). Therefore, it can be expected that renewables in general and wind farms in particular will be allowed to participate in ancillary services in the near future.

This Master Thesis will focus on the economic assessment of the participation of wind generation in the Spanish ancillary services markets. A review of the features of the different ancillary services markets will be carried out in order to determine the most suitable circumstances when wind generation can be interested in participating in these services. Furthermore, some bid strategies will be proposed to enable wind generation to enter into these markets, which will be one of the main challenges that wind generation will face in the following years.

1.2 ORGANIZATION OF THE SPANISH WHOLESALE MARKET

The Spanish wholesale market belongs to the Iberian Electricity Market (MIBEL), an integrated regional electricity market for both Spain and Portugal (OMIP, 2015).On the one hand, the day-ahead market and the intraday markets are managed by the Market

Operator OMEL, resulting in the same price for Spain and Portugal if the interconnections between both countries are not congested. In case of congestion in the interconnections, Market Splitting is carried out, resulting in different prices for each country. On the other hand, the constraints solving markets and the ancillary services markets are managed independently for each country by its System Operator: Red Eléctrica de España (REE) in Spain and Redes Energéticas Nacionais (REN) in Portugal ((Saíz Marín, 2010), (Red Eléctrica de España, 2015)).

For the purposes of trading and settlement (determining the amount of electricity used/generated and arranging payment for it) in Spain electricity is considered to be generated, transported, delivered and used in hourly periods called Settlement Periods. The amount of energy that should be produced or consumed by each agent in each Settlement Period is the aggregation of the result of the following markets:

- Day-ahead market: It is the market in which the purchase and sale transactions of energy for all the Settlement Periods of the following day take place, but without taking into account the technical constraints that may appear in the network. It is a physical electricity market since all the producers need to declare their units unavailable, send a bid to the Day-Ahead market or declare a physical bilateral contract. The bids reception process for each of the 24 Settlement Periods of the following day is closed at 12:00 of the day ahead (D-1), with the exception of physical contracts that should be declared prior to 11:00 of D-1. Then, the market algorithm Euphemia is run, getting as a result the energy hourly schedule for each unit and the hourly marginal prices for the next day. At 13:00 of D-1, OMEL communicates these results to the agents whose bids or offers have been accepted (Bogas, 2015). The aggregation of these results with the physical bilateral contracts constitutes the *Programa Diario Base de Funcionamiento* (PDBF), which is established by REE and is published at 14:00 of D-1 (P.O. 3.1., Resolución de 08/05/2014).

- Technical constraints: REE is in charge of modifying the PDBF if it is not feasible due to technical constraints (Bogas, 2015).The technical constraints solving process is managed in two steps. The first phase involves modifying the scheduled programs to solve the technical constraints and avoid new constraints in subsequent markets. The second phase implies to change the scheduled programs to restore the balance between generation and demand taking into account the security limits established in phase 1 (Red Eléctrica de España, 2015).

  After PDBF being published, REE opens the process to receive offers to solve the technical constraints. This process will be open during 30 minutes. Then, REE will accept the offers that solve the grid constraints with minimum costs. The result of the technical constraints solving process, called *Programa Diario Viable Provisional* (PDVP), is published by REE at 16:00 of D-1 (P.O. 3.1., Resolución de 08/05/2014).

- Additional upward reserve market: This market is aimed to ensure that the following day (D) there will be enough upward reserves to deal with real time uncertainties. Only thermal generators are allowed to participate in it (Iberdrola, 2015). After PDVP is published, REE will determine the additional upward reserve requirements of each Settlement Period of the next day and it will open a process to receive offers to provide this service during 30 minutes (P.O. 3.9., Resolución de 01/08/2013). The accepted offers will be communicated to their agents before 17:00 of D-1 (P.O. 3.1., Resolución de 08/05/2014).

- Secondary reserve market: The secondary regulation is in charge of bringing the frequency back to 50 Hz after a disturbance, as well as maintaining the flows across the interconnections to other TSO-areas in the scheduled value (Andersen et al., 2012).

  REE publishes the secondary regulation reserves requirements for the following day (D) before 16:00 of D-1. After publishing these requirements, REE opens a process to receive bids to provide the secondary regulation service. This process is closed at 17:30 of D-1. Considering the received bids, REE assigns the provision of the secondary regulation reserves service minimizing the costs incurred. Before 17:45 of D-1, REE will publish which units will provide secondary regulation reserves in each Settlement Period (P.O. 3.1., Resolución de 08/05/2014).

  The aggregation of the PDVP with the assignation of secondary reserves is known as *Programa Diario Viable Definitivo* (PDVD) (Red Eléctrica de España, 2015).

- Intraday markets: These no mandatory markets facilitate the adjustment of the day-ahead schedule (Iberdrola, 2015). They are open to all agents, independently of the way in which they have contracted their energy at the day-ahead time (organized market or any kind of physical bilateral contract). Every day there are six auction sessions that take place at fix hours and with the same conditions for all the agents (González, 2015). The following figure shows when the six intraday auctions sections take place (depicted with an arrow), as well as their timeframe horizon (depicted with a rectangle) (Cuéllar, 2015).

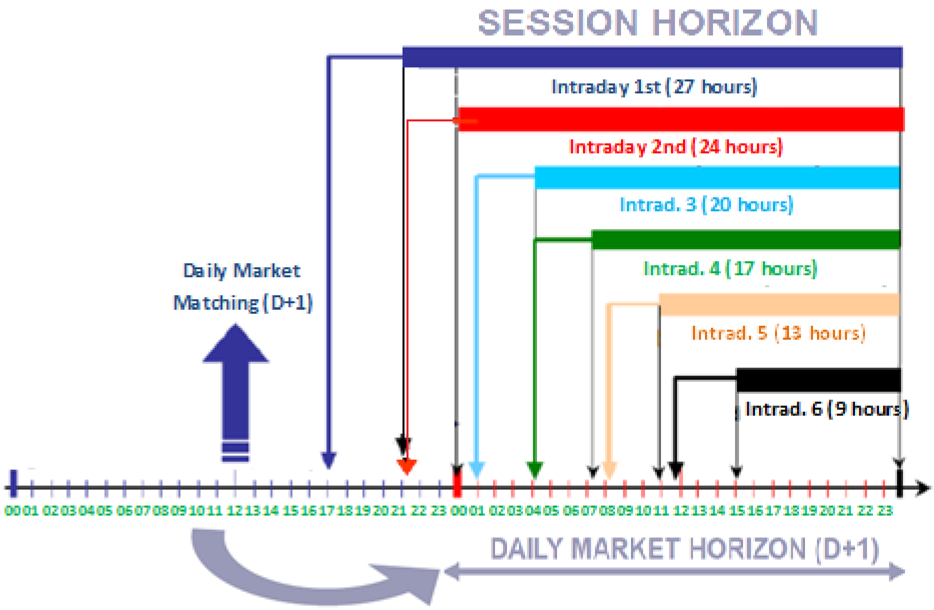

Figure 2: Intraday market sessions in Spain (Cuéllar, 2015).

The aggregated schedule obtained after each intraday market session, including technical constraints solving processes, constitutes the *Programa Horario Final* (PHF) (Red Eléctrica de España, 2015).

- Deviations management market: If the difference between the scheduled supply and the demand forecasted by REE exceeds 300 MW, REE might solve it through the deviation management market. In order to do it, the System Operator may announce the energy required (upward or downward) in every Settlement Period. The process to receive offers lasts 30 minutes. The resulted firm assignation is announced 15 minutes before the first hour of the time horizon covered by the deviations management market. This time scope extends to, at the most, all the Settlement Periods between an intraday session closure and the first hour of the time horizon of the next intraday session (P.O. 3.3., Resolución de 18/05/2014).

- Tertiary reserve market: The tertiary regulation is in charge of restoring the secondary reserves that have been used. REE publishes the tertiary regulation reserves requirements for the following day (D) before 21:00 of D-1. As it takes places in the secondary regulation market, after publishing the tertiary regulation requirements REE opens a process to receive bids to provide this service (P.O. 3.1., Resolución de 08/05/2014).During this process, it is mandatory that all the agents allowed to participate in tertiary regulation offer all their tertiary reserve available (upward and downward) for each Settlement Period of D. Despite the fact that the process of receiving bids is closed at 23:00 of D-1, in order to ensure that all the available reserve is offered, the offers have to be updated every time the unit program is modified, as well as if there is any change in the availability of the unit (P.O. 3.1., Resolución de 08/05/2014). The period for updating the offers finishes 60 minutes before the beginning of the Settlement Period (P.O. 7.3., Resolución de 08/05/2014).

- Secondary energy provision: The net energy generated following the secondary regulation requirements is valued at the marginal price of the tertiary regulation energy that has been necessary (or would have been necessary) to use in the Settlement Period to replace the secondary regulation energy delivered (P.O. 7.2., Resolución de 18/05/2014).

The operating schedule established in each Settlement Period up to the end of the day D is known as Programa Horario Operativo (P48 or PHO). It is published 15 minutes before the beginning of each Settlement Period (Red Eléctrica de España, 2015).

Figure 3 shows the organization of the markets explained. The time interval for trading in each market is depicted in dark blue, while the time horizon for the schedules associated with each market is presented in light blue.

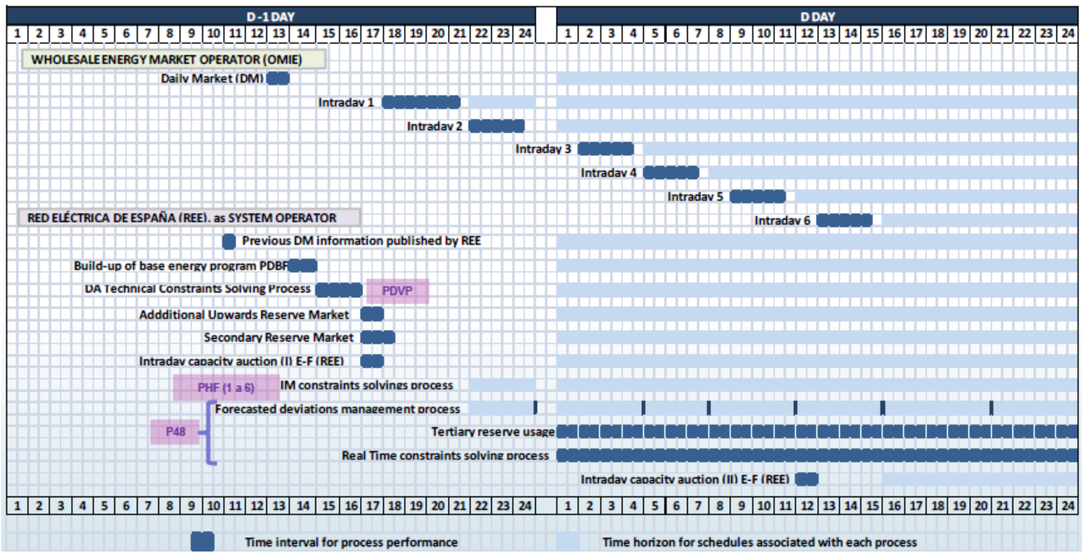

Figure 3: Organization of the Spanish wholesale market (Red Eléctrica de España, 2015).

1.3 OBJECTIVES OF THE MASTER THESIS

As it has been explained in the section1.1, this Master Thesis will focus on the economic assessment of the participation of wind generation in the Spanish ancillary services markets. The main objectives to be achieved are presented below:

- Development of a comprehensive review of the organization of the ancillary services markets in Spain: It will be studied which are the features of the different products that are currently traded in the ancillary services markets, as well as the requirements demanded to participate in these markets.

- Theoretical assessment of the most suitable circumstances in which a portfolio of wind farms could be interested in taking part in the ancillary services: After studying the organisation of the ancillary services markets in Spain, the conditions under which the participation of wind generation in these markets could not only be feasible, but also more profitable than its current operational mode, will be identified.

- Estimation of the economic impact for wind generation if it enters into the ancillary services: The economic consequences that would have taken place in a specific year in the past if wind generation had participated in ancillary services will be assessed. In order to do it, the profits that this generation would have received will be estimated employing actual data for wind production, prices and volumes of energy traded in the Spanish system in the studied year.

- Development of a strategy for wind farms owners to participate in the Spanish ancillary services markets: A specific strategy for a portfolio of wind farms will be developed based on actual data for wind production and energy prices in order to maximize their profits.

1.4 ORGANIZATION OF THE DOCUMENT

The document is divided into eight chapters. In this chapter an introduction to the Master Thesis has been carried out. In Chapter 2 the most relevant studies found in the review of the state of art regarding the participation of wind generation in the ancillary services will be presented. Then, a review of the organization of the ancillary services markets in Spain will be included in Chapter 3. The most suitable circumstances for wind generation to participate in these services will be assessed in Chapter 4. In Chapter 5 the economic impact for wind generation of its participation in the Spanish ancillary services will be estimated if the tertiary regulation market is only employed to adjust the wind production schedule to diminish the wind production deviations (base strategy). Then, a possible alternative strategy for wind agents to participate in tertiary regulation will be proposed in Chapter 6. In Chapter 7 a joint strategy that combines the advantage of the base strategy and the alternative strategy will be described. Finally, the conclusions of the Master Thesis will be presented in Chapter 8.

Chapter 2 STATE OF THE ART

In this chapter, the most important results of the review of the state of the art carried out will be presented. The chapter is divided into two sections. In the first section the main results of the state of the art will be covered, from which the proposal for the Master Thesis will be carried out in the second section.

2.1 STATE OF ART REVIEW

An extensive review of the literature has been carried out in order to know the most relevant studies related to the participation of wind power in frequency control.This section will present the main findings obtained.

The section is divided into four sub-sections. Firstly, the studies focussed on the capability of wind technology to provide regulating reserves will be presented. Then, the studies carried out about the participation of wind generation in primary, secondary and tertiary regulation will be described in sections 2.1.2, 2.1.3 and 2.1.4 respectively.

2.1.1 CAPABILITY OF WIND TECHNOLOGY TO PARTICIPATE IN FREQUENCY REGULATION

Firstly, the technical capability of wind technology to participate in frequency regulation should be assessed. In order to do it, a wide review of the studies that have covered this issue has been carried out, concluding that nowadays modern wind power plants can provide suitable performance and capability for power regulation and frequency response services (Tarnowski et al., 2010; Soares et al., 2015).

To enable wind generation participating in frequency regulation, controlling the active power produced by wind turbines is necessary. Moreover, to provide regulating reserves wind turbines should be deloaded, instead of running at the maximum wind power production.

There are two main methods to regulate the power generated by the wind turbines in order to operate below the optimum point: (i) changing the pitch angle (β) while keeping the rotational speed corresponding to the optimum operation point or (ii) increasing the rotational speed of the wind turbine, without changing the pitch angle β (Han et al., 2010; Sun et al., 2010; Castro et al., 2012). Both strategies are depicted in the following figure.

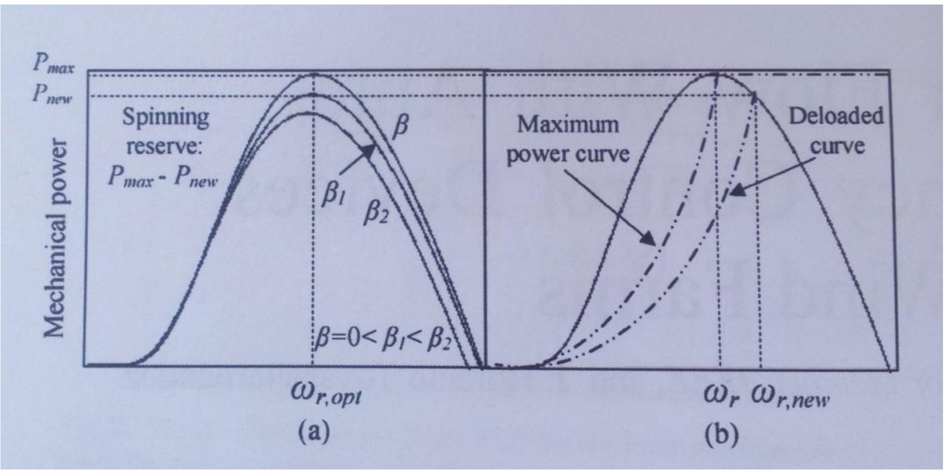

Figure 4: Achieving a spinning reserve: (a) by using the blade pitch mechanism, (b) by increasing the mechanical rotor angular speed (Castro et al., 2012).

It should be pointed out that with the strategy of changing the rotational speed, a lower active power could also be achieved by reducing the speed, as Figure 5 shows. Nevertheless, underspeeding may decrease the small signal stability. Therefore, overspeeding is preferable (Sun et al., 2010).

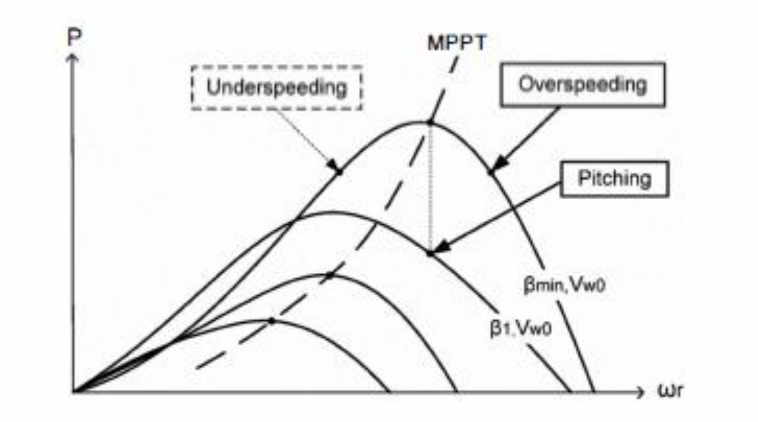

Figure 5: Deloading possibilities: overspeeding and pitching (Sun et al., 2010).

In (Chang-Chien et al., 2011) the authors indicate when each of the strategies should be used, depending on wind conditions. Under high wind conditions, the pitch angle will be changed in order to keep the rotational speed within stable limits. Under medium and low wind conditions, the rotational speed will be modified, with a pitch angle equal to zero. The study concludes that wind turbines are able to produce the set-point active power with the previous strategies under medium and high wind conditions. On the other hand, under low wind conditions wind turbines face difficulties to produce the set-point power due to stability issues. Additionally, it should be noted that the authors do not specify the wind speeds that correspond to high, medium and low wind conditions.

The reserve provided by wind turbines could be constant or variable. The constant reserve consists on maintaining always the same MW reserve (or a constant percentage reserve of the available power). The variable reserve is provided when an active power upper limit (set-point) is imposed to the wind turbine. Therefore, the reserve (the difference between the available wind power and the set-point) will be different each second (Margaris et al., 2012).

Regarding the papers presented in this subsection, a significant amount of authors have studied the different ways to regulate the production of wind farms. Consequently, to maintain an operation point below the maximum available wind power can be thought to be technically feasible nowadays. This feasibility is essential regarding the participation of wind generation in primary, secondary or tertiary regulation since these ancillary services require the regulation of the power produced.

2.1.2 PARTICIPATION OF WIND GENERATION IN PRIMARY REGULATION

Even though wind generation is not allowed to participate in the ancillary services in most countries, some studies have been developedregarding the potential of wind generation to contribute to the system security. The following papers deal with the participation of wind generation in primary regulation:

- (Ma & Chowdhury, 2010): Three types of wind turbine controllers based on inertia, pitch angle and rotor speed are compared. Both inertial controller and rotor speed controller are able to react fast enough to help to restrain the initial drop in the grid frequency. However, the inertia controller cannot perform well beyond just a few seconds and thus cannot be used for an extended period of time. Therefore, either a rotor speed controller or the combination of an inertia controller and a pitch controller are recommended regarding primary regulation.

- (Chang-Chien et al., 2011): The authors investigate the amount of the available wind power that should be employed to provide reserves. They propose to set the wind farm set-point using the moving average estimation of turbine output with a multiple of the deviation.

- (Margaris et al., 2012): This paper presents an investigation on wind turbine contribution to the frequency control of non-interconnected island systems. The authors support that maintaining a balance power reserve between 5% and 10% of the available power in wind farms ensures enough primary reserves for regulation purposes of the power system.

- (Soares et al., 2015): This paper optimises the offering strategies for a joint participation of wind generation in energy (day-ahead) and primary reserve markets. It develops two strategies:

    - Proportional reserve offering strategy: It consists on a proportional curtailment of potentially available power generation. This strategy leads to a binary behaviour where all the available energy is submitted in either energy or reserve market, converging to the market that presents greater profitability.

- Constant reserve offering strategy: A fixed amount of power is curtailed over a certain expected level of wind power. This strategy enables a joint participation of wind power in both energy and primary reserve markets.

It should be noted that the results of the previous strategies strongly depend on the market prices and penalties for energy and reserve, data that has been considered as known in the paper. Moreover, the authors assume that the primary reserve is remunerated, a fact that in Spain does not take place.

In this subsection several studies have been presented related to the participation of wind generation in primary regulation. Firstly, it should be noted that the inertia of wind turbines is very small and thus other alternatives should be implemented to regulate the power of wind turbines, such as the rotor speed control or the pitch angle control. Secondly, it should be outlined that importance of the choice of the strategy employed to determine the reserves. This will be very relevant when deciding the design of secondary regulation reserves. For instance, the constant reserve offering strategy proposed in(Soares et al., 2015) will be also supported by other authors,

Furthermore, it should be noted that the provision primary regulation by wind farms is not advisable if this service can be provided by other units (such as thermal units) that could reduce their costs when being deloaded. If wind generation is deloaded, the profit that it would have obtained in the market by selling this energy would be lost. Consequently, in countries as Spain when the provision of primary regulation is not remunerated there is no interest in wind generation to participate in this ancillary service.

2.1.3 PARTICIPATION OF WIND GENERATION IN SECONDARY REGULATION

Few studies have dealt with the participation of wind generation in secondary regulation.

In (Serrano Alonso, 2014) two wind farm controls (a control with proportional sharing and a control with priority) are designed to allow wind farms to participate in the Spanish secondary frequency regulation with unfulfilments lower than 10%, provided that there is enough wind.

Twenties project is a project in which a group of Transmission System Operators from Belgium, Denmark, France, Germany, Spain and The Netherlands participate in order to evaluate the contributions that intermittent generation can bring to system services, determine what should be implemented by the network operators to allow for off-shore wind development and give more flexibility to the transmission grid. Regarding the scope of this Master Thesis, the first task force of Twenties project (Contribution of variable generation and flexible load to system services)is the most interesting one and, within Task Force 1, the demonstration project 1 (System services provided by wind farms) (Twenties, 2013). Four main points of this demonstration project should be pointed out:

- Determination of the secondary regulation band: The following figure shows the design of the regulation band proposed in Twenties project. It is an alternative approach to those presented in the previous section from (Soares et al., 2015).

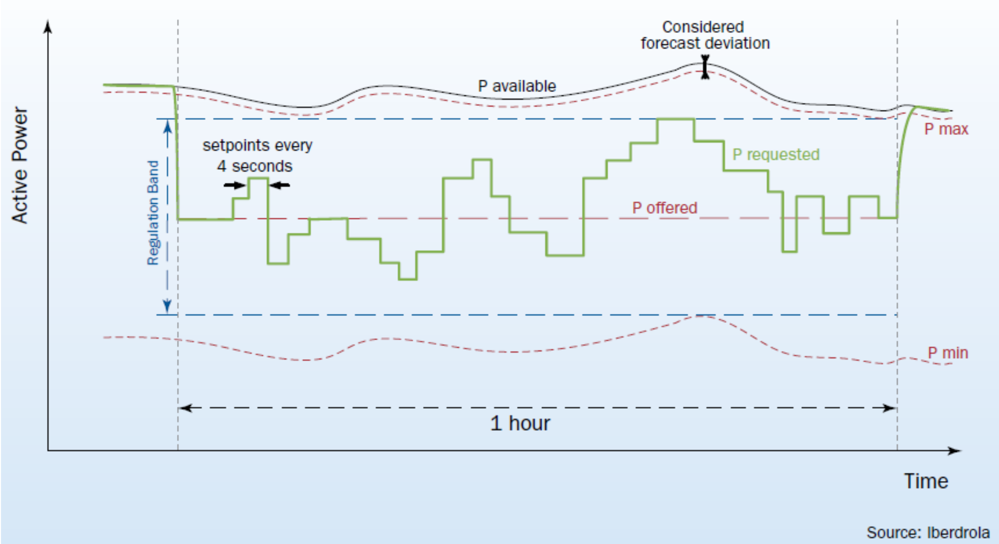

Figure 6: Determination of the regulation band in Twenties project (Twenties, 2013).

The fifteen minutes prior to the beginning of the demonstration, the wind forecast system calculates the expected available active power for the following hour. The minimum value of this forecast is used as the upper limit of the regulation band. It is necessary to use the minimum value; otherwise there is no guarantee that all the setpoints will be followed accurately. Moreover, in order to avoid the uncertainties of the wind forecasting algorithms, this upper value is lowered in correspondence to the estimated forecast error (Twenties, 2013).

The lower value of the regulation band is calculated taking into account the technical limitations of wind turbines. In the case of the generators used in the demonstration, this value is between 25% and 50% of the nominal power (Twenties, 2013).

Consequently, the regulation band provided in the demonstration project is small. Of the total installed capacity of 482 MW, the band provided is +/-20 MW with an initial value of 100 MW (Twenties, 2013).

- Required cost expenditure: The CAPEX for delivering voltage and frequency control services is reduced (around 100 – 150 K€ per 50 – 100 MW wind farm) and there is not a clear impact on the OPEX (Twenties, 2013).

- The participation of wind generation in secondary regulation is technically possible: Grouped wind farms are able to control their active power, in real time and in a coordinated way, according to the TSO’s secondary frequency control requirements (Twenties, 2013).

- The participation of wind generation in secondary regulation is not economically advisable: In order to participate in secondary regulation, a large amount of energy has to be curtailed for providing the upward power reserve service, so it is not currently economically attractive. The following alternatives are proposed (Twenties, 2013):

- Offer upward reserve only once wind generation has been curtailed by technical constraints.

- Just offer downward reserve: This option would require a change in the Spanish regulation. The current regulation, under which upward reserves must be provided at the same time as downward reserves, would limit the provision of downward reserves by wind generators to a specific amount which depends on the capacity offered for upward reserve provision.

(Sáiz-Marín et al., 13/01/2012)is focused on the economic assessment of the participation of wind generation in the Spanish secondary regulation market. Firstly, the author evaluates the maximum possible profits that the wind generation could have gained in the years 2004-2008 if it would have participated in the secondary regulation. For evaluating the profits, two scenarios are studied (Sáiz-Marín et al., 13/01/2012):

- Wind remuneration according to the RD 661/2007: Wind energy is paid with a feed-in-premium at market price plus a bonus.

- Wind power remuneration at marginal market price: without any premium.

The authors have analysed the additional profits that could have been obtained by offering 1 MW of total band in every hour of the studied period, differentiating two types of benefits(Sáiz-Marín et al., 13/01/2012):

- A theoretical roof: Perfect information is assumed (bound 1).

- A practical roof: The decision to participate on the secondary regulation market is made the day-ahead if the secondary band is enough to compensate the regulation costs, but the secondary energy that it will be used is unknown and it could reduce the benefits (bound 2).The price of secondary regulation reserves and intraday prices, as well as the percentage of the total band that constitute the upward reserve requirements are considered known data since they are considered to be able to be forecasted the day-ahead with high degree of precision.

The results obtained can be shown in the following figure.

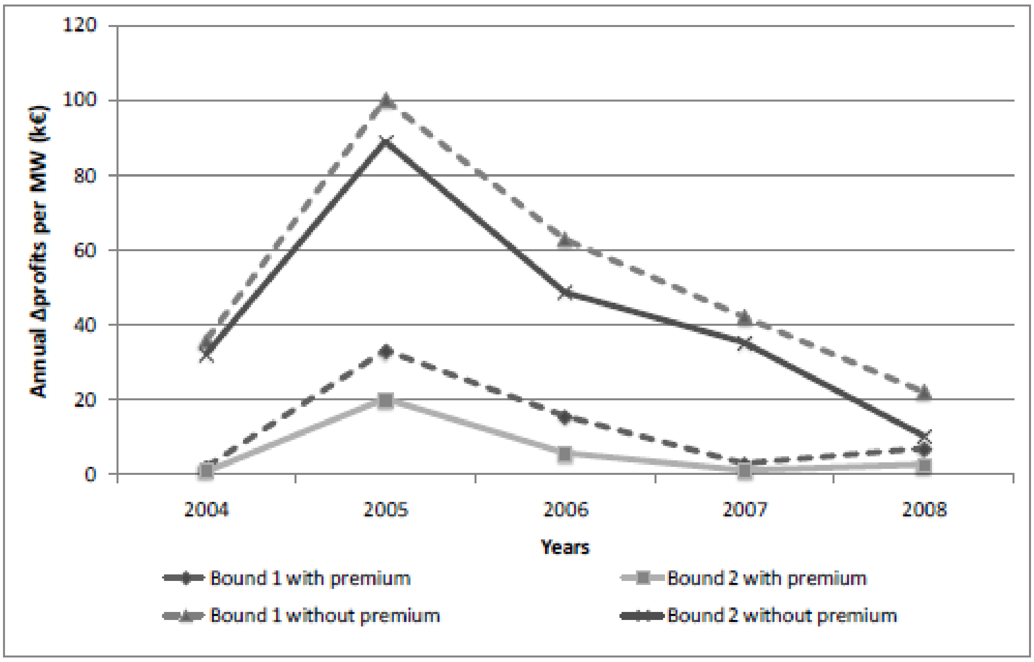

Figure 7: Annual additional profits in the period 2004-2008 (Sáiz-Marín et al., 13/01/2012).

Additionally, the paper (Sáiz-Marín et al., 13/01/2012) proposes a strategy of offer for the band market that allows capturing around 90% of the practical additional profits computed before, offering a regulation band of 10% of production forecast.

This study concludes that under the regulatory frameworks considered, especially if the RD 661/2007 is applied, the expectation of additional profits for wind generation when participating in the secondary regulation, although positive, is not very high (Sáiz-Marín et al., 13/01/2012).

2.1.4 PARTICIPATION OF WIND GENERATION IN TERTIARY REGULATION

Little attention has been paid to the participation of wind generation in tertiary regulation. Regarding this issue, the only study that has been found is (Andersen et al., 2012). According to this paper, the Danish Transmission System Operator changed in 2011 its regulation in order to make it manageable for wind turbines themselves to offer activation in the Tertiary reserve market (The Scandinavian Regulating power market). However, any further information has been found regarding whether this participation is actually taking place or not or related to the way it is carried out.

Nevertheless, (Andersen et al., 2012) presents some relevant conclusions related to a study carried out for a 21 MW wind farm. Based on historic spot prices and historic activation prices in the Tertiary reserve market, during the test period it was simulated that a 21 MW wind farm could increase income from the electricity market by offering activation in the Tertiary reserve market. Moreover, all the turbines will benefit from these proactive turbines offering activation, because all turbines thus will avoid extreme imbalance costs. However, it should be noted that, within the Danish historic data employed, negative prices were allowed for tertiary regulation downward energy. Wind generation also received a premium on top of the spot price in a certain amounts of full load hours. None of these features is implemented in Spain; hence maybe the conclusions of this study cannot be extrapolated.

2.2 MASTER THESIS PROPOSAL

In the previous section the main studies that have covered the participation of wind generation in frequency regulation have been presented.

Three main conclusions should be pointed out:

- Modern wind power plants can provide suitable performance and capability for power regulation and frequency response services (Tarnowski et al., 2010).

- In power systems with weak interconnections and/or high wind power penetration, frequency reserves can be more valuable to the system than maximizing the wind power generation (Tarnowski et al., 2010).

- Nevertheless, most of the active power controls involve an output power below the maximum available production, which means a reduction in revenue. Consequently, the reduction in wind power output should be used as a last resort (Tarnowski et al., 2010).

In this Master Thesis the economic assessment of the participation of wind generation in the Spanish ancillary services markets will be carried out. Due to the findings of the state of the art, this assessment won’t cover primary regulation. Moreover, wind technology will be assumed to be able to provide frequency regulation services, as many authors and studies support.

Firstly, a review of the organisation of the ancillary services markets in Spain will be carried out, as well as the theoretical assessment of the most suitable circumstances for wind generation to participate in these services. The second part of the Master Thesis will focus on the estimation of the economic impact of the participation of wind generation in tertiary regulation, since in Spain primary regulation is not remunerated and the expected profits from the participation in secondary regulation are not high. Therefore, the second part of the Master Thesis has been chosen to focus on tertiary regulation since little attention has been paid to the participation of wind energy in this field, not having found any study that covers it in the Spanish market.

Chapter 3 REVIEW OF THE ORGANISATION OF THE ANCILLARY SERVICES MARKETS IN SPAIN

In the near future, wind generation is expected to be able to participate in some ancillary services markets in Spain. Not only could this participation contribute to the system stability, but also it would allow reducing the wind energy deviations (one of the main operation costs of wind generation). Therefore, in this chapter a review of the organisation of the ancillary services markets and a description of the current imbalance pricing scheme will be carried out.

The chapter is divided into four sections. Firstly, the Spanish imbalance pricing scheme will be presented in section 3.1. Secondly, the Spanish secondary regulation market will be described in section 3.2. The organisation of the tertiary regulation market will be explained in section 3.3. In section 3.4, the main features of the deviations management market will be described. Finally, in section 3.5 the conclusions of this chapter will be presented.

3.1 IMBALANCE PRICING SCHEME

In Spain, a dual imbalance pricing scheme is established (P.O. 14.4., Resolución de 08/05/2014). Therefore, different imbalance prices are applied to balance responsible parties (BRPs) with long and short positions. Consumption units are short when their real time demand is higher than the scheduled and they are long when real time demand is lower than the scheduled. As far as production units are concerned, they are short when real time generation is lower than the scheduled and they are long when generation is higher than the scheduled.

In Spain, the following cases can be distinguished:

- If both the production unit and the overall system are long: The production unit contributes to the system imbalance since it deviates in the same direction of the overall system. Consequently, the unit will be penalised receiving an imbalance price for its upward deviation lower than the day-ahead marginal price (Sáiz-Marín et al., 13/01/2012). This imbalance price is settled as the average price of activated balancing energy (downward deviation management energy, tertiary regulation energy, secondary regulation energy and cross-border balancing energy) (P.O. 14.4., Resolución de 08/05/2014).

- If the production unit is long and the overall system is short: The production unit reduces the system imbalance since it deviates in the opposite direction of the overall system. Therefore, the unit won't be penalised and it will receive an imbalance price equal to the day-ahead marginal price (P.O. 14.4., Resolución de 08/05/2014).

- If both the production unit and the overall system are short: The production unit contributes to the system imbalance and thus it unit will be penalised. It will have to pay an imbalance price for its downward deviation higher than the day-ahead marginal price (Sáiz-Marín et al., 13/01/2012). This imbalance price is settled as the average price of activated balancing energy (upward deviation management energy, tertiary regulation energy, secondary regulation energy and cross-border balancing energy) (P.O. 14.4., Resolución de 08/05/2014).

- If the production unit is short and the overall system is long: The production unit reduces the system imbalance since it deviates in the opposite direction of the overall system. The unit won't be penalised hence and it will pay an imbalance price equal to the day-ahead marginal price (P.O. 14.4., Resolución de 08/05/2014).

3.2 SECONDARY REGULATION MARKET

In this section a description of the secondary regulation market is carried out. It is divided into 4 subsections. Firstly, the type of units that can currently participate in the secondary regulation is presented. Secondly, in the subsection 3.2.2, the organisation of the market is described. Then, the remuneration of secondary regulation services is explained in the sub-section 3.2.3. Finally, the allocation of the incurred costs in the provision of secondary regulation services is presented in the sub-section 3.2.4.

3.2.1 ALLOWED SECONDARY REGULATION PROVIDERS

The providers of secondary regulation services are the regulating zones. Within each regulating zone, only the conventional generation and the manageable renewable generation authorised by the System Operator can participate in the secondary regulation (P.O. 7.2., Resolución de 18/05/2014).

3.2.2 ORGANIZATION OF THE SECONDARY REGULATION MARKET

Every day, the Spanish System Operator Red Eléctrica de España (REE) publishes the secondary regulation reserves requirements for the following day (D) before 16:00 of the day ahead (D-1). After publishing these requirements, REE opens a process to receive bids to provide the secondary regulation service (P.O. 3.1., Resolución de 08/05/2014). During this process the agents responsible for each regulating zone will be able to submit bids for secondary regulation bands of power (MW) with a price (€/MW) for each Settlement Period of the following day. The secondary regulation band is composed by upward and downward reserve. The relationship between these reserves should be equal to the ratio between the total upward and the downward reserve demanded by REE for the whole system. The bid can be composed of different blocks, but only one block can be indivisible (P.O. 7.2., Resolución de 18/05/2014).

The process of receiving bids is closed at 17:30. Considering the received bids, REE assigns the provision of the secondary regulation reserves service trying to minimize the costs incurred (P.O. 3.1., Resolución de 08/05/2014). It should be noted that, if the marginal price belongs to several offers, REE will carry out a pro-rata distribution of the reserves to be assigned according to the power band offered by each unit. Furthermore, if the acceptance of an offer resulted in a technical constraint, it would not be considered in the assignation process (P.O. 7.2., Resolución de 18/05/2014).

Before 17:45 the System Operator publishes which units will provide secondary regulation reserves in each Settlement Period of the following day (P.O. 3.1., Resolución de 08/05/2014). This assignation is firm, hence the regulating zones acquire the obligation to provide the power band assigned. If the units needed to modify their previous committed dispatch to provide the secondary regulation reserves, they would be able to achieve the desired dispatch participating in the Intraday Markets. Nevertheless, if they did not succeed to obtain the desired dispatch in the Intraday Markets, the agent would communicate the required redispatch to REE and the System Operator would carry out this redispatch organizing a Deviation Management Market or with the assignation of tertiary regulation reserved. The incurred cost would be assumed by the responsible agent (P.O. 7.2., Resolución de 18/05/2014).

3.2.3 REMUNERATION OF SECONDARY REGULATION SERVICES

In this sub-section the secondary regulation remuneration is described. This remuneration is related to the provision of two services: the provision of secondary regulation reserves and the net energy generated following the secondary regulation requirements (P.O. 7.2., Resolución de 18/05/2014). The remuneration of each service is explained below.

3.2.3.1 Remuneration of secondary regulation reserves

All the units whose bids have been accepted for the provision of secondary regulation reserves will be remunerated with the marginal price obtained in the auction, which is the same for upward and downward reserves. This marginal price is equal to the price of the last bid that has been required to accept (P.O. 7.2., Resolución de 18/05/2014). Therefore, if a secondary regulation band is assigned to a unit u, this unit will have a right to be paid ($RPSRB_u$) according to the following formula (P.O. 14.4., Resolución de 08/05/2014):

$$RPSRB_u = SRB_u \times MP_{SRB}$$

where:

SRB_u = Secondary regulation band assigned to the unit u [KW].

MP_{SRB} = Marginal price for secondary regulation band [€/KW].

3.2.3.2 Remuneration of net secondary regulation energy

The net energy generated following the secondary regulation requirements is valued at the marginal price of the tertiary regulation energy that had been necessary (or would have been necessary) to use in the Settlement Period to replace the secondary regulation energy delivered (P.O. 7.2., Resolución de 18/05/2014). Nevertheless, the remuneration of the regulating zone will be different depending on whether the net energy generated is positive (upward energy) or negative (downward energy) (P.O. 14.4., Resolución de 08/05/2014).

On the one hand, the contribution of a regulating zone z providing upward energy gives this zone a right to be paid ($RPSRUE_z$) according to the following formula:

$$RPSRUE_z = SRUE_z \times MP_{SRUE} \times KU$$

where:

$SRUE_z$ = Secondary regulation upward energy provided by the regulating zone z [KWh].

MP_{SRUE} = Marginal price for secondary regulation upward energy [€/KWh].

KU = 1 if there is enough tertiary upward energy and 1.5otherwise.

On the other hand, the contribution of a regulating zone z providing downward energy gives this zone an obligation to pay ($OPSRDE_z$) according to the following formula (P.O. 14.4., Resolución de 08/05/2014):

$$OPSRDE_z = SRDE_z \times MP_{SRDE} \times KD$$

where:

$SRDE_z$ = Secondary regulation downward energy provided by the regulating zone z [KWh].

MP_{SRDE} = Marginal price for secondary regulation downward energy [€/KWh].

KD = 1 if there is enough tertiary downward energy and 0.85otherwise.

It should be pointed out that the price for the secondary regulation downward energy is bounded by the maximum price allowed in the Day Ahead Market (P.O. 7.2., Resolución de 18/05/2014).

3.2.4 COST ALLOCATION OF SECONDARY REGULATION SERVICES

The cost of secondary regulation reserves (band cost) is paid by the consumers proportionally to metered energy, with the exception of pumping consumption and exports (Red Eléctrica de España, 2015).

The cost of secondary regulation energy is paid by the generation and demand units that have deviated from their programmes (Red Eléctrica de España, 2015).

3.3 TERTIARY REGULATION MARKET

In this section the Spanish tertiary regulation market is described. The section is divided into 4 sub-sections. Firstly, the type of units that can currently participate in the tertiary regulation is presented. Secondly, in the sub-section 3.3.2, the organisation of the market is described. Then, the remuneration of tertiary regulation service is explained in the subsection 3.3.3. Finally, the allocation of the incurred costs in the provision of tertiary regulation services is presented in the sub-section 3.3.4.

3.3.1 ALLOWED TERTIARY REGULATION PROVIDERS

Tertiary regulation can be provided by the generating units and the pumping consumption authorised by the System Operator (P.O. 7.3., Resolución de 08/05/2014).

3.3.2 ORGANIZATION OF THE TERTIARY REGULATION MARKET

Every day, REE publishes the tertiary regulation reserves requirements for the following day (D) before 21:00 of the day ahead (D-1) (P.O. 3.1., Resolución de 08/05/2014). The minimum requirement for tertiary reserve is generally dimensioned by the rated power of the largest unit in the system plus 2% of the forecast hourly load. . The requirement for tertiary regulation downward reserve will be established depending on the status of the system and it will take a value between 40% and 100% of the requirement for tertiary upward reserve (P.O. 1.5., Resulocíon de 13/07/2006). As it takes places in the secondary regulation market, after publishing the tertiary regulation requirements REE opens a process to receive bids to provide this service (P.O. 3.1., Resolución de 08/05/2014).

During this process, it is mandatory that all the agents allowed to participate in tertiary regulation offer all their tertiary reserve available (upward and downward)[MW]and the price for the related energy [€/MWh] for each Settlement Period of the following day. Despite the fact that the process of receiving bids is closed at 23:00 of the day ahead (D-1), in order to ensure that all the available reserve is offered for the following day, the offers have to be updated every time the unit program is modified, as well as if there is any change in the availability of the unit (P.O. 3.1., Resolución de 08/05/2014). The period for updating the offers finishes60 minutes before the beginning of the Settlement Period (P.O. 7.3., Resolución de 08/05/2014).

3.3.3 REMUNERATION OF TERTIARY REGULATION SERVICES

The tertiary regulation remuneration is only related to the provision of the net energy generated following the tertiary regulation requirements. This energy is valued at the hourly marginal price of the accepted offers in each Settlement Period(P.O. 14.4., Resolución de 08/05/2014).

The contribution of a unit u providing upward energy gives this unit a right to be paid ($RPTRUE_u$) according to the following formula:

$$RPTRUE_u = TRUE_u \times MP_{TRUE}$$

where:

$TRUE_z$ = Tertiary regulation upward energy provided by the unit u [KWh].

MP_{TRUE} = Marginal price for tertiary regulation upward energy [€/KWh].

On the other hand, the contribution of a unit providing downward energy gives this units an obligation to pay ($OPTRDE_u$) according to the following formula (P.O. 14.4., Resolución de 08/05/2014):

$$OPTRDE_u = TRDE_u \times MP_{TRDE}$$

where:

$TRDE_u$ = Tertiary regulation downward energy provided by unit u [KWh].

MP_{TRDE} = Marginal price for tertiary regulation downward energy [€/KWh].

3.3.4 COST ALLOCATION OF TERTIARY REGULATION SERVICES

The cost of tertiary regulation is paid by the generation and demand units that have deviated from their programmes (Red Eléctrica de España, 2015).

3.4 DEVIATIONS MANAGEMENT MARKET

In this section a description of the Spanish deviation management market is carried out. The section is divided into 3 sub-sections. The type of units that can currently participate in deviation management is presented in the sub-section 3.4.1. Secondly, in the sub-section 3.4.2, the organisation of this market is described. Finally, the remuneration of deviation management service is explained in the sub-section 3.4.3.

3.4.1 ALLOWED DEVIATIONS MANAGEMENT PROVIDERS

The deviations management providers are the conventional generation and the manageable renewable generation authorised by the System Operator, as well as the pumping units (P.O. 3.1., Resolución de 08/05/2014).

3.4.2 ORGANIZATION OF THE DEVIATIONS MANAGEMENT MARKET

Every day, REE assesses the difference between the scheduled supply and the forecasted demand. If the forecasted deviation exceeds 300 MW, REE can solve it though the deviation management market. In order to do it, the System Operator will announce the energy required (upwards or downwards) in every Settlement Period, as well as the maximum and the minimum bounds applicable to energy offers (P.O. 3.3., Resolución de 18/05/2014).

The process to receive offers is launched after the assignation of the bids of the last intraday session and it lasts 30 minutes. The resulted firm assignation carried out by REE is not announced until 15 minutes before the first hour of the time scope covered in the deviations management market. This time scope extends to, at the most, all the Settlement

Periods between an intraday session closure and the first hour of the programming horizon of the next intraday session (P.O. 3.3., Resolución de 18/05/2014).

3.4.3 REMUNERATION OF DEVIATIONS MANAGEMENT SERVICES

As in tertiary regulation, the deviations management remuneration is only related to the provision of the net energy generated following the deviations management requirements. This energy is valued at the marginal price of the accepted offers in each Settlement Period (P.O. 14.4., Resolución de 08/05/2014).

The assignation of upward energy to a unit u in the deviations management market gives this unit a right to be paid ($RPDMUE_u$) according to the following formula:

$$RPDMUE_u = DME_u \times MP_{DMUE}$$

where:

$DMUE_z$ = Deviations management upward energy assigned to the unit u [KWh].

MP_{DMUE} = Marginal price for deviations management upward energy [€/KWh].

On the other hand, the assignation of downward energy to a unit u in the deviations management market gives this unit an obligation to pay ($OPDMDE_u$) according to the following formula (P.O. 14.4., Resolución de 08/05/2014):

$$OPDMDE_u = DMDE_u \times MP_{DMDE}$$

where:

$DMDE_u$ = Deviations management downward energy assigned to the unit u [KWh].

MP_{DMDE} = Marginal price for deviations management downward energy [€/KWh]

3.5 CONCLUSIONS

Although tertiary regulation and deviation management services are supposed to be reliable, the deviations that can take place in these services have a similar impact on system security than the deviations produced in the daily schedule. On the other hand, secondary regulation has a key role in ensuring the stability of the system. Therefore, secondary regulation reserves must be very reliable.

The wind forecast error diminishes as closer as real time it is carried out. Consequently, the uncertainty in the provision of ancillary services by wind generation will decrease for those services whose bids can be submitted closer to real time. These services are tertiary regulation and deviation management. In tertiary regulation, considering the worst case scenario (the last minute of the Settlement Period traded), the bids can be submitted up to two hours before real time. In deviation management, also considering the worst case scenario (the last minute traded after the sixth intraday market), the bids can be submitted up to 8 hours before real time. As far as secondary regulation is concerned, since the process for receiving the bids is closed at 17:30 of D-1, the time scope of the last minute traded is 30 hours and a half before real time. Consequently, the uncertainty in the wind forecast for secondary regulation makes more difficult for wind generation to participate in this service, taking into account that a higher reliability is also demanded for secondary regulation.

In conclusion, due to the current organization of the ancillary services markets in Spain, tertiary regulation seems to be the service most suitable for wind generation to participate in. Moreover, since the bids to provide it can be submitted up to an hour before the beginning of the Settlement Period, this participation could also reduce wind deviations; hence decreasing the balancing costs both for the system and wind farm owners. Therefore, the participation in this service presents many advantages that motivate a deeper assessment of it, which will be carried out in the following chapters.

Chapter 4 THEORETICAL ASSESSMENT OF THE MOST SUITABLE CIRCUMSTANCES TO PARTICIPATE IN ANCILLARY SERVICES

After analysing the main features about the imbalance price scheme and the ancillary services related to frequency regulation in Chapter 3, in this chapter the theoretical assessment of the most suitable circumstances for wind generation to participate in these will be carried out. The chapter is divided into three sections. The theoretical analysis of the participation of wind generation in secondary regulation will be described in section 4.1. A similar assessment will be carried out in section 4.2 for the participation in tertiary regulation and deviation management services. Finally, in section 4.3 the main conclusions obtained will be presented.

4.1 THEORETICAL ASSESSMENT OF THE MOST SUITABLE CIRCUMSTANCES TO PARTICIPATE IN SECONDARY REGULATION

This section will focus on the assessment of the participation of wind energy in secondary regulation in Spain. It is divided into three sections. Some initial considerations that should be taken into account to carry out the analysis will be presented in section 4.1.1. Then, the participation in this ancillary service will be assessed, firstly under low and medium wind conditions in section 4.1.2 and secondly under high wind conditions in section 4.1.3.

4.1.1 INITIAL CONSIDERATIONS

In the Spanish secondary regulation both upward and downward reserves have to be provided simultaneously, as it has been explained in Chapter 3. The addition of these reserves constitutes the secondary regulation band.

In order to provide the upward reserves of the secondary regulation band, wind generation should be deloaded, instead of running at the maximum wind power production. The required power to be deloaded depends on the methodology applied to determine the secondary regulation band. The two different methodologies that can be employed are described below:

- Constant band bounds: The minimum value of the forecasted available active power is used as the upper limit of the regulation band. As it was explained in the section 2.1.3, it is necessary to use the minimum value because otherwise there would not be guarantee that all the setpoints were followed accurately. Furthermore, in order to avoid the uncertainties of the wind forecasting mechanisms, this upper value is lowered in correspondence to the estimated forecast error, as it can be seen in the following figure.

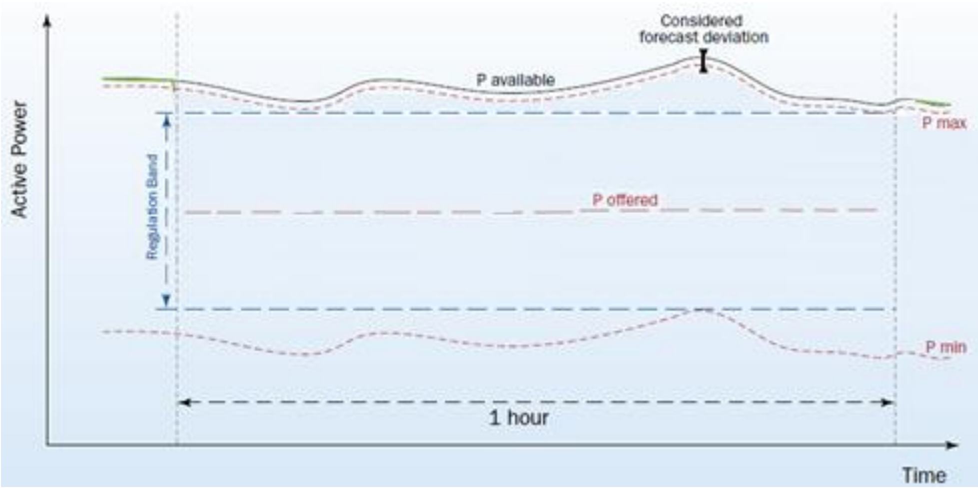

Figure 8: Determination of the regulation band: constant band bounds.

The lower value of the regulation band is calculated taking into account the technical limitations of wind turbines.

This way of determining the regulation band was employed in the Twenties project. In this case, the lower value of the regulation band was between 25% and 50% of the nominal power of wind turbines (Twenties, 2013).

- Variable band bounds: The upper limit of the regulation band (P_{max}) corresponds to the available power minus the estimated forecast error, as it can be seen in Figure 9. The lower limit (P_{min}) corresponds to the upper limit minus the regulation band. The regulation band is constant, as in the previous case, and the lower limit is also constrained by the technical characteristics of wind turbines.

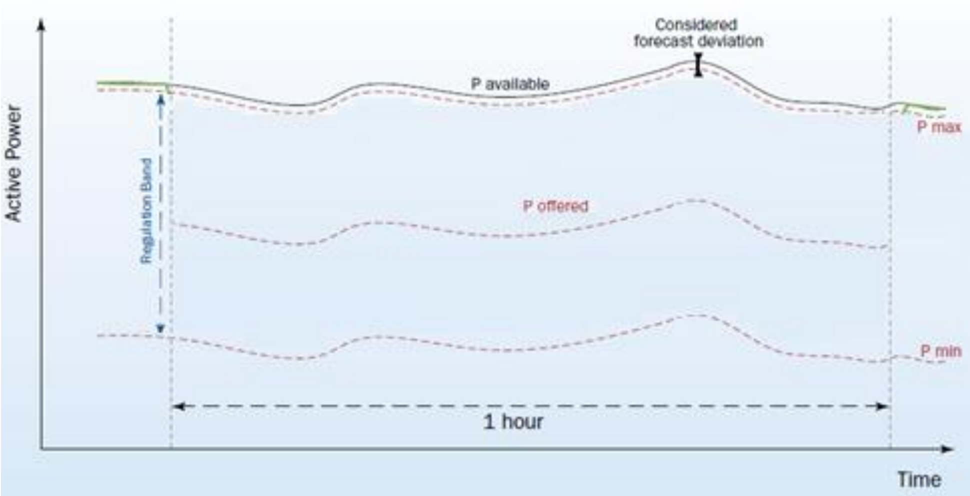

Figure 9: Determination of the regulation band: variable band bounds.

For the same regulation band, the second approach allows to reduce the amount of energy that has to be curtailedand thus decreasing the loss of profits from the day-ahead and intraday markets. However, the power scheduled to be achieved in those markets (the power offered in Figure 8 and Figure 9) is not constant in the time scope considered; hence it will imply to incur in some deviations since within the hourly Spanish settlement periods a constant schedule is required. Similar deviations would be incurred if wind turbines operated at maximum power and thus this is not an important issue. However, the current Spanish AGC works with constant band bound and a fixed power offered. Consequently, if a variable band bound reserves is wanted to be employed, the current AGC mechanism should be redesigned.

Both methodologies imply a reduction in the power output of wind turbines, which will be very significant if the power variations in the power available within the hour are high, especially if the first methodology is applied. Therefore, the participation in the secondary regulation market is not clear to be profitable.

The loss of the profit from the reduction of the energy schedule in the day-ahead will be compensated either if the price of secondary regulation band is higher than the day-ahead price or if the income from the whole remuneration of secondary regulation (reserves and net energy provided) is higher than the income from the day-ahead. Since the energy demanded by the AGC is unknown beforehand, a first approach focus on the first recovery option has been carried out.

The difference between the price of secondary regulation reserves and the day-ahead price in all the hours of the year 2014 has been analysed. As it can be seen in Figure 10, the probability of having a price for the secondary regulation band higher than the day-ahead price increases with the level of wind contribution in demand coverage.

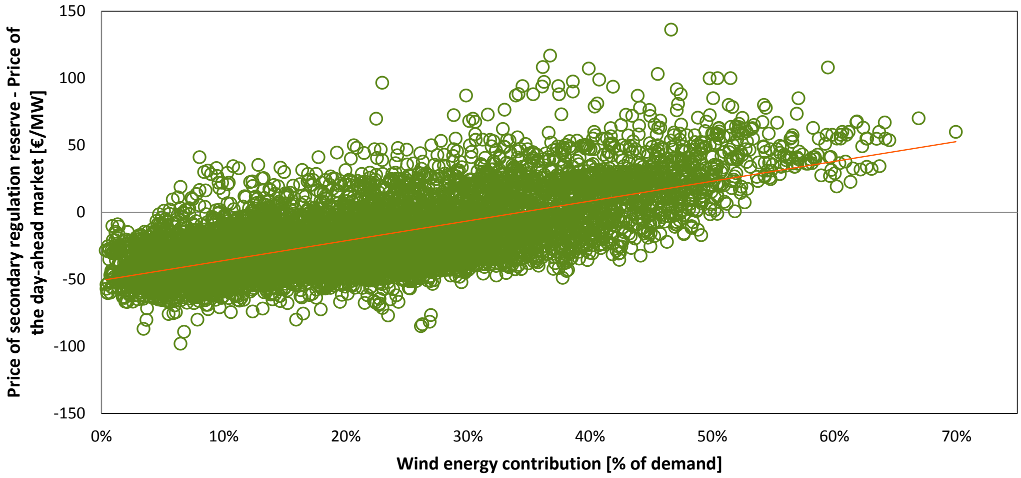

Figure 10: Price of secondary regulation reserve – price of the day-ahead market depending on the wind energy contribution in the year 2014.

Consequently, the interest of wind generation to enter into the secondary regulation market will depend on the expected wind conditions.

4.1.2 PARTICIPATION IN THE SECONDARY REGULATION UNDER LOW AND MEDIUM WIND CONDITIONS

Under low wind conditions, the provision of reliable upward reserves is not feasible due to the technical limitations that constrain the lower bound of the regulation band. Under medium wind conditions the provision of a small upward reserve could be technically feasible. However, since wind conditions are not high the price of the day-ahead market won't probably be decreased. Therefore, assuming that the agents (the owners of the wind farms) have no incentives to reduce their production to provide upward energy would be reasonable.

As far as downward reserve is concerned, under low wind conditions the provision of this reserve will be very low, or even impossible, due to the technical limitations of wind turbines. On the other hand, the provision of downward reserves under medium wind conditions would be reasonable. However, this option would be difficult to implement since it would require changing the current regulation and the current AGC design in which all the units that are involved provide simultaneously upward and downward reserves.

In conclusion, the participation of wind generation in the secondary regulation under low and medium wind conditions is not desirable either for the agents or for the System Operator.

4.1.3 PARTICIPATION IN THE SECONDARY REGULATION UNDER HIGH WIND CONDITIONS

Under high wind conditions, the provision of upward secondary regulation could be reasonable depending on the amount of energy that would have to be reduced in the day-ahead schedule. If the reserve provided has constant band bounds, the energy that should be reduced in the day-ahead will be higher than the upward band remunerated in the secondary regulation. Therefore, not only the price for the secondary regulation reserves have to be higher than the price of the day-ahead market, but also it should be able to compensate the energy curtailed and not remunerated in the secondary regulation.

Nevertheless, the provision of upward reserves will be desirable when curtailments of wind generation take place due to an excess of wind production in the system. In this case, the possibility for agents to reduce the output of the wind turbines while being remunerated to provide this service will be very interesting.

Under high wind conditions, there will be a significant amount of power available to offer downward reserves. For conventional power plants, the reduction of their production to provide downward energy involves the savings in fuel costs related to this energy. However, for wind farms the reduction of their output does not imply any cost savings. Consequently, they will be interesting in provide downward reserves if the remuneration received for this service is higher than the payment that they will have to make if downward energy is required by the AGC.

The difference between the price of secondary regulation reserves and the price of secondary regulation downward energy has been analysed for the year 2014. The results obtained are depicted in the figure below.

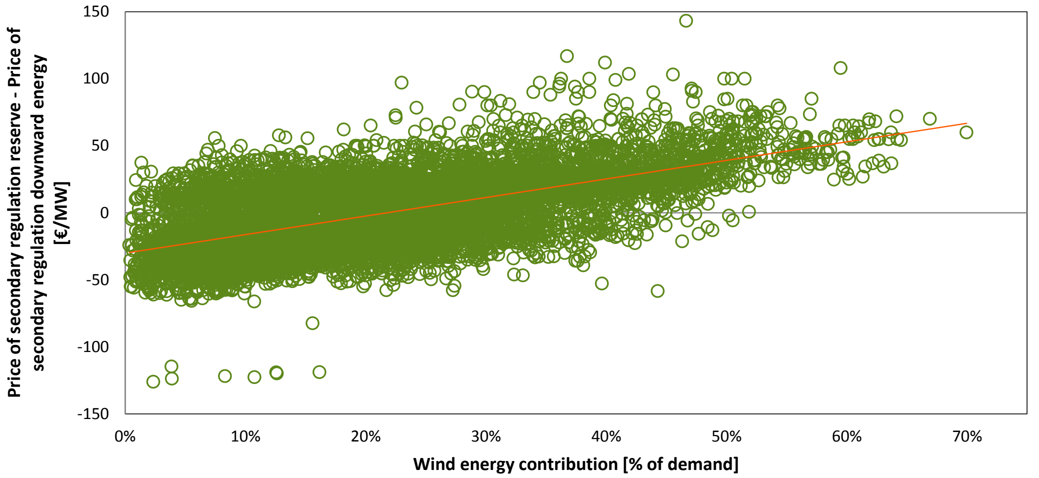

Figure 11: Price of secondary regulation reserve – price of secondary regulation downward energy depending on the wind energy contribution in the year 2014.

It can be observed that under high wind conditions the price of secondary regulation reserves is higher than the price of secondary regulation downward energy in most of the hours. Therefore, in the worst case scenario in which the AGC requires to reduce the output corresponding to all the downward reserve, the remuneration obtained for providing these reserves will be higher than the payment carried out for reducing the energy schedule.

In conclusion, the participation of wind generation in secondary regulation under high wind conditions is desirable as far as downward reserves are concerned. Regarding upward reserves, the interest in this participation will depend on the amount of energy that has to be curtailed. Consequently, if the provision of both services has to be carried out simultaneously the participation in secondary regulation will be desirable in some circumstances. The investments related to the implementation of the AGC in the wind farms, although not expected to be high (Twenties, 2013), should be also considered in the profitability analysis; hence this participation could be interesting in the medium term.

4.2 THEORETICAL ASSESSMENT OF THE MOST SUITABLE CIRCUMSTANCES TO PARTICIPATE IN TERTIARY REGULATION AND DEVIATIONS MANAGEMENT MARKET

This section will deal with the assessment of the participation of wind energy in tertiary regulation and deviation management services in Spain. It is divided into three sections. Some initial considerations that should be taken into account to carry out the analysis will be presented in section 4.2.1. Then, the participation in these ancillary services will be assessed, firstly under low and medium wind conditions in section 4.2.2 and secondly under high wind conditions in section 4.2.3.

4.2.1 INITIAL CONSIDERATIONS

After analysing in Chapter 3 the features of the different frequency regulation markets in Spain and the current imbalance price scheme, the major interest identified for wind generation in participating in tertiary regulation was the reduction of deviations, one of the main operating costs of wind energy.

Furthermore, not only is the participation in tertiary regulation interesting for wind agents, but also it would benefit the System Operator and consumers. If the owners of wind farms adjust their schedule closer to real time according to the wind forecast, the System Operator will have more accurate information about the system status. Moreover, the consumers will benefit from lower balancing system costs.

4.2.2 PARTICIPATION IN THE TERTIARY REGULATION AND DEVIATIONS MANAGEMENT MARKETS UNDER LOW AND MEDIUM WIND CONDITIONS

As far as upward energy is concerned, if the agent expects to be able to produce more energy than the committed schedule, he will bid it in the tertiary regulation market or in the deviation management market with a competitive price in order to reduce its forecasted deviations. Then, the following situations can take place:

- If the system is short: The System Operator will accept the bid; hence the deviations of the system will be reduced, as well as the reserves required by the system and their related costs. Consequently, the participation of wind generation will benefit the agent, the system and the consumers.

- If the system is long: The System Operator won't accept the bid and thus the wind generation deviations won't decrease, as it takes place in the current Spanish system.

As far as downward energy is concerned, if the agent expects to be able to produce less energy than the committed schedule, the agent will offer the difference in the tertiary regulation market or in the deviation management market with a competitive price in order to reduce its forecasted deviations. Then, the following situations can take place:

- If the system is short: The System Operator won't accept the offer; hence the wind generation deviations won't be reduced, as it takes place in nowadays in Spain.

- If the system is long: The System Operator will accept the offer; hence the deviations of the system will be reduced, as well as the reserves required by the system and their related costs.

Therefore, the participation of wind generation in tertiary regulation or deviation management services can either keep the same situation as the current one or improve it, benefiting all the agents involved.

4.2.3 PARTICIPATION IN THE TERTIARY REGULATION AND DEVIATIONS MANAGEMENT MARKETS UNDER HIGH WIND CONDITIONS

Under high wind conditions, the energy available but not previously committed due to an excess in wind production in the system will be bided in the tertiary regulation market or in the deviations management market as upward energy. Moreover, the price of this bid will be very low due to the high interest in producing all the available wind energy.

As far as downward energy is concerned, a huge amount of energy will be available to be deloaded. Moreover, the owners of wind farms will be willing to provide this downward energy in order to diminish the mechanical efforts suffered by the wind turbines under high wind conditions.

Consequently, the participation of wind generation in the tertiary regulation and deviations management markets is desirable under high wind conditions because it benefits both wind agents and the systems since it would probably be the most economical reserve.

4.3 CONCLUSIONS

In this chapter, a theoretical assessment of the most suitable circumstances for wind generation to participate in ancillary services has been carried out. Due to the impact of wind conditions on the prices of the day-ahead market and the different ancillary services markets, low, medium and high wind conditions have been distinguished.

The conclusions obtained are presented in the following table.

	Low and medium wind conditions	High wind conditions
	The price is high enough to motivate wind agents to produce	The price is low. Some wind generation can even have not been committed
Participation in secondary regulation	Not possible/ Not desirable	Under certain circumstances
Participation in tertiary regulation or deviation management	Desirable	Very desirable

Table 1: Theoretical assessment of the participation of wind generation in the Spanish frequency regulation.

Due to the reliability required in secondary regulation, under low and medium wind conditions the participation of wind generation is not desirable (or even not possible) with the current regulation of this service, by which upward and downward reserves should be provided simultaneously. On the other hand, under high wind conditions, depending on the method employed to determine the regulation band, the participation of wind generation could be interesting. Nevertheless, some additional investment would be required in order to design and implement the AGC mechanisms in the wind farms.

The participation of wind generation in tertiary regulation or deviation management services can either keep the same situation as the current one or improve it, benefiting wind agents, the system and thus the consumers, especially under high wind conditions. Therefore, allowing wind generation to participate in these services as soon as possible in Spain would be desirable.

Although deviations management mechanisms present similar features to tertiary regulation, this service is only demanded in specific circumstances that depend on the status of the system. The potential benefits that could be obtained will vary a lot depending on the year analysed; hence reducing the significance of the conclusions obtained.

Consequently, the following chapters will focus on the economic assessment of the participation of wind generation in tertiary regulation since this service seems to have the highest potential benefits for both wind generation and the system.

Chapter 5 ESTIMATION OF THE ECONOMIC IMPACT OF THE PARTICIPATION OF WIND GENERATION IN TERTIARY REGULATION: BASE STRATEGY

After analyzing the organization of the ancillary services in Chapter 3 and the theoretical assessment of the most suitable circumstances for wind generation to participate in them in Chapter 4, we can support that the main advantage of tertiary regulation in Spain is its closeness to real time. The participation in tertiary regulation will allow reducing the wind production deviations (which constitute one of the major operating costs for wind generation), as well as the overall system deviation. This will benefit both wind agents and the System Operator. Consequently, the base strategy for wind agents when participating in tertiary regulation market will be to reduce their forecasted deviations.

The economic impact for wind generation if the base strategy is employed will be assessed in this chapter. The chapter is divided into three sections. Firstly, the objective and the market participation process of the base strategy will be explained in section 5.1. Then, the economic impact for wind generation of having implementing this strategy in the years 2012, 2013, 2014 and in the first five months of the year 2015 will be estimated in section 5.2. It should be noted that some of the results obtained are only presented for the year 2014 for simplicity, while the results for the rest of the years can be found in the Annex 1 . 2014 has been considered the reference year because it is the last year with hourly data available; thus its energy mix and the features of the system operation in this year could be the most similar characteristics to the current Spanish electric power system. Finally, the conclusions of the chapter will be presented in section 5.3.

5.1 OBJECTIVE AND MARKET PARTICIPATION PROCESS

In the base strategy, it is proposed to employ the tertiary regulation market to adjust the wind production schedule in order to reduce real-time deviations. The participation of wind agents in tertiary regulation will be similar to the participation in intraday markets, which main purpose is to adjust the wind production schedule to the last forecast wind production available.

Nowadays, in Spain, the last intraday market in which a given hour h is traded constitutes the last opportunity for wind agents to adjust their schedule. Within the day, depending on the hour h considered, the number of hours before real time when this hour is traded for the last time can vary from 4 hours (hours 1, 5, 8, 12 and 16) to 9 hours (hour 21). It should be noted that, these time scopes have been computed for the last minute of each hour h in order to be conservative and consider the highest forecast error(since errors in wind forecasting are greater as the predictions take place further from real-time). Figure 12 shows the 'Sipreolico errors' from the year 2008 up to 2014. The 'Sipreolico errors' represent the expected wind production forecast errors as a function of the prediction horizon. They are the errors of the whole sector wind production forecast carried out by REE.

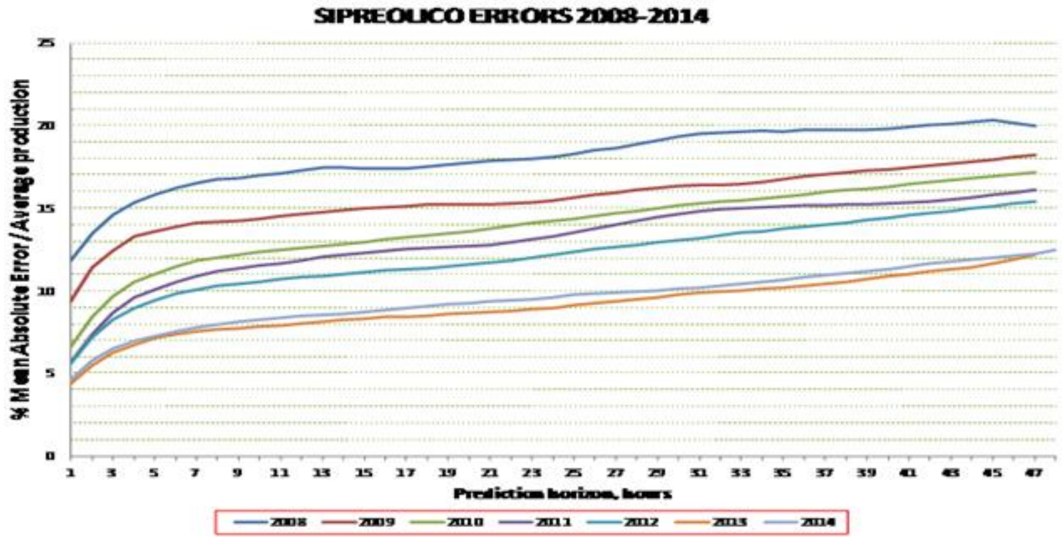

Figure 12: Wind forecast error depending on the prediction horizon (Source: REE).

The development of more accurate wind forecast techniques resulted in a lower forecast error in the last years. This error decreases if the forecast is made closer to real time.

The following table shows, for each hour h, the last intraday market where this hour has been traded, as well as the number of hours before real time when this last trade has taken place. Depending on this prediction horizon, the expected wind forecast error has been obtained from Figure 12 for each of the years analyzed in the Master Thesis (2012, 2013 and 2014). The values obtained for the year 2014 are presented in Table 2. The results for the rest of the years can be found in the Annex 1 .

Hour	Last intraday market	Prediction horizon [hours]	Estimated wind production forecast error [%]
1	2	4	6,8
2	2	5	7
3	2	6	7,5
4	2	7	7,8
5	3	4	6,8
6	3	5	7
7	3	6	7,5
8	4	4	6,8
9	4	5	7
10	4	6	7,5
11	4	7	7,8
12	5	4	6,8
13	5	5	7
14	5	6	7,5
15	5	7	7,8
16	6	4	6,8
17	6	5	7
18	6	6	7,5
19	6	7	7,8
20	6	8	8
21	6	9	8,2
22	1	5	7
23	1	6	7,5
24	1	7	7,8
25	1	8	8

Table 2: Hourly wind production forecast error for the year 2014.

If wind generation was allowed to participate in tertiary regulation the prediction horizon will be reduced up to two hours (considering the last minute of the hour h) since tertiary regulation bids can be updated up to one hour before the beginning of the Settlement Period traded. Therefore, according to Figure 12, the wind production forecast error will decrease up to 5,8% in the hours with tertiary regulation in the year 2014.

5.2 ESTIMATED ADDITIONAL PROFITS FOR PARTICIPATING IN TERTIARY REGULATION

The main objective of wind agents when participating in tertiary regulation will be to decrease their expected deviations. The economic impact of having implemented this base strategy in the whole wind sector in the years2012, 2013 and 2014 has been estimated, as well as in the first five months of the year 2015.

The section is divided into five subsections. Firstly, the data employed and the assumptions made will be presented in the sections 5.2.1 and 5.2.2. The formulation of the additional profits obtained will be explained in the section 5.2.3. The bid design proposal will be described in the section 5.2.4. Finally, the results obtained will be presented in the section 5.2.5.

5.2.1 DATA EMPLOYED

In order to estimate the economic impact of the implementation of the base strategy, the following data has been employed for each of the four years studied. The number of data presented in the third column corresponds to the year 2014. For the year 2012 the number of data is higher since it was a leap year. For the year 2015 the number of data is lower because only the first five months are studied.

Data	Source	Number of data
Hourly prices of the day ahead market	(Red Eléctrica de España, Liquidaciones, 2014)	8760
Hourly prices of tertiary regulation upward energy		8760
Hourly prices of tertiary regulation downward energy		8760
Hourly volumes of tertiary regulation upward energy		8760
Hourly volumes of tertiary regulation downward energy		8760
Hourly prices of upward deviations		8760
Hourly prices of downward deviations		8760
Wind sector energy schedule		8760
Wind sector energy measured		8760
Monthly costs of deviations for the wind sector		12
Estimated wind production forecast error	Figure 12	25

Table 3: Data employed in the base strategy for the year 2014.

The data employed is huge. For instance, for the year 2014 it amounts to 78877 data. Therefore, in order to download and organize the information, some macros have been developed in the Excel program, in Visual Basic.

It should be noted that the estimated wind production forecast error for the year 2015 has not been provided by REE yet. Consequently, the data from the year 2014 of Figure 12 has been employed for the year 2015 since it is the most recent information available.

5.2.2 ASSUMPTIONS

In order to determine the resulting wind deviations, the following assumptions have been made:

- The whole wind energy sector has been treated as a single agent. Therefore, the deviations for the whole sector have been reduced simultaneously, submitting a single bid by the wind sector.

- When the deviations are reduced due to the participation of wind generation in the tertiary regulation, the sign of the deviation does not change, as it can be seen in Figure 13. In this figure the schedule after participating in tertiary regulation (TR) is depicted for the case in which an upward deviation takes place (in the left side) and for the case in which a downward deviation is incurred (in the right side).

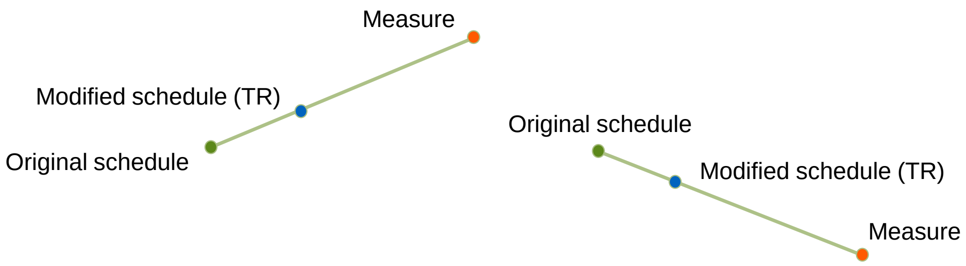

Figure 13: Qualitative representation of the reduction of the deviations when participating in tertiary regulation.

Therefore, for instance, if wind sector had an upward deviation, after participating in tertiary regulation it will have a lower upward deviation

- The resulting deviation is equal to the initial deviation times the reduction in the forecast error.

- The participation of wind generation in tertiary regulation does not affect the prices of the different electricity markets, with the exception of the tertiary regulation market.

- The price of tertiary regulation energy won't be affected by the participation of wind energy if its contribution is lower than 80% of the total tertiary regulation energy (either upward or downward energy). In these hours wind generation has been assumed to not be the marginal technology in the tertiary regulation market. On the other hand, in the hours in which the wind generation provides tertiary regulation energy and it amounts to 80% or more of the total tertiary regulation required for the whole system, the price of tertiary regulation has been considered to be equal to the wind generation bid.

5.2.3 FORMULATION OF THE ADDITIONAL PROFITS

Under the previous assumptions, in each hour the following situations can take place:

- The System Operator does not require tertiary regulation energy: the wind production deviations will remain the same.

- The System Operator requires tertiary regulation upward energy and the wind sector is short: the wind production deviations (downward deviations) will remain the same.

- The System Operator requires tertiary regulation upward energy and the wind sector is long: the wind production deviations (upward deviations) will be reduced.

- The System Operator requires tertiary regulation downward energy and the wind sector is short: the wind production deviations (downward deviations) will be reduced.

- The System Operator requires tertiary regulation downward energy and the wind sector is long: the wind production deviations (upward deviations) will remain the same.

Consequently, the only circumstances when an additional profit can be obtained are when the tertiary regulation energy requirement has the same sign as the wind sector deviation. The additional profit in these circumstances will be formulated below.

5.2.3.1 Tertiary regulation upward energy is required and the wind sector is long

The tertiary regulation upward energy (TRUE) provided by wind generation in the hour h will be equal to the reduction of its upward deviation (RUD) and it will be:

$$TRUE = RUD = UD_i * \frac{(WPFE_i - WPFE_f)}{WPFE_i}$$

where UD_i is the original upward deviation (the actual upward deviation in 2014), $WPFE_i$ is the original wind production forecast error and $WPFE_f$ is the final wind production forecast error.

The additional profit estimated (ΔProf) will be:

$$\Delta Prof = RUD * (P_{TRUE} - P_{UD})$$

where P_{TRUE} is the price of tertiary regulation upward energy and P_{UD} is the price of upward deviations.

The additional profit will be positive if the price obtained for the provision of tertiary regulation upward energy is higher than the price received for the upward deviations. In principle, this condition is expected to be fulfilled in all the hours in which tertiary regulation upward energy is required since the price of the upward deviations is lower or equal to the day-ahead price and the units that provide tertiary regulation are the ones that have not been committed in the day-ahead market because their bid (their expected variable cost) was higher than the day-ahead price. In the tertiary regulation market these units are expected to bid at least the same price (their variable cost) than in the day-ahead market and, if they are accepted to provide this service, the price of tertiary regulation will be higher than the price of the day-ahead market and thus also higher than the price of upward deviations.

Nevertheless, if the units that provide tertiary regulation upward energy need to increase their committed schedule for whatever reasons, they could bid a price lower than their variable costs; hence the price of tertiary regulation upward energy could be lower than the price of upward deviations.

The following table presents the number of hours when the condition for obtaining a positive additional profit took place in the year 2014, as well as the hours in which a loss had been incurred. The same information for the years 2012, 2013 and 2015 can be found in the Annex 1 .

	Year 2014
Number of hours with TRUE [hours]	4798
Number of hours with TRUE [% of hours of the year]	54,8%
Number of hours with TRUE when $P_{TRUE} > P_{UD}$ [% of the hours with TRUE]	89,6%
Number of hours with TRUE when $P_{TRUE} < P_{UD}$ [% of the hours with TRUE]	9,3%

Table 4: Analysis of the hours with tertiary regulation upward energy in the year 2014.

In the year 2014, tertiary regulation upward energy was required in 4798 hours (54,8% of the year). In 89,6% of these hours, the price obtained for the provision of tertiary regulation upward energy was higher than the price paid for the upward deviations. However, in 9,3% of these hours the price of tertiary regulation upward energy was lower than the price of upward deviations. Consequently, wind generation would have had a negative profit if it had provided tertiary regulation upward energy in these hours.

5.2.3.2 Tertiary regulation downward energy is required and the wind sector is short

The tertiary regulation downward energy (TRDE) provided by wind generation will be equal to the reduction of its downward deviation (RDD) and it will be:

$$TRDE = RDD = DD_i * \frac{(WPFE_i - WPFE_f)}{WPFE_i}$$

where DD_i is the original downward deviation (the actual downward deviation in 2014), $WPFE_i$ is the original wind production forecast error and $WPFE_f$ is the final wind production forecast error.

The additional profit estimated will be:

$$\Delta Prof = RDD * (P_{DD} - P_{TRDE})$$

where P_{TRDE} is the price of tertiary regulation downward energy and P_{DD} is the price of downward deviations.

The additional profit will be positive if the price paid for the provision of tertiary regulation downward energy is lower than the price paid for the upward deviations. In principle, this condition is expected to be fulfilled in all the hours in which tertiary regulation downward energy is required since the price of the downward deviations is higher or equal to the day-ahead price and the units that provide tertiary regulation are the ones that have been committed in the day-ahead market because their bid (their expected variable cost) was lower than the day-ahead price. In the tertiary regulation market these units are expected to bid at most the same price (their variable cost) than in the day-ahead market and, if they are accepted to provide this service, the price of tertiary regulation will be lower than the price of the day-ahead market and thus also lower than the price of downward deviations.

However, if the units that provide tertiary regulation downward energy need to decrease their committed schedule for whatever reasons, they could bid a price higher than their variable costs; hence the price of tertiary regulation downward energy could be higher than the price of downward deviations.

The following table presents the number of hours when the condition for obtaining a positive additional profit took place in the year 2014, as well as the hours in which an additional loss had been incurred.

	Year 2014
Number of hours with TRDE [hours]	3283
Number of hours with TRDE [% of hours of the year]	37,5%
Number of hours with TRDE when $P_{TRDE} < P_{DD}$ [% of the hours with TRDE]	96,9%
Number of hours with TRDE when $P_{TRDE} > P_{DD}$ [% of the hours with TRDE]	0,3%

Table 5: Analysis of the hours with tertiary regulation downward energy in the year 2014.

In the year 2014, tertiary regulation downward energy was required in 3283 hours (37,5% of the year). In almost all these hours (96,9%), the price paid for the provision of tertiary regulation downward energy was lower than the price paid for the downward deviations. Only 0.3% of these hours, the price of tertiary regulation downward energy was higher than the price of downward deviations and could result in a negative profit.

5.2.4 BID DESIGN

As it was explained in Chapter 3, in the section 3.2.2, all the agents allowed to participate in tertiary regulation have the obligation to offer all their tertiary reserve available (upward and downward) [MW] and the price for the related energy [€/MWh] for each Settlement Period of the following day.

If wind energy was allowed to participate in tertiary regulation, it would also be required to offer all their reserve available. The design of the offer (the price for the provided energy) will depend on whether upward reserves or downward reserves are being offered. The design proposed in this Master Thesis is described below.

Regarding the price bided for tertiary regulation upward energy two different situations should be analysed if the base strategy is implemented:

- If wind generation expects to have upward deviations: Wind generation will offer the expected upward deviations (the difference between the maximum expected available power and the schedule committed) at the day-ahead price in order to ensure that an additional positive profit will be captured if it is accepted in this market. Nevertheless, this decision could result in not being accepted in the hours in which the price of tertiary regulation upward energy, although lower than the day-ahead price, is higher than the price of upward deviations. However, if wind generation bided lower prices, it could be accepted in hours with very low prices for tertiary regulation, such as the hours in which wind energy was the marginal technology. Consequently, to prevent this risk and taking into account the uncertainty of the impact on tertiary regulation prices due to the participation of wind generation, it has been decided to bid the day-ahead price.

- If wind generation does not expect to have upward deviations: If wind generation forecast that the maximum available power is going to be lower than its schedule it won't be interested in providing tertiary regulation upward energy. Actually, in most situations wind generation schedule is equal to the maximum available power forecasted when trading; hence wind energy not only won't be interested in providing tertiary upward energy, but also there won't be upward reserves available for tertiary regulation.

As far as downward reserve is concerned, two different circumstances should also be analysed:

- If wind generation expects to have downward deviations: Wind generation will be interested in having its expected downward deviations accepted for providing tertiary regulation downward energy. However, a very high price won't be offered in order to prevent the risk of being the marginal technology and having to pay a higher price for providing tertiary regulation downward energy than for incurring in a downward deviation. Therefore, the price submitted in the offer will be the day-ahead price to ensure that if wind generation is accepted to provide tertiary regulation downward energy it will obtain an additional profit.

  The remaining available downward reserve that wind generation is not interesting in employing for providing tertiary regulation downward energy will be offered at 0 €/MWh to ensure that if this band is accepted wind generation won't have to incur in any payment.

- If wind generation does not expect to have downward deviations: Wind generation won't be interested in being accepted for providing tertiary regulation downward energy; hence it will offer all its available downward reserve at 0 €/MWh.

It should be pointed out that in a real offer process, the wind energy traders have information adapted to the actual situation and they could estimate a more suitable price in order to reduce the risk of incurring in a loss and increase the additional profits obtained.

5.2.5 RESULTS

The economic impact for wind generation if it had participated in tertiary regulation with the base strategy in the last years has been assessed.

The bid design described in the subsection 5.2.4 has been employed. In addition to the assumptions presented in the subsection 5.2.2, the following hypotheses have been made:

- If the price of tertiary regulation upward energy is higher or equal to the price of the wind agents' bid, all the reserve bided with this price will be provided as tertiary regulation upward energy.

- If the price of tertiary regulation downward energy is lower or equal to the price of the wind agents' bid, all the reserve bided with this price will be accepted as tertiary regulation upward energy.

Under these assumptions, the base strategy proposed in this chapter has been implemented in the years 2012, 2013, 2014 and in the first five months of the year 2015. The results obtained are presented in the table below.

	Year			
	2012	2013	2014	2015*
Hours in which wind generation would have participated in tertiary regulation [% of hours of the year]	30,6%	32,3%	27,7%	27,2%
Hours with positive additional profit [% of hours of the year]	28,6%	29,1%	26,5%	26,3%
Hours with negative additional profit [% of hours of the year]	0%	0%	0%	0%
Annual additional profits [€]	4.000.074	5.077.232	2.888.934	1.140.412
Annual additional profits [% original profit]	0,19%	0,24%	0,16%	0,11%
Annual additional profits [% costs of deviations]	6,6%	7,9%	5,2%	4,0%
Wind energy provided in tertiary regulation [% of the total wind energy measured]	0,58%	0,52%	0,34%	0,27%
Tertiary regulation upward energy provided by wind generation [% of TRUE]	5,9%	3,8%	3,3%	2,2%
Tertiary regulation downward energy provided by wind generation [% of TRDE]	4,5%	8,5%	4,0%	4,5%

*From January to May

Table 6: Results of the base strategy for the years 2012, 2013, 2014 and 2015.

If wind generation had participated in tertiary regulation in the last three years with the aim of reducing its deviations, it would have provided tertiary regulation in approximately 30% of the hours of each year. Thanks to the bid design proposed, the implementation of the base strategy would have allowed capturing additional profits in most part of these hours, preventing wind agents to incur in a loss. Consequently, the security (risk aversion) is one of the main advantages of this strategy.

The annual additional profits obtained vary from 2,9 million € to 5,1 million €. The original profit for wind generation has been estimated as the energy schedule times the price of the day-ahead market (assuming that the energy traded in the intraday markets has the same price as the day-ahead price, which can be a reasonable approximation) plus the upward deviations times the price of upward deviations minus the downward deviations times their corresponding price. The annual additional profits achieved with the base strategy would represent around 0,2% of the total original profits of each year and around 6,6% of the original costs of the deviations for wind agents. Despite the fact that these percentages can seem to be small, it should have also be taking into account that a small amount of energy, around 0,48% of the original energy, has been traded in tertiary regulation. Therefore, only optimizing this small amount of the total wind energy measured in the years, the profits for wind energy would have increased more than 2,5 million € in all of them, which is a very attractive figure.

As it can be seen in Table 6, the results for the first five months of the year 2015 are also similar to the ones obtained for the last three years. Nevertheless, the energy provided in tertiary regulation is a bit lower; and thus the additional profits obtained are also lower in relative terms (percentage of the original profits and percentage of the costs of deviations). The reason for this could be the improvement of the wind forecast techniques in the last years that result in lower deviations to reduce. The additional profit obtained (1,1 million €) is also lower, but it should be taken into account that we are only studying the first five months of the year.

As far as the contribution of wind generation to the provision of tertiary regulation energy is concerned, in the four years studied wind generation would have provided less than 6% of the total tertiary regulation upward energy required and less than 9% of the downward energy demanded. Consequently, the effect of the participation of wind generation on the prices of the tertiary regulation energy can be expected to not be significant if the whole year is considered. Nevertheless, the impact in some hours will be relevant.

In Figure 14 the contribution of wind generation to the total upward and downward tertiary regulation energy provided is depicted for every hour in which wind generation would have participated in tertiary regulation the year 2014. The same figures for the years 2012, 2013 and 2015 can be found in the Annex 1 .

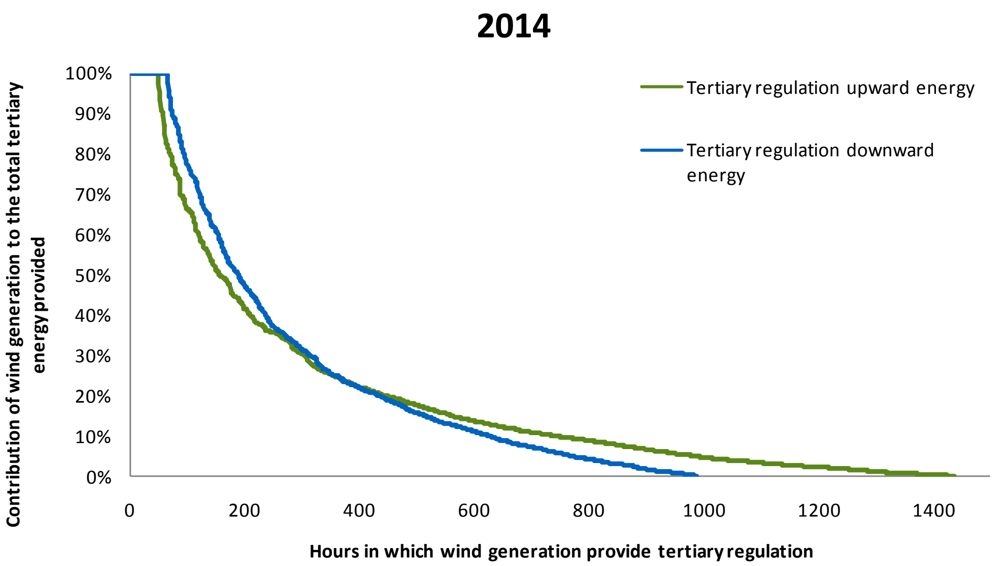

Figure 14: Contribution of wind generation to the total tertiary regulation energy provided in 2014 with the base strategy.

With the base strategy, in 2014 wind generation had provided tertiary regulation upward energy in 1437 hours and tertiary regulation downward energy in 987 hours. In less than 100 hours wind generation had represented more than 80% of the total tertiary regulation energy provided. Therefore, under the assumptions made, wind generation had been the marginal technology of tertiary regulation upward energy in less than 7% of the hours in which it had participated and of tertiary regulation downward energy in less than 10% of the hours.

It should be taken into account that in half of the hours in which wind generation had participated in tertiary regulation upward and downward energy its contribution would be less than 20%. Consequently, it could be concluded than the hypothesis of neglecting the impact on tertiary regulation prices when the contribution of wind energy is lower than 80% is reasonable.

5.3 CONCLUSIONS

In this chapter, the economic impact of the participation of wind generation in the tertiary regulation Spanish market for wind agents has been assessed. Firstly, it has been explained the main objective to achieve through the provision of this ancillary service: the reduction of current wind deviations. Not only would the achievement of this objective benefit wind agents, but also the system operation. It would reduce the system balancing costs and thus also the costs for the consumers. A proof of this are the hours in which wind generation would be the marginal technology of tertiary regulation; thus reducing the cost of this service. This would have taken place in around 70 hours for tertiary regulation upward energy and in approximately 95 hours for tertiary regulation downward energy for the year 2014.

Secondly, it has been described the circumstances in which wind generation could reduce its deviations participating in tertiary regulation. The different possibilities that can take place in an hour are summed up in the figure below.

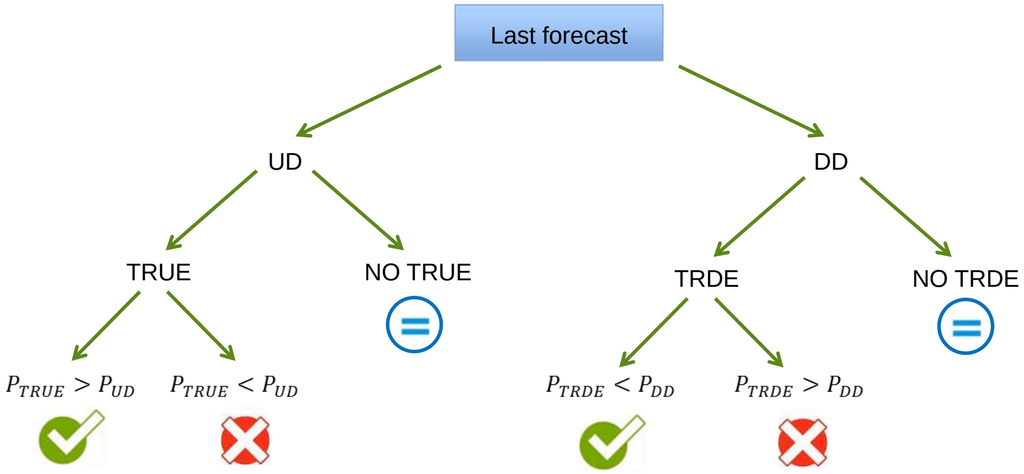

Figure 15: Possibilities when trying to reduce the wind production deviations.

The last forecast made before submitting the bid for participating in tertiary regulation can forecast an upward deviation (UD) or a downward deviation (DD). If a downward deviation is forecasted and REE requires tertiary regulation upward energy (TRUE) this deviations will be reduced. If wind generation would provide this energy at any price, it would obtain an additional profit if the price of tertiary regulation upward energy is higher than the price for upward deviations. On the other hand, if REE does not demand tertiary regulation upward energy, the deviations won't be reduced; thus wind agents won't obtain any additional profit. The analogous case will take place if downward deviations are forecasted.

A design for the bid submitted in the tertiary regulation market has been proposed with the aim to reduce the deviations and prevent wind agents from providing tertiary regulation energy if they could incur in a loss. Consequently, bidding the day-ahead price for tertiary regulation upward and downward energy has been suggested.

Finally, the economic impact for wind generation if it had participated in tertiary regulation in the years 2012, 2013, 2014 and in the first five months of the year 2015, implementing the proposed strategy, has been carried out. The results of this assessment reveal that wind generation could have obtained between 2,9 to 5,1 million € of additional profits in each year if it had employed around 0,48% of its annual production to provide tertiary regulation energy.

To conclude, the participation of wind generation in tertiary regulation presents very attractive benefits for both wind agents and the system operation if it is employed to reduce the current wind deviations. Only with this objective, the potential profit for wind generation is attractive and would encourage wind agents to provide this new service. Moreover, this extra benefit does not require further investment or additional operation costs since the operation of wind turbines is the same as the current one but being able to adjust to the most updated wind forecasts available. Nevertheless, the opportunity costs of the participation in tertiary regulation by wind generation could be even higher if other factors (in addition to reducing the forecasted deviations) were considered. This additional opportunity cost will be assessed in Chapter 6.

Chapter 6 POSSIBLE ALTERNATIVE STRATEGY FOR WIND AGENTS TO PARTICIPATE IN THE SPANISH TERTIARY REGULATION MARKET

In this chapter a possible alternative strategy for wind agents to participate in the tertiary regulation market will be described. The chapter is divided into six sections. Firstly, the objective and the market participation process of this alternative strategy will be explained. Then, the data employed for the analyses will be presented in the section 6.2. A theoretical assessment to identify the most suitable circumstances for implementing the strategy will be carried out in the section 6.3. According to the results of this assessment, the features of the strategy proposed will be described in the section 6.4. The estimated additional profits that would have been obtained if this strategy had been employed in the last years will be determined in the section 6.5. Finally, the conclusion of the chapter will be presented in the section 6.6.

6.1 OBJECTIVE AND MARKET PARTICIPATION PROCESS

Nowadays, in the day-ahead market wind agents bid their last wind generation forecast. Later, in the intraday markets they adjust their schedule to the most updated forecasts.

Wind production forecasts are composed of a confidence interval where the probability of finding the actual maximum wind production is higher than a significance level. Since the location of the actual wind production within the confidence interval is unknown, wind agents usually bid the mean value of the interval.

In this chapter a possible alternative strategy for wind agents to participate in the tertiary regulation market is proposed. This strategy will take into account the new opportunity cost of wind generation if it is allowed to participate in the tertiary regulation market.

The strategy consists of changing the current bid design for the day-ahead market. The day-ahead schedule will be modified in some hours, but always keeping it within the confidence interval. Then, in the tertiary regulation market the schedule will be restored to the original value (the day-ahead schedule).

In the alternative strategy two cases should be distinguished:

- The day-ahead schedule is increased to later restore its original value providing tertiary regulation downward energy: This alternative will be implemented to take advantage of the opportunity cost of having a downward reserve available within the confidence interval in order to provide tertiary regulation downward energy. A qualitative representation of this alternative can be seen in the figure below.

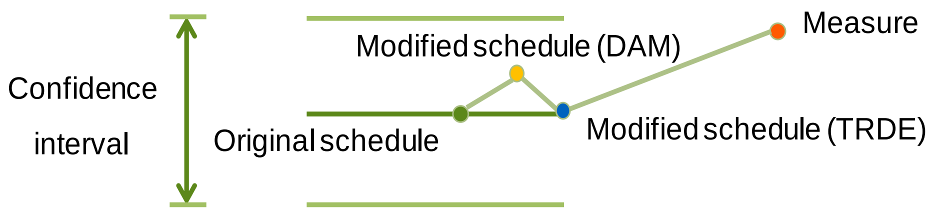

Figure 16: Qualitative representation of the alternative strategy increasing the original schedule.

- The day-ahead schedule is decreased with respect to the original value to later restore it providing tertiary regulation upward energy: This alternative will be employed to take advantage of the opportunity cost of having an upward reserve available within the confidence interval in order to provide tertiary regulation upward energy. A qualitative representation of this alternative can be seen in the figure below.

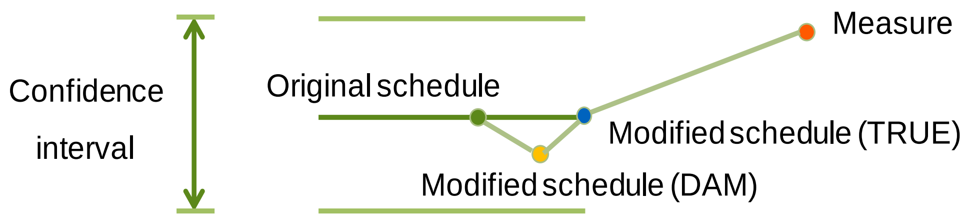

Figure 17: Qualitative representation of the alternative strategy increasing the original schedule.

It should be taken into account that, under this strategy the day-ahead schedule is also adjusted to the most updated forecasting the intraday markets. However, the adjustments are made maintaining a schedule higher or lower than the mean value of the confidence interval.

6.2 DATA EMPLOYED

In order to estimate the economic impact of the implementation of the base strategy, the following data has been employed for each of the four years studied. As it was presented in the previous chapter, third column corresponds to the number of data that appear in the year 2014.

Data	Source	Number of data
Hourly prices of the day ahead market	(Red Eléctrica de España, Liquidaciones, 2014)	8760
Hourly prices of tertiary regulation upward energy		8760
Hourly prices of tertiary regulation downward energy		8760
Hourly volumes of tertiary regulation upward energy		8760
Hourly volumes of tertiary regulation downward energy		8760
Hourly prices of upward deviations		8760
Hourly prices of downward deviations		8760
Wind sector energy schedule		8760
Wind sector energy measured		8760
Hourly demand		8760

Table 7: Data employed in the alternative strategy for the year 2014.

The data employed is huge. Therefore, some macros have been developed in the Excel program, in Visual Basic, to download and organize the information,

6.3 THEORETICAL ASSESSMENT

Firstly, a theoretical assessment has been carried out in order to analyze the most suitable circumstances to modify the day-ahead schedule.

The section is divided into four subsections. In the subsection 6.3.1 the assumptions made to carry out the theoretical assessment will be described. The formulation of the additional profit obtained will be presented in the subsection 6.3.2. Then, the upper bound for this profits computed with perfect information will be presented in the subsection 6.3.3. Finally, the most relevant factors which influence on the additional profit has been analyzed are described in the subsection 6.3.4.

6.3.1 ASSUMPTIONS

In the theoretical assessment the impact on the additional profits due to a modification of ±1 MW in each hour for the whole wind sector has been analyzed. It has been chosen this small variation to carry out a sensitivity analysis in which the prices of the different electricity markets were not affected.

Additionally, the following assumptions have been made:

- The whole wind energy sector has been treated as a single agent.

- Since the sensitivity of the modification of the original schedule in order to later restore it in the tertiary regulation market is been assessed, the original deviations of the wind sector won't be taken into account. Only a marginal deviation will be considered in the following cases:

    - If the original schedule is increased 1 MW in one hour in order to provide tertiary regulation downward energy but finally REE does not require this energy, the wind sector will have a downward deviation of 1 MW in that hour.

- If the original schedule is decreased 1 MW in one hour in order to provide tertiary regulation upward energy but finally REE does not require this energy, the wind sector will have an upward deviation of 1 MW in that hour.

6.3.2 FORMULATION OF THE ADDITIONAL PROFIT

To estimate the opportunity cost of wind energy, the additional profit that wind agents could obtain if one MWh was committed to provide tertiary regulation instead of being accepted in the day-ahead market will be estimated. In order to do it, the power offered in the day-ahead will not be exactly the mean value of the confidence interval, but a MWh higher or lower, depending on whether the wind agent wants to provide tertiary regulation downward or upward energy. If in an hour one MW less is bided in the day-ahead with the aim to provide tertiary regulation upward energy, the additional profit obtained in the hour will be

$$\Delta Prof = -P_{DAM} + Y_{TRUE} * P_{TRUE} + (1 - Y_{TRUE}) * P_{UD}$$

where P_{DAM} is the price of the day-ahead market, Y_{TRUE} is a binary variable that will take the value 1 if tertiary regulation upward energy is demanded in the hour and 0 otherwise, P_{TRUE} is the price of tertiary regulation upward energy in that hour and P_{UD} is the price for upward deviations.

The price for upward deviations is at maximum equal to the day-ahead price. Therefore, if tertiary regulation upward energy is not required the additional profit will be zero (if the price for upward deviations is the same as the day-ahead price) or negative.

On the other hand, if one MWh more is bided in the day-ahead with the aim to provide tertiary regulation downward energy, the additional profit obtained in the hour will be

$$\Delta Prof = P_{DAM} - Y_{TRDE} * P_{TRDE} - (1 - Y_{TRDE}) * P_{DD}$$

where P_{DAM} is the price of the day-ahead market, Y_{TRDE} is a binary variable that will take the value 1 if tertiary regulation downward energy is demanded and 0 otherwise, P_{TRUE} is the price of tertiary regulation downward energy and P_{DD} is the price for downward deviations.

The price for downward deviations is at least the price of the day-ahead market. Consequently, if tertiary regulation downward energy is not required the additional profit will be zero (if the price for downward deviations is the same as the day-ahead price) or negative.

6.3.3 UPPER BOUND FOR THE ADDITIONAL PROFITS

As it has been explained in the previous section, if the energy term submitted for the day-ahead bid is not exactly the mean value, but one MW more or one MW less, additional profits could be obtained, as well as additional losses. In order to estimate the potential benefits of the alternative strategy, the upper bound of the potential profits have been computed for the years 2012, 2013, 2014 and the first five months of the year 2015 employing perfect information regarding the prices of all the electricity markets involved.

Table 8presents the results obtained for the studied years. Since the maximum bound for the potential additional profits with perfect information has been computed, a loss is not incurred in any hour.

	Year			
	2012	2013	2014	2015*
Hours in which the day-ahead schedule would have been modified [% of hours of the year]	74,3%	73,9%	78,1%	80,8%
Hours with positive additional profit [% of hours of the year]	74,3%	73,9%	78,1%	80,8%
Hours with negative additional profit [% of hours of the year]	0%	0%	0%	0%
Hours in which wind energy would have provided tertiary regulation upward energy [% of hours of the year]	36,6%	41,6%	44,2%	43,9%
Hours in which wind energy would have provided tertiary regulation downward energy [% of hours of the year]	37,7%	32,3%	33,9%	36,9%
Annual additional profits [€]	111.384	120.788	109.955	50.144
Annual additional profits [€/MWh modified]	17,1	18,7	16,1	17,1

*From January to May

Table 8: Bound for potential additional profits for the year 2014.

It can be observed that the profit obtained by wind agents could be increased in many hours of the years (between 74% and 81%) if the mean value of the wind forecast was not bided. Only modifying this forecast in a MW, the annual additional profits amount to more than 100.000 €, with the exception of the year 2015 in which the additional profits are 50.144 € because only the first five months are considered. The additional profit per MWh optimized (or MWh participating in tertiary regulation) will vary from 16 to 19 €/MWh, which is not a negligible figure. Furthermore, it should be noted that the number hours in which decreasing the original schedule allows to capture additional profits exceed the number of hours in which it is interesting to increase the original day-ahead schedule.

6.3.4 POSSIBLE FACTORS TO BE CONSIDERED

In order to capture the highest possible amount of the upper bound presented in the previous subsection, the conditions that reduce the probability of incurring in a loss when modifying the day-ahead schedule should be found. In order to find these conditions, several factors could be considered.

In this subsection the most relevant factors found will be assessed. The results for years 2012, 2013 and 2014 have been studied. The first five months of the year 2015 have not been analyzed because it has been considered that it is relevant to evaluate the information of entire years. In this subsection, for the sake of simplicity, only the results for the year 2014 are explained. The results for the years 2012 and 2013 are similar and they can be found in the Annex 2 .

6.3.4.1 Day-ahead price

If the price of the day-ahead market is low, the technologies committed in this market will be mainly nuclear, run-of-the-river hydro, wind and solar. These technologies usually operate at maximum power and present low flexibility. Therefore, their capacity to provide tertiary regulation upward energy is low; hence the price for providing this service can be expected to be higher than the day-ahead price (probably set by combine cycles committed for solving technical constraints)thus increasing the potential profits expected. Regarding tertiary regulation downward energy, the results are more difficult to be estimated. Since the technologies committed have almost no capability to reduce their output, manageable hydro could be requested if necessary but its bids will depend on its opportunity cost.

When the price of the day-ahead market is intermediate, some thermal generation could have been committed. Since they will work close to the technical minimum, they will be willing to increase their output providing tertiary regulation upward energy, but they will be reluctant to reduce their output. Consequently, they will present the opposite behavior of the other committed technologies (nuclear, run-of-the-river hydro, wind and solar) and thus the expected profits are difficult to be estimated.

As far as high prices are concerned, there can be more units operating at intermediates points. Consequently, their willingness to reduce or increase their output participating in tertiary regulation is not clear, neither the expected profits obtained.

Since there are some uncertain circumstances, the previous theoretical assessment will be checked assessing the additional profits that wind agents would have obtained in the years 2012, 2013 and 2014.

The additional profits have been computed differentiating two cases:

- The day-ahead schedule is reduced one MW each hour because wind agents rely on providing tertiary regulation upward energy (TRUE).

- The day-ahead schedule is increased one MW each hour because wind agents rely on providing tertiary regulation downward energy (TRDE).

Table 9 presents the results obtained for both cases, depending on the day-ahead price (P_{DAM}) for the year 2014.

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	0 ≤ PDAM < 15	1043	29,5%	34,3%	5189	4,98
	15 ≤ PDAM < 30	941	42,9%	36,7%	-143	-0,15
	30 ≤ PDAM < 45	2448	42,1%	36,8%	-10808	-4,42
	45 ≤ PDAM < 60	2896	56,3%	30,0%	-414	-0,14
	60 ≤ PDAM	1432	56,4%	30,8%	-3826	-2,67
TRDE	0 ≤ PDAM < 15	1043	48,8%	32,5%	-4.712	-4,52
	15 ≤ PDAM < 30	941	48,1%	48,4%	1.727	1,84
	30 ≤ PDAM < 45	2448	40,6%	47,9%	15.571	6,36
	45 ≤ PDAM < 60	2896	28,0%	57,6%	3.250	1,12
	60 ≤ PDAM	1432	22,6%	58,4%	2.263	1,58

Table 9: Additional profits depending on the price of the day-ahead market for the year 2014.

Under the light of the results, it can be seen that the potential to increase the original profits depends on the day-ahead price. The strategy to employ will be different in the following cases:

- If the price of the day-ahead market is lower than 15 €/MWh: additional profits will be capture if the day-ahead schedule is reduced one MWh in order to provide tertiary regulation upward energy. Although the probability of incurring in a loss is higher than obtaining a profit (34,3% vs. 29,5%), the losses incurred are lower than the profits, resulting in a 4,98 €/MWh net positive profit.

- If the price of the day-ahead market is higher or equal to 15 €/MWh: additional profits will be capture if the day-ahead schedule is increased one MWh in order to provide tertiary regulation downward energy, if possible. In this case, the probability of incurring in a loss is also higher than obtaining a profit, but the losses incurred are still lower than the profits, resulting in a net positive profit. However, the different cases should be distinguished:

    - If the price of the day-ahead market is lower than 30 €/MWh: The additional profit obtained is not high (1,84 €/MWh) and there is almost the same probability to incur in a loss or in a profit. Therefore, since the risk of having a loss is not negligible (48,4%) and the expected profits are not so high to compensate this risk, in these hours is not attractive to modify the original bid design.

    - If the price of the day-ahead market is higher or equal to 30 €/MWh and lower than 45 €/MWh: The additional profit obtained is not low (6,36 €/MWh). Consequently, the risk of having a loss can be compensated with the higher potential profits expected. It would be interesting to modify the original design bid to provide tertiary regulation downward energy.

    - If the price of the day-ahead market is higher or equal to 45 €/MWh: The additional profits obtained, although positive, are low and the probability of incurring in a loss is much higher than of increasing the profits. Consequently, in these hours the modification of the day-ahead schedule does not seem to be attractive.

In conclusion, ifthe price of the day-ahead market is low (lower than 15 €/MWh), it will be interesting to provide tertiary regulation downward energy and if the price is not very high (from 30 €/MWh to 45 €/MWh) it would be desirable to provide in tertiary regulation upward energy. Moreover, this result presents some advantages regarding the willingness of wind agents to assume some risk when modifying the design of their day-ahead energy bids. The agents won't oppose to reduce their day-ahead schedule when the price is low since the expected profit in this market won't be high. On the other hand, with an intermediate price the agents won't oppose to offer one MWh more in the day-ahead market because the expected profits obtained from this market are not low and they can compensate the risk of incurring in a deviation.

6.3.4.2 Demand coverage by forecasted wind energy

I have decided to employ the forecasted wind energy (the one scheduled in the last intraday market) instead of the actual one (the energy measured) in order to take into account the wind forecast errors since the bid submitted in the day-ahead and the intraday markets will be influenced by them.

The profits that would have been obtained in the year 2014 have been computed. As in the previous subsection, two cases have been distinguished:

- The day-ahead schedule is reduced one MW each hour because wind agents rely on providing tertiary regulation upward energy (TRUE).
- The day-ahead schedule is increased one MW each hour because wind agents rely on providing tertiary regulation downward energy (TRDE).

The results for the year 2014can be shown in the table below.

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	0 ≤ Demand Coverage < 0,1	1750	57,2%	27,9%	-288	-0,16
	0,1 ≤ Demand Coverage < 0,2	2766	51,6%	31,5%	-3.099	-1,12
	0,2 ≤ Demand Coverage < 0,3	2157	43,5%	37,8%	-8.751	-4,06
	0,3 ≤ Demand Coverage < 0,4	1294	39,8%	37,8%	-1.451	-1,12
	0,4 ≤ Demand Coverage	793	37,6%	31,4%	3.587	4,52
TRDE	0 ≤ Demand Coverage < 0,1	1750	19,5%	63,2%	-2.432	-1,39
	0,1 ≤ Demand Coverage < 0,2	2766	28,7%	55,7%	4.688	1,69
	0,2 ≤ Demand Coverage < 0,3	2157	43,8%	44,8%	13.063	6,06
	0,3 ≤ Demand Coverage < 0,4	1294	48,3%	42,7%	4.320	3,34
	0,4 ≤ Demand Coverage	793	48,8%	38,1%	-1.542	-1,94

Table 10: Additional profits depending on the demand coverage by forecasted wind energy for the year 2014.

The probability of having positive additional profits is higher than the probability of incurring in a loss if one MWh less is bided in the day-ahead market in order to provide tertiary regulation upward energy with this MWh (if it is required). However, although in less hours wind agents incur in a loss, the losses surpass the positive profits resulting in a net negative additional profit for the hours when the demand coverage by wind generation is lower than 40%.

Consequently, wind agents would only be interested in modifying their design of the day-ahead bids for providing tertiary regulation upward energy when the demand coverage is high (higher or equal to 40%). The probability of having additional losses is high (57,2%) and it almost doubles the probability of incurring in a loss; hence reducing the risk. Therefore, since the risk is not high and the potential additional profits are medium (4,52 €/MWh), it would be interesting to bid in the day-ahead market one MWh less than the mean value of the forecasted wind generation confidence interval.

Regarding the provision of tertiary regulation downward energy, it would be interesting to increase the energy term of the day-ahead bid by one MWh for medium levels of demand coverage by forecasted wind generation (demand coverage higher or equal to 20% and lower than 30%).The probability of incurring in a loss, although higher, is very similar to the probability of capturing additional profits. Therefore, since the risk of additional losses is not high and the potential profits are not low (6,06 €/MWh), wind agents could be interesting in having one MWh more committed in the day-ahead market with the aim to provide tertiary regulation downward energy.

For low levels of demand coverage by wind energy, the possibility to incur in a loss is much higher than to obtain positive profits and the expected net profits are very low. Consequently, it is not advisable to modify the day-ahead bid design.

As far as high levels of demand coverage by forecasted wind generation, it is also not advisable to not bid the mean value of the confidence interval of the wind production forecast since the additional net profits obtained are very low or even negative if wind energy covers more than 40% of the hourly demand.

It should be pointed out that the results of this subsection seem to be coherent with the ones obtained in the subsection 6.3.4.1 because the hours with a low or medium level of demand coverage probably correspond to the hours with a medium or low day-ahead price; and the hours with low demand coverage by wind generation might present high day-ahead prices.

6.3.4.3 Hourly ramp of the net wind demand

For each hour of the year 2014, the ramp of the net wind demand (actual demand minus wind generation) has been computed. The objective is to assess whether this variable has an impact or not on the potential profits that wind generation can obtain for modifying its day-ahead schedule in order to participate in tertiary regulation. It can be expected that if the net wind demand ramp is high there will be a large requirement of tertiary regulation upward energy by the System Operator in order to be able to face this ramp. On the other hand, if the net wind demand ramp is very low (very negative) the System Operator will probably require a relevant amount of tertiary regulation downward energy in order to respond to such variation of the net wind demand.

The results obtained for the year 2014 are presented in the table below.

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Net Wind Demand Ramp < -2000	637	42,5%	42,1%	-2.227	-3,50
	-2000 ≤ Net Wind Demand Ramp < -1000	1.382	43,9%	37,0%	-4.029	-2,92
	-1000 ≤ Net Wind Demand Ramp < 0	2.682	39,7%	37,0%	-6.687	-2,49
	0 ≤ Net Wind Demand Ramp < 1000	2.137	46,7%	32,6%	-2.866	-1,34
	1000 ≤ Net Wind Demand Ramp < 2000	1.092	58,7%	28,2%	869	0,80
	2000 ≤ Net Wind Demand Ramp	829	72,0%	16,2%	4.958	5,98
TRDE	Net Wind Demand Ramp < -2000	637	51,5%	39,4%	4.291	6,74
	-2000 ≤ Net Wind Demand Ramp < -1000	1.382	41,8%	47,1%	5.851	4,23
	-1000 ≤ Net Wind Demand Ramp < 0	2.682	38,4%	48,4%	7.175	2,68
	0 ≤ Net Wind Demand Ramp < 1000	2.137	31,8%	51,2%	3.087	1,44
	1000 ≤ Net Wind Demand Ramp < 2000	1.092	27,3%	56,5%	222	0,20
	2000 ≤ Net Wind Demand Ramp	829	21,1%	67,2%	-2.547	-3,07

Table 11: Additional profits depending on the hourly ramp of the net wind demand for the year 2014.

As in the previous subsection, if the day-ahead schedule is reduced one MWh to provide tertiary regulation upward energy, the number of hours with positive additional profits exceeds the hours with negative ones. Nevertheless, only for net wind demand ramps higher than 1000 MW, the net additional profit obtained will be positive. It should be pointed out the high probability (72%) of capturing additional profits if the net wind demand ramp is higher or equal to 2000 MW. This probability is much higher than the possibility of incurring in a loss (16,2%). Moreover, the net profits captured are not low (5,98 €/MWh). Consequently, reducing the day-ahead schedule for providing tertiary regulation upward energy is highly advisable for wind agents.

Regarding the increase of the day-ahead schedule for providing tertiary regulation downward energy, net positive additional profits would have been obtained for net wind demand ramps lower than 2000 MW. As the net wind demand ramp increases, the probability of capturing positive profits decreases, as well as the net profits obtained. However, only for net wind demand ramps lower than -2000 MW the probability of capturing positive profits is higher than the one of incurring in a loss. Furthermore, the net additional profit could be considered high (6.74 €/MWh); hence it would be interesting for wind agents to modify their day-ahead schedule.

6.3.4.4 Peak hours

In this subsection, the additional profits obtained if the day-ahead schedule is only modified in the peak hours (from hour 9 to hour 24, both included) have been computed. The aim of this study is identifying possible trends in the additional profits making a distinction between the different quarters. This is especially interesting in the year 2014 since the first quarter can be considered as an unusual one. The quarter Q1 was very windy and it also rained a lot. A lot of hydro was forced to produce in order to prevent spillages. Therefore, the day-ahead prices were lower than the usual prices in these three months.

The results obtained only modifying the day-ahead schedule in the peak hours of the year 2014 are presented in the table below.

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Q1 Peak	1440	32,8%	50,6%	-10.246	-7,12
	Q2 Peak	1456	46,4%	36,5%	-3.143	-2,16
	Q3 Peak	1472	59,9%	28,9%	-956	-0,65
	Q4 Peak	1472	54,6%	30,1%	-465	-0,32
TRDE	Q1 Peak	1440	49,4%	36,0%	9.920	6,89
	Q2 Peak	1456	37,8%	48,8%	4.915	3,38
	Q3 Peak	1472	21,8%	60,3%	925	0,63
	Q4 Peak	1472	30,6%	56,9%	2.085	1,42

Table 12: Additional profits in the peak hours of each quarter of the year 2014.

If the day-ahead schedule is reduced one MWh in order to provide tertiary regulation upward energy if it is required, wind agents would reduce their profits. Therefore, this strategy is not advisable. This conclusion is coherent with the one obtained in the subsection 6.3.4.1 in which decreasing the day-ahead schedule to provide tertiary regulation upward energy was only interesting for very low day-ahead prices (lower than 15 €/MWh). Low prices do not usually take place in peak hours; hence it could be expected that the strategy was not profitable, as the results corroborate.

On the other hand, if the day-ahead schedule was increased one MWh to provide one MWh of tertiary regulation downward energy if it is demanded, wind agents would have captured a higher amount of profits. This result is also coherent with the ones obtained in the subsection 6.3.4.1 in which positive additional profits were obtained for intermediate and high day-ahead prices (prices higher than 15 €/MWh). Nevertheless, it should be noted that the additional profits captured are much higher in the peak hours of quarter Q1 than in the other quarters and in the subsection 6.3.4.1 they were also much higher for intermediate prices than high prices. If we take into account that the prices in the quarter Q1 were low, we can assume than the prices in the peak hours of this quarter were intermediate and not high. Consequently, the high additional profits captured with the intermediate day-ahead prices could be explained with the extraordinary features of the first quarter of the year.

6.3.4.5 Off-peak hours

The variation in the actual profits produced if the day-ahead schedule is modified in the off-peak hours (from hour 1 to hour 8, both included) has also been computed. The results obtained for the year 2014can be shown in the following table.

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Q1 Off-peak	719	31,6%	28,9%	1.424	1,98
	Q2 Off-peak	728	43,0%	33,1%	-602	-0,83
	Q3 Off-peak	736	60,5%	21,7%	1.613	2,19
	Q4 Off-peak	736	49,0%	23,9%	2.390	3,25
TRDE	Q1 Off-peak	719	40,2%	37,7%	-800	-1,11
	Q2 Off-peak	728	37,9%	53,3%	1.091	1,50
	Q3 Off-peak	736	26,8%	59,6%	262	0,36
	Q4 Off-peak	736	39,9%	56,8%	-322	-0,44

Table 13: Additional profits in the off-peak hours of each quarter of the year 2014.

Diminishing the day-ahead schedule one MWh to provide it as tertiary regulation upward energy (if it is required) would have increased the profits captured, except in the second quarter. However, the additional profits obtained in the other quarters are low.

To compare the previous result with the conclusions of the subsection 6.3.4.1, it should be taken into account that the number of off-peak hours in the year (2920) is higher than the number of hours with very low day-ahead prices (1043). Consequently, even if all the hours with very low prices correspond to off-peak hours, the peak hours would also include hours with higher prices. According to the results of the subsection6.3.4.1, decreasing the day-ahead schedule was only interesting for very low prices (lower than 15 €/MWh). Since not all the off-peak hours present these prices, the additional profits obtained in these hours are lower or even negative (quarter Q2) than the ones captured with very low prices.

On the other hand, if the day-ahead schedule is increased in the off-peak hours to provide tertiary regulation downward energy the impact on the profits will be low, in some quarters negative (Q1 and Q4) and in others positive (Q2 and Q3).Therefore, the implementation of this strategy in off-peak hours it is not advisable. These results can be also considered coherent with the ones of the subsection 6.3.4.1, since in that case losses were incurred for very low prices, but additional profits were captured in the intermediate ones.

6.4 STRATEGY PROPOSED

In this section the strategy proposed will be described. It is divided into two subsections. Firstly, according to the results of the theoretical assessment carried out, the criteria selected to modify the day-ahead schedule will be explained. Secondly, the bid design suggested will be described.

6.4.1 CRITERIA EMPLOYED

The modification of the current bid design for the day-ahead market could reduce the profits of wind agents. It should be also taken into account that the results of the previous section have been obtained for the year 2014. Consequently, the coherence between the impacts of the different factors analysed has been checked and compare to the ones obtained for the years 2012 and 2013 in order to ensure the reliability of the results.

The two requirements for modifying the original bid design will be to increase the profits captured as much as possible and to try to reduce the risk of incurring in a loss. The strategy proposed will try to achieve a trade-off between these goals.

The following table presents a summary of the results obtained for the year 2014 when the day-ahead schedule was decreased one MW for providing tertiary regulation upward energy with this MW, if possible. A qualitative classification of the features of each factor (probability of obtaining a positive additional profit, probability of obtaining a negative additional profit and additional unitary profit obtained) has been carried out in order to assess the impact of each factor.

Additional profit (TRUE)				
Conditions for changing the day-ahead schedule		Probability of obtaining a possitive additional profit	Probability of obtaining a negative additional profit	Additional unitary profit
PDAM	Low	Low	Low	Medium
	Medium	Medium	Medium	Negative
	High	Medium	Low	Negative
Demand coverage by wind	Low	Medium	Low	Negative
	Medium	Medium	Medium	Negative
	High	Medium	Low	Medium
Peak hours	Q1	Low	Medium	Negative
	Q2	Medium	Medium	Negative
	Q3	Medium	Medium	Negative
	Q4	Medium	Medium	Negative
Off-peak hours	Q1	Low	Low	Low
	Q2	Medium	Low	Negative
	Q3	Medium	Low	Low
	Q4	Medium	Low	Medium
Net demand ramp	High (negative)	Medium	Medium	Negative
	Medium (negative)	Medium	Medium	Negative
	Low (negative)	Medium	Medium	Negative
	Low (positive)	Medium	Low	Negative
	Medium (positive)	Medium	Low	Low
	High (positive)	High	Low	High

Table 14: Influence of the different factors in the original profit if the day-ahead schedule is decreased one MWh in the year 2014.

The most attractive circumstances for decreasing the day-ahead schedule are highlighted in blue. Although the results are presented in a qualitative way, in all these possibilities the probability of increasing the original profits is higher than the probability of decreasing them. High probabilities of capturing positive profits are also looked for in order to hedge the risk of incurring in a loss. Moreover, the additional profits in the selected options are medium (between 2.5 €/MWh and 5 €/MWh) or high (higher than 5 €/MWh).

As it can be shown in Table 14, three circumstances are candidates for the implementation of the new bid design: low prices of the day-ahead market, high demand coverage by wind generation and high net wind demand ramps. The first two circumstances could be considered almost equivalent, since when wind generation constitutes a high percentage of the demand the prices are usually low. The third circumstance does not present a clear relationship with the previous ones; hence it will be considered as a different factor to take into account when designing the bids for the different markets. This factor is very attractive for the implementation of the alternative strategy since the additional profit obtained is high, with a high probability of increasing the original profits whereas the probability of decreasing them is low.

Table 15 presents the results obtained for the case in which the day-ahead schedule was increased one MWh for providing tertiary regulation downward energy with this MWh, if possible. The candidate options for modifying the current bid design are highlighted in blue.

Additional profit (TRDE)				
Conditions for changing the day-ahead schedule		Probability of obtaining a possitive additional profit	Probability of obtaining a negative additional profit	Additional unitary profit
PDAM	Low	Medium	Low	Negative
	Medium	Medium	Medium	High
	High	Low	Medium	Low
Demand coverage by wind	Low	Low	Medium	Low
	Medium	Medium	Medium	High
	High	Medium	Medium	Low
Peak hours	Q1	Medium	Medium	High
	Q2	Medium	Medium	Low
	Q3	Low	Medium	Low
	Q4	Low	Medium	Low
Off-peak hours	Q1	Medium	Medium	Negative
	Q2	Medium	Medium	Low
	Q3	Low	Medium	Low
	Q4	Medium	Medium	Negative
Net demand ramp	High (negative)	Medium	Medium	High
	Medium (negative)	Medium	Medium	Medium
	Low (negative)	Medium	Medium	Low
	Low (positive)	Low	Medium	Low
	Medium (positive)	Low	Medium	Low
	High (positive)	Low	High	Negative

Table 15: Influence of the different factors in the original profit if the day-ahead schedule is increased one MWh.

As it can be shown in the table, there are four candidates circumstances for modifying the current bid design: medium day-ahead prices, medium demand coverage by wind generation, peak hours of the first quarter and with high negative net wind demand ramps. As it has been explained before, the first two circumstances could be considered equivalent. Under them, capturing a high unitary additional profit is possible. Nevertheless, as it was explained in the subsection 6.3.4.4, the third circumstance could be also equivalent to the first two selected options because the peak hours of the first quarters probably presented medium prices, not high ones. Therefore, since the quarter Q1 of the year 2014 could only be representative for years with a lot of rain and wind, these three options will be rejected to avoid basing the strategy in unreliable results.

As far as the fourth candidate condition is concerned, it is proposed to modify the current bid design (increasing the day-ahead schedule) when there were high net wind demand ramps. Under these circumstances the unitary additional profit captured is expected to be high. Moreover, the probability of increasing the original profits exceeds the probability of incurring in a loss, although both probabilities are medium.

An analogous analysis for the years 2012 and 2013 has been carried out, obtaining similar conclusions. Consequently, in this Master Thesis it is proposed to modify the current day-ahead bidding strategy under the following circumstances:

- In the hours with an expected high negative net wind demand ramp: it would be interesting to increase the day-ahead schedule in order to provide tertiary regulation downward energy.

- In the hours with an expected high positive net wind demand ramp: it would be interesting to decrease the day-ahead schedule in order to provide tertiary regulation upward energy.

- In the hours with low day-ahead prices and without an expected high negative net wind demand ramp: it would be interesting to decrease the day-ahead schedule in order to provide tertiary regulation upward energy.

It has been prioritized the high negative net wind demand ramp condition over the condition of low day-ahead prices because the potential unitary profits of the former are higher than the expected unitary profits of the latter. Moreover, the risk of incurring in a loss is lower under the first condition. Therefore, if in an hour with low prices there is a high negative net wind demand ramp, it would be advisable to decrease the day-ahead schedule instead of increase it.

It should be taken into account that under real conditions, either the day-ahead price nor the exactly demand and wind production can be known in advance. Consequently, the results obtained under real operation could slightly differ from the ones presented in this Master Thesis in which predictions equal to the actual values have been considered. Nevertheless, some intervals for these values have been proposed. Therefore, even if the forecast does not coincide with the actual data, the forecast might be included in the same interval as the actual data thanks to the accurate techniques available nowadays to make the forecasts.

Finally, it should be noted that, although the previous criteria is qualitative, in this Master Thesis the following qualitative values have been employed to characterise each condition:

- High negative net wind demand ramp: hourly net wind demand ramps lower than -2000 MW.

- High positive net wind demand ramp: hourly net wind demand ramps higher or equal to 2000 MW.

- Low day-ahead prices: prices lower than 15 €/MWh.

6.4.2 BID DESIGN

The bid design proposed will employ the criteria described in the previous subsection to determine the hours in which the day-ahead schedule will be either increased or decreased.

Regarding the price bided for tertiary regulation upward energy, the amount of energy increased in the day-ahead schedule will be bided at the day-ahead price to try to ensure that an additional positive profit will be captured if wind generation is committed in the tertiary regulation market. This decision takes into account the possibility of wind generation being the marginal technology; thus reducing the tertiary regulation upward energy prices below the price of the deviations incurred if it is not committed in the market.

As far as downward reserve is concerned, two different bands should be distinguished:

- The amount of energy decreased in the day-ahead schedule: It will be offered at the day-ahead price also to try to ensure that an additional positive profit will be captured if wind generation is committed in the tertiary regulation market and to reduce the risk of having to pay a very high price for providing tertiary regulation downward energy, incurring in a loss.

- The remaining available downward reserve: It will be offered at 0 €/MWh to ensure that if this band is accepted wind generation won't have to incur in any payment.

Finally, the amount of energy that will be modified in the selected hours should be decided. It is proposed to be a small percentage of the original energy schedule, between 1% and 3%, in order to maintain the modified schedule within the confidence interval and also to prevent to have a significant impact on the prices of the different electricity markets.

6.4.3 UNITARY ADDITIONAL PROFITS CAPTURED

With the criteria and the bid design proposed, the unitary additional profits captured modifying ±1 MW the day-ahead schedule in the hours with low prices and high net wind demand ramps (positive and negative) have been computed. The results can be seen in the table below.

Year	Additional profits [€]	Additional profits [% upper bound]	Hours modified [%]	Hours with positive additional profit [% of hours modified]	Hours with negative additional profit [% of hours modified]
2015*	3.516	7%	24%	54%	28%
2014	16.131	15%	27%	53%	21%
2013	23.038	19%	29%	53%	16%
2012	16.770	15%	24%	57%	17%

*From January to May

Table 16: Unitary additional profits captured with the alternative strategy.

If the alternative strategy was implemented in the last three years, it is estimated that from 15% to 19% of the upper bound of the additional profits could have been captured. The day-ahead schedule would have been modified in around 27% of the hours. In more than half of these hours an additional profit would have been obtained and in less than 25% of the hours a loss would have been incurred. Although a 25% is not a very low risk, it is lower than half of the probability of increasing the original profits.

As far as the first five months of the year 2015 are concerned, it should be noted than only 7% of the upper bound of the unitary additional profits would have captured. Moreover, the number of hours reducing the original profits amounts to 28% of the hours modified. Even if this percentage is not very high and it is lower than the hours with an additional profit (54%), it is higher than in the rest of the years. Nevertheless, it should be pointed out that maybe in the rest of the year 2015 the hours modified, according to the criteria suggested, might bring higher additional profits that can improve the results obtained considering the whole year.

6.5 *ESTIMATED ADDITIONAL PROFITS FOR PARTICIPATING IN TERTIARY REGULATION*

In this section the estimated additional profits obtained if the alternative strategy had been implemented in the last years will be described. The section is divided into two subsections. Firstly, the hypotheses assumed will be presented. Secondly, the results obtained will be explained.

6.5.1 ASSUMPTIONS

For this assessment the following assumptions have been made:

- The whole wind energy sector has also been treated as a single agent.

- The participation of wind generation in tertiary regulation does not affect the prices of the different electricity markets, with the exception of the tertiary regulation market.

- The price of tertiary regulation energy won't be affected by the participation of wind energy if its contribution is lower than 80% of the total tertiary regulation energy. Therefore, only in the hours in which its contribution isat least 80% the price of tertiary regulation will equal the wind generation bid.

Although with the alternative strategy the original deviations are not pretended to be reduced, their sign have been taken into account to properly determine the impact of the strategy on the deviations. Two cases have been distinguished:

- If the original schedule is increased in one hour in order to provide tertiary regulation downward energy but finally REE does not require this energy:
    - If the wind sector had an original upward deviation, this deviation would be reduced and could even result in a downward deviation.
    - If the wind sector had an original downward deviation, this deviation would be increased.

- If the original schedule is decreased in one hour in order to provide tertiary regulation upward energy but finally REE does not require this energy:
    - If the wind sector had an original upward deviation, this deviation would be increased.
    - If the wind sector had an original downward deviation, this deviation would be reduced and could even result in an upward deviation.

6.5.2 RESULTS

The additional profits that had been obtained in the years 2012, 2013, 2014 and the first five months of the year 2015 if the alternative strategy had been implemented have been computed. They have been depicted in Figure 18, distinguishing the percentage of the day-ahead modified in the selected hours.

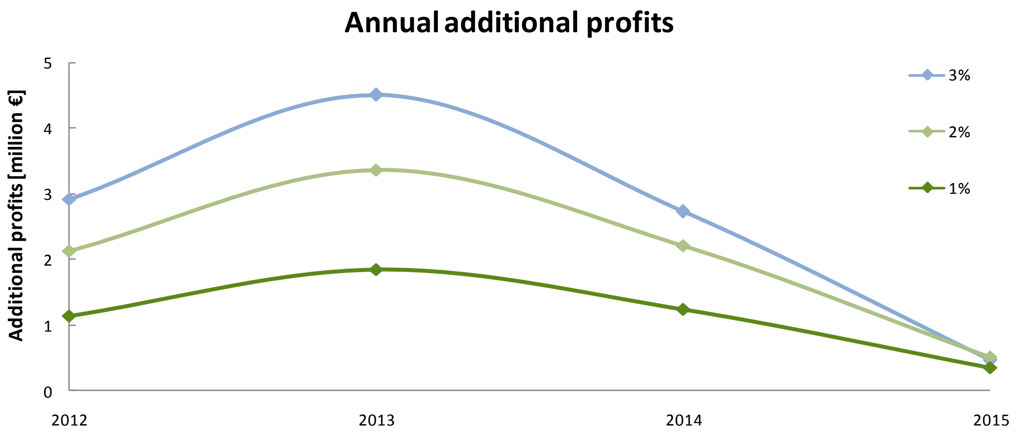

Figure 18: Annual additional profits obtained if the alternative strategy was implemented.

In all the years the profits increase if the amount of energy modified in the day-ahead schedule to provide tertiary regulation reserves increases. If a 3% of the day-ahead schedule was changed, the profits would amount to more than 4 million € in the year 2013 (the year in which highest profits could be captured). Even if we consider the lowest band suggested, 1%, the annual additional profits would rise up to more than 1 million € in the last three years. The results for the year 2015 are not so high, but we have to take into account that only the first five months have been analysed. Therefore, to obtain more relevant conclusions we would need to assess it at the end of the year.

In order to valuate more accurately the influence of the energy band chosen to modify the day-ahead schedule, further measures (in addition to the profits obtained) have been analysed. The results obtained for the year 2014 are presented in Table 17. Similar results have been obtained for the rest of the years and can be found in the Annex 2 .

	Percentage of the day-ahead schedule		
	1%	2%	3%
Hours in which the day-ahead schedule would have modified [% of hours of the year]	27,0%	27,0%	27,0%
Hours with positive additional profit [% of hours of the year]	14,0%	13,2%	12,4%
Hours with negative additional profit [% of hours of the year]	6,0%	6,5%	6,8%
Annual additional profits [€]	1.244.153	2.208.817	2.727.768
Annual additional profits [€/MWh modified]	7,3	6,5	5,3
Tertiary regulation upward energy provided by wind generation [% of TRUE]	1,9%	3,7%	5,3%
Tertiary regulation downward energy provided by wind generation [% of TRDE]	1,5%	2,8%	4,0%

Table 17: Results of the alternative strategy for the year 2014.

As it can be seen in the table, in the year 2014 the day-ahead schedule of wind generation would have been modified in 27% of the hours. If we increase the percentage of energy modified in these hours, the probability of capturing additional positive profits decreases and the opposite occurs regarding the probability of incurring in a loss. The reason of that is related to the fact that a higher amount of tertiary regulation (upward and downward) is provided by wind generation. Even the contribution of wind generation is not significant (lower than a 6% in tertiary regulation upward energy and lower than a 4% in tertiary regulation downward energy) in some hours it could affect the prices of the tertiary regulation market and thus the profits obtained. This will be explained in more detail with Figure 19.

It should also be noted that if the percentage of energy modified in the day-ahead schedule increases, the annual additional profits grow in absolute terms, but they the profits obtained per MWh modified decrease. Consequently, modifying higher bands within the confidence interval will allow capturing more profits in the year, but the risk associate of incurring in a loss will also be higher.

Figure 19 shows the contribution of wind generation to the total tertiary regulation upward and downward energy provided in the year 2014 if the alternative strategy was implemented.

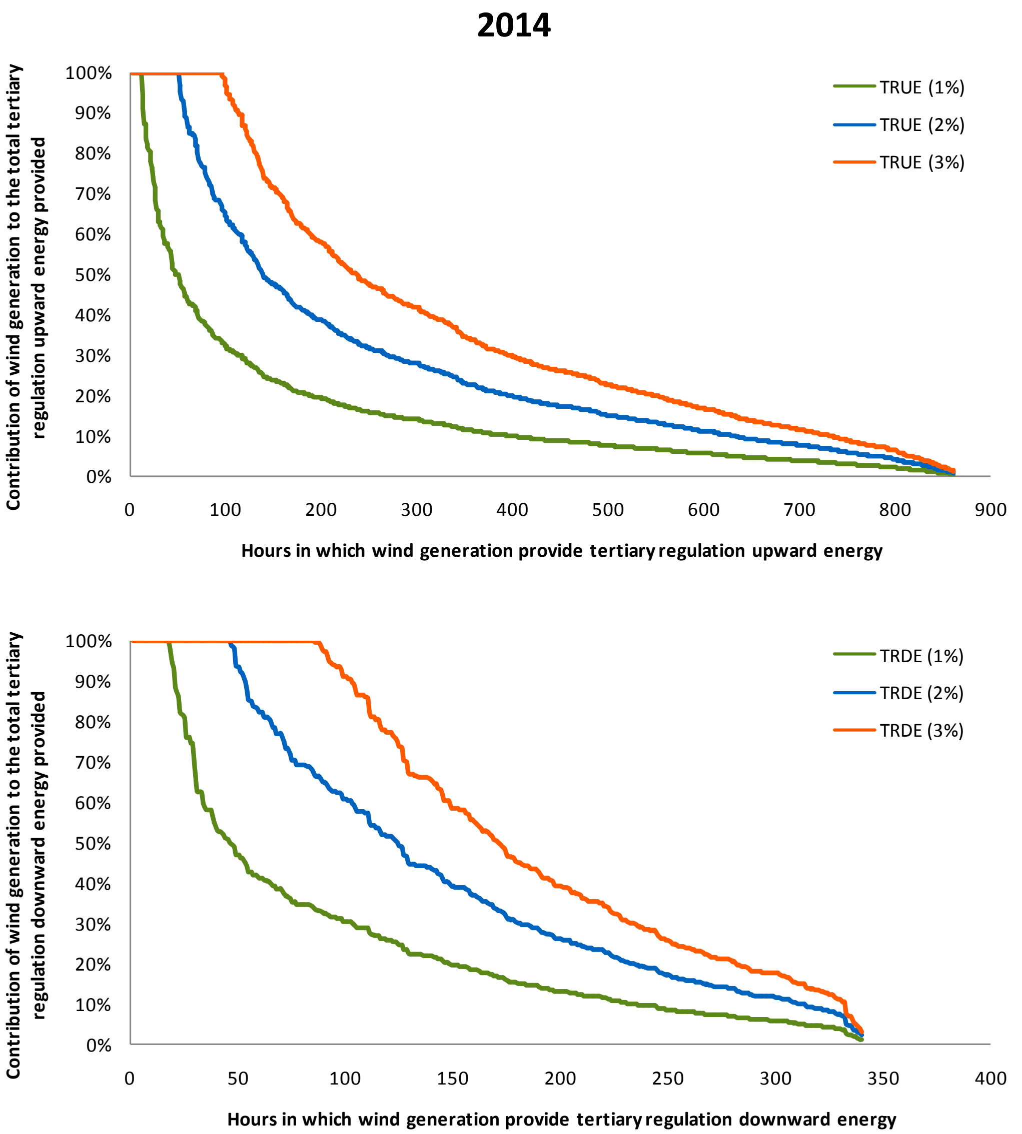

Figure 19: Contribution of wind generation to the total tertiary regulation energy provided in 2014 with the alternative strategy.

If the percentage of the day-ahead schedule modified increases, the contribution of wind generation to the total tertiary regulation energy increases. There are more hours in which wind generation is the single technology providing tertiary regulation. In these hours it is probable that the amount of energy modified in the day-ahead schedule exceeds the total tertiary regulation required by REE. Consequently, wind generation could increase its deviations; thus increasing the probability of incurring in a loss. Moreover, as the band modified of the day-ahead schedule increases, the number of hours in which the contribution of wind generation surpass 80% grows; hence the hours in which wind generation is the marginal technology of the tertiary regulation market increases. This is an additional reason that explains why the probability of incurring in a loss increases as the band modified is higher; while the probability of obtaining additional profits decreases.

To conclude, in order to achieve a trade-off between the growth of the annual additional profits obtained and the risk associated with this growth, a 2% percentage for modifying the day-ahead schedule is suggested in the Master Thesis. Nevertheless, the percentage chosen by wind agents in real operation will depend on their risk aversion.

6.6 CONCLUSIONS

In this chapter a possible alternative strategy for wind agents when participating in tertiary regulation has been proposed. It consist of modifying the current day-ahead market bid design, not biding exactly the mean value of the wind production confidence interval, but a value higher or lower (but always within the confidence interval) in some hours to take advantage of the opportunity cost of providing tertiary regulation reserves. Later, in the tertiary regulation market, if tertiary regulation is required, the wind production schedule will be restore to its original value; without having any impact on the deviations of the wind sector.

Firstly, a theoretical assessment has been carried out to select the hours in which it could be attractive to modify the day-ahead schedule. The hours with a very high hourly net wind demand ramp (at least 2000 MW)or with low day-ahead market prices (lower than 15 €/MWh) have been chosen to decrease the day-ahead schedule. On the other hand, in the hours with very low hourly net wind demand ramps (lower than -2000 MW) the day-ahead schedule will be increased. These criteria have been selected trying to increase the additional profits captured while diminishing the risk of incurring in a loss.

Secondly, the profits obtained if the alternative strategy was implemented in the years 2012, 2013, 2014 and in the first five months of the year 2015 have been estimated. If the percentage of the day-ahead schedule modified increases, the annual additional profits grow, but also the probability of having a loss. This drawback is caused by the higher impact of wind generation on the prices of tertiary regulation market, as well as for the impossibility of wind generation to allocate the whole variation of the day-ahead schedule as tertiary regulation energy in the hours in which it provides the 100% of tertiary regulation energy required.

Finally, a percentage of 2% has been proposed to modify the day-ahead schedule in order to achieve a trade-off between the maximization of the profits obtained and the risk of reducing the original profits. Nevertheless, the alternative strategy does not take advantage of the closeness of tertiary regulation to real time to reduce the deviations, which will benefit both the wind agents and the system operation. Not taking advantage of this seems to have no sense because the risk of incurring in a loss was zero and the profits obtained were very attractive. Therefore, a joint strategy that combine the advantages of the base and the alternative strategies will be proposed in the next chapter.

Chapter 7 JOINT STRATEGY FOR WIND AGENTS TO PARTICIPATE IN THE SPANISH TERTIARY REGULATION MARKET

7.1 OBJECTIVE AND MARKET PARTICIPATION PROCESS

The joint strategy is aim to combine the advantages of the base strategy and the alternative strategy. In order to do it, the following market participation process will be follow:

- Day-ahead market: In some selected hours the schedule will be increased or decreased with respect to the mean value of the wind production forecast's confidence interval. The objective is taking advantage of the opportunity cost of providing tertiary reserve within the confidence interval, as it was done in the alternative strategy.

- Intraday markets: The wind production schedule will be adjusted to reduce the forecasted deviations, as it is currently done.

- Tertiary regulation market: The wind production schedule will be also adjusted to reduce the deviations according to the last forecasts carried out, as it was done in the base strategy. Consequently, after the participation in tertiary regulation, the wind production schedule will be equal to the last wind production forecast, the one made before submitting the last bid before the tertiary regulation market is close.

7.2 ASSUMPTIONS

In order to assess the adequacy of the joint strategy similar assumptions as the ones considered for the base and the alternative strategy have been made:

- The whole wind energy sector has been treated as a single agent. Therefore, a single bid is submitting in the tertiary regulation market for the whole wind sector.

- When the deviations are reduced due to the participation of wind generation in the tertiary regulation, the sign of the deviation does not change.

- If wind generation participates in tertiary regulation, its last schedule will be equal to the last wind production forecast made (if there is room enough), regardless whether the day-ahead schedule has been modified or not, as it took place in the base strategy.

- If the TSO does not call tertiary reserves, or if there is not room for all the adjustment, the final schedule will be the one closest to the last wind production forecast that has been possible to trade.
- The participation of wind generation in tertiary regulation does not affect the prices of the different electricity markets, with the exception of the tertiary regulation market.
- The price of tertiary regulation energy won't be affected by the participation of wind energy if its contribution is lower than 80% of the total tertiary regulation energy. Therefore, only in the hours in which its contribution is at least 80% the price of tertiary regulation will equal the wind generation bid.

7.3 QUALITATIVE ASSESSMENT OF THE ADDITIONAL PROFITS OBTAINED

The formulation of the additional profits obtained if the joint strategy is implemented is complex because many cases should be distinguished. In this section, for the sake of simplicity, three representative cases will be explained, in which the profits obtained will be compared to the ones achieved with the base strategy. For the remaining ones, the analysis will be similar.

7.3.1 DAY-AHEAD SCHEDULE INCREASED BELOW THE LAST FORECAST AVAILABLE AND LAST FORECAST AVAILABLE LOWER THAN THE MEASURE

This first case corresponds to the hours in which the last wind production forecast is lower than the actual wind production measure and the day-ahead schedule has been increased up to a value lower than the last wind production forecast available. This case is represented in the figure below.

Figure 20: Day-ahead schedule increased below the last forecast available and last forecast available lower than the measure.

The following figure shows the different possibilities that can take place.

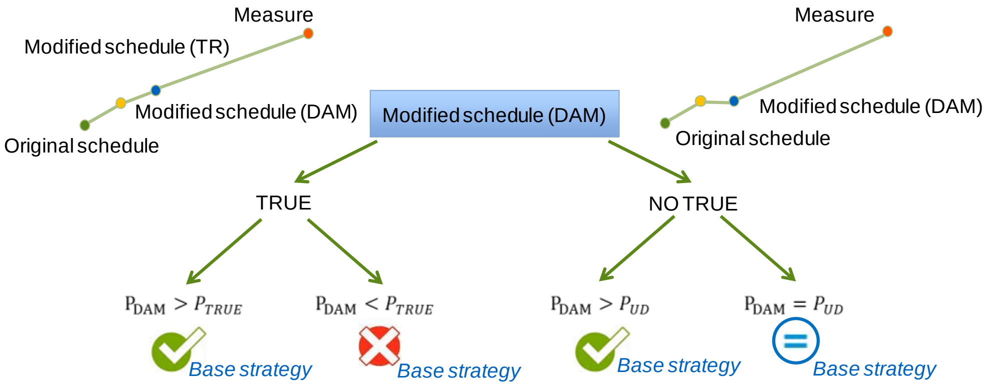

Figure 21: Possibilities if the day-ahead schedule is increased below the last forecast available and the last forecast available is lower than the measure.

Since the modified day-ahead schedule is lower than the last wind production forecast, to adjust it the provision of tertiary regulation upward energy will be needed. Consequently, as it can be seen in Figure 21, the following cases should be distinguished:

- Tertiary regulation upward energy is required; If the price of the day-ahead market is higher than the tertiary regulation upward energy price (which is not common) an additional profit with respect to the base strategy will be obtained. Otherwise, a loss will be incurred with respect to the base strategy.

- Tertiary regulation upward energy is not required: If the price of the day-ahead market is higher than the price of upward deviations an additional profit will be captured with respect to the base strategy. Otherwise, since the price of upward deviations cannot be higher than the day-ahead price, the result will be the same.

7.3.2 DAY-AHEAD SCHEDULE INCREASED BELOW THE LAST FORECAST AVAILABLE AND LAST FORECAST AVAILABLE LOWER THAN THE MEASURE

This case corresponds to the hours in which the last wind production forecast is lower than the actual wind production measure and the day-ahead schedule has been decreased up to a value lower than the last wind production forecast available. This case is represented in the figure below.

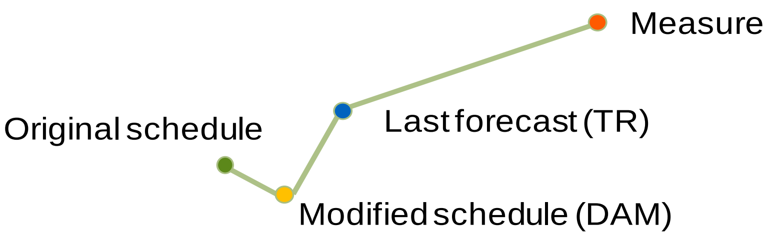

Figure 22: Day-ahead schedule decreased and last forecast available lower than the measure.

The following figure shows the different possibilities that can take place.

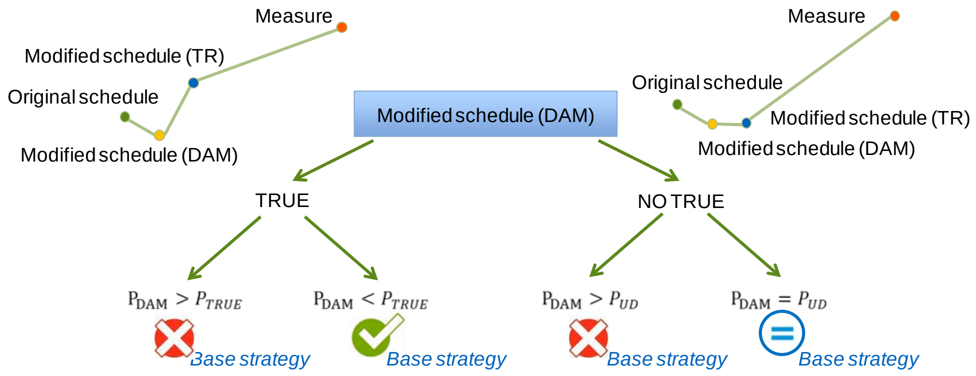

Figure 23: Possibilities if the day-ahead schedule is decreased and the last forecast available is lower than the measure.

Since the modified day-ahead schedule is lower than the last wind production forecast, to adjust it the provision of tertiary regulation upward energy will be needed. The following cases should be distinguished:

- Tertiary regulation upward energy is required; If the price of the day-ahead market is higher than the tertiary regulation upward energy price (which is not common) a loss will be incurred with respect to the base strategy. Otherwise, more profits will be captured.
- Tertiary regulation upward energy is not required: If the price of the day-ahead market is higher than the price of upward deviations less profits will be captured with respect to the base strategy. Otherwise, the result will be the same.

7.3.3 DAY-AHEAD SCHEDULE INCREASED ABOVE THE LAST FORECAST AVAILABLE AND LAST FORECAST AVAILABLE LOWER THAN THE MEASURE

This case corresponds to the hours in which the last wind production forecast is lower than the actual wind production measure and the day-ahead schedule has been increased up to a value higher than the last wind production forecast available. This case is represented in the figure below.

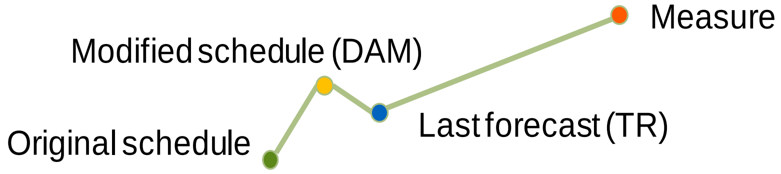

Figure 24: Day-ahead schedule increased above the last forecast available and last forecast available lower than the measure.

The following figure shows the different possibilities that can take place.

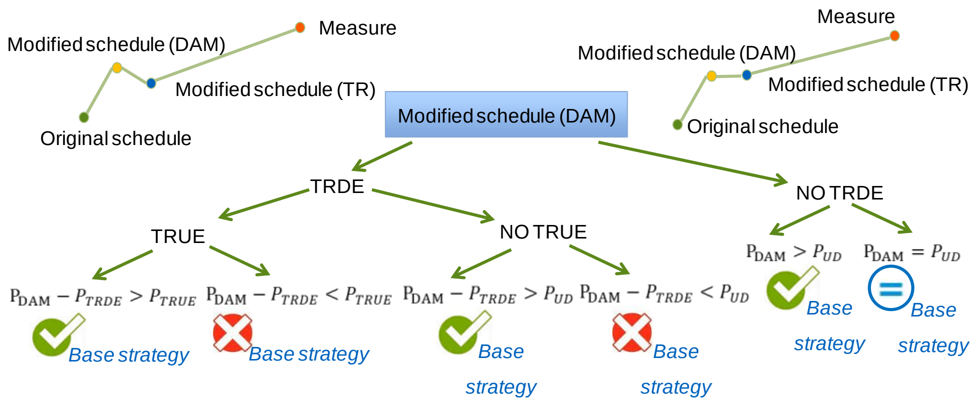

Figure 25: Possibilities if the day-ahead schedule is increased above the last forecast available and the last forecast available is lower than the measure.

Since the modified day-ahead schedule is higher than the last wind production forecast, to adjust it the provision of tertiary regulation downward energy will be needed. Consequently, the following cases should be distinguished:

- Tertiary regulation downward energy is required;
  - Tertiary regulation upward energy is also required: If the difference between the prices of the day-ahead market and the tertiary regulation downward energy is higher than the price of tertiary regulation upward energy an additional profit with respect to the base strategy will be obtained. Otherwise, a loss will be incurred with respect to the base strategy.
  - Tertiary regulation upward energy is not required: If the difference between the prices of the day-ahead market and the tertiary regulation downward energy is higher than the price of upward deviations an additional profit with respect to the base strategy will be obtained. Otherwise, lower profits will be captured.
- Tertiary regulation downward energy is not required: If the price of the day-ahead market is higher than the price of upward deviations an additional profit will be captured with respect to the base strategy. Otherwise, the result will be the same.

7.4 DATA EMPLOYED

The data employed for the analysis of the joint strategy is the same than the data used for the alternative strategy that was presented in the Chapter 6, in the section 6.2, plus the monthly costs of the deviations for wind agents that was also employed for comparing the profit obtained with the base strategy in the Chapter 5.

7.5 STRATEGY PROPOSED

The criteria employed to modify the day-ahead schedule is the same as the one proposed in Chapter 6:

- The day-ahead schedule will be increased 2% of the original schedule in the hours with very low hourly net wind demand ramps (lower than -2000 MW).

- The day-ahead schedule will be decreased 2% of the original schedule in the hours with very high hourly net wind demand ramps (higher or equal to 2000 MW) and in the hours with low day-ahead market prices (lower than 15 €/MWh) if these hours does not present very low net wind demand ramps.

Additionally, in all the hours the wind production deviations will be tried to be reduced participating in the tertiary regulation, with the same bid design employed in the base strategy. The difference between the last schedule committed and the last wind production forecast will be tried to be provided as tertiary regulation energy. If this difference is positive, it will be offered for tertiary regulation downward energy at the day-ahead market price to reduce the risk of incurring in a loss. On the other hand, if the difference is negative, it will be bidding at the day-ahead price for providing tertiary regulation upward energy.

The remaining downward reserve available will be offered at 0 €/MWh to avoid to make any payment for further reducing the schedule. Since the maximum wind power available will be produced, there won't be any remaining upward reserve to offer in the tertiary market.

7.6 ESTIMATED ADDITIONAL PROFITS FOR PARTICIPATING IN TERTIARY REGULATION

The results of the implementation of the joint strategy for the years 2012, 2013, 2014 and the first five months of the year 2015 are presented in the table below.

	Year			
	2012	2013	2014	2015*
Hours with positive additional profit [% of hours of the year]	34,2%	35,0%	31,4%	29,8%
Hours with negative additional profit [% of hours of the year]	4,5%	5,3%	6,5%	8,5%
Annual additional profits [€]	5.620.114	7.638.043	4.522.739	1.347.596
Annual additional profits [% original profit]	0,27%	0,36%	0,26%	0,13%
Annual additional profits [% costs of deviations]	9,2%	12,0%	8,1%	4,7%
Tertiary regulation upward energy provided by wind generation [% of TRUE]	7,1%	5,6%	5,6%	3,5%
Tertiary regulation downward energy provided by wind generation [% of TRDE]	5,4%	9,5%	5,1%	4,9%

*From January to May

Table 18: Results of the joint strategy for the years 2012, 2013, 2014 and 2015.

If the joint strategy had been implemented in the last three years, in around 33% of the hours of each year a higher profit would have been captured, while in around 5,5% of the hours the profit would have been reduced. Since the number of hours with a greater profit is 6 times higher than the number of hours with losses, the risk of reducing the current profits can be considered low.

The additional profits obtained vary from 4,5 million € for the year 2014 and 7,6 million € for the year 2013. Although these figures constitute a low percentage of the original annual profit captured by wind generation and of the cost of deviations of wind agents, in absolute terms they could be considered very attractive. Therefore, the joint strategy seems to be reasonable to be implemented because not only it presents a low risk of incurring in a loss, but it would also have allowed to capture more than 4 million € in each of the last three years.

The joint strategy is also attractive for increasing the efficiency of the system operation because it reduces the deviations of the wind sector and thus the costs for the consumers decrease.

As far as the year 2015 is concerned, only the first five months have been analysed. Therefore, the results obtained could not be representative for the whole year because maybe hours with high additional profit will be found in the next months. Nevertheless, it should be pointed out that the current profit could have been increased in more than 1 million €, with a probability of increasing the original profit more than 3 times higher than the probability of reducing it. Nevertheless, both the percentages of the growth of the original profit and the reduction of the cost of wind production deviations are lower than the results for the last three years. The reason for this could be that only five months are been analysed or than the data employed for the wind production forecast errors (the data of the year 2014) is not representative of the year 2015.

Finally, it should be also noted that in all the years studied, the annual contribution of wind generation to the provision of tertiary regulation upward energy is not high (lower than 8%). Regarding tertiary regulation downward energy, wind generation would have provided less than 10% of the total energy required. Therefore, the impact of the participation of wind generation on the prices of tertiary regulation is not expected to be significant if the whole year is considered. Nevertheless, its impact on some hours will be relevant.

The Figure 26 shows the contribution of wind generation to the total tertiary regulation energy provided in the hours in which wind generation participate in this ancillary service in the year 2014. The years 2012, 2013 and 2015 present similar results, which can be found for in the Annex 3 .

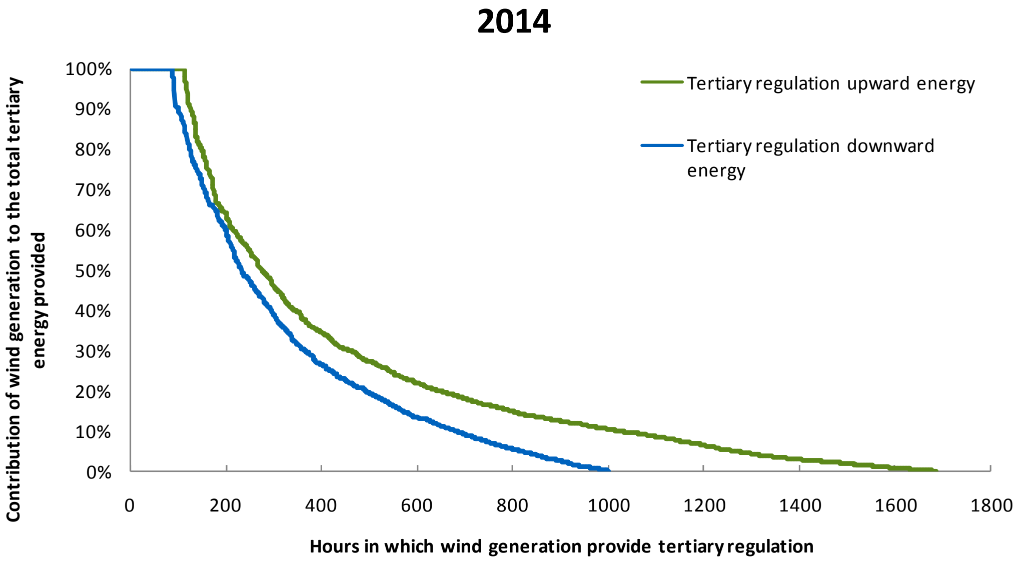

Figure 26: Contribution of wind generation to the total tertiary regulation energy provided in 2014 with the joint strategy.

Wind generation has been considered to be the marginal technology of the tertiary regulation market only in the hours in which its contribution exceeds 80% of the total energy provided. In the year 2014, this happen in less than 10% of the hours in which wind generation provides tertiary regulation upward energy and in less than 15% of the hours in which it provides tertiary regulation downward energy. Consequently, it would have an impact on the prices of the tertiary regulation upward energy in less than 150 hours and on the prices of the tertiary regulation downward energy in less than 130 hours.

7.7 COMPARISON WITH THE BASE STRATEGY AND THE ALTERNATIVE STRATEGY

In this section, the joint strategy will be compare to the base strategy described in Chapter 5 and the alternative strategy proposed in Chapter 6 (modifying 2% of the day-ahead schedule, as it was suggested at the end of the chapter).

Firstly, the additional profits captured with the three strategies in the last three years, as well as in the first five months of the year 2015, have been analysed. The results obtained are depicted in the figure below.

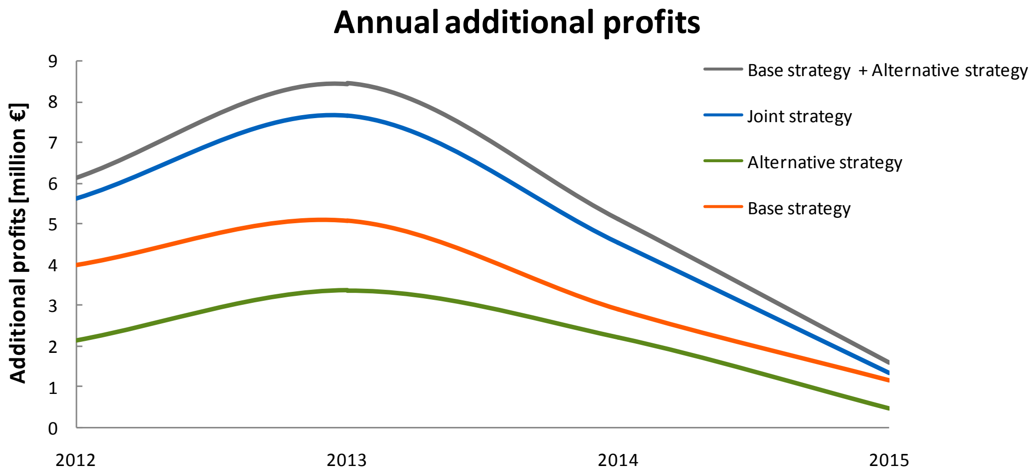

Figure 27: Comparison of the strategies: Additional profits captured.

As it can be seen in Figure 27, the alternative strategy is the strategy that captures less profits because it does not take advantage of the opportunity of reducing the wind production deviations thanks to the participation in tertiary regulation. However, it is able to increase the original profits in more than 2 million € in each of the last three years.

The joint strategy joins the advantages of the base strategy and the alternative strategy. Therefore, it could be thought that the profits obtained with it would be equal to the addition of the profits captured with the base strategy and the profits obtained with the alternative strategy (grey line). Nevertheless, the profits captured with the joint strategy, although being higher than the ones of the previous strategies, are lower than the grey line. The reason is that the result of the combination of both strategies is more complex that the addition of them due to the variety of cases that can take place, as it was explained in the section 7.3.

Secondly, the risk associated to incurring a loss versus the probability of increasing the original profits has been assessed. In order to do it, the number of hours with positive and negative additional profits depending on the strategy implemented has been analysed. The results obtained for the year 2014 are shown in the Figure 28. The results for the years 2012, 2013 and 2015 can be found in the Annex 3

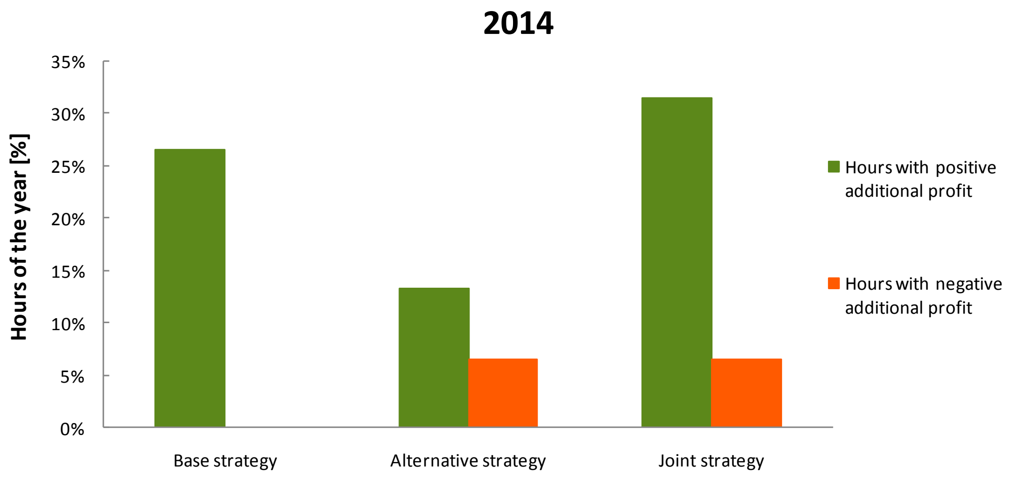

Figure 28: Comparison of the strategies: Number of hours with a higher and lower profit captured in the year 2014.

As it can be seen, the base strategy ensures that in any hour the original profit is not reduced, which is one of its main advantages. The alternative strategy presents two drawbacks:

- There are some hours in which the original profit is reduced.
- Although the number of hours with an additional profit doubles the hours with an additional loss, the hours with additional profits are much lower than in the base strategy.

These disadvantages, in addition to the lower profits captured, make the base strategy preferable over the alternative strategy.

The joint strategy increases (up to more than 30%) the number of hours with positive additional profits, improving the results of the base strategy and the alternative strategy. The number of hours with negative additional profits is almost the same than in the alternative strategy (6,50% in the alternative strategy vs. 6,46% in the joint strategy). Consequently, the joint strategy will be also preferable over the alternative strategy because it allows capturing more profits with a lower risk.

Regarding its comparison with the base strategy, with the joint strategy higher profits are obtained, but there are some hours in which the profit is reduced with respect to the original one. Therefore, the choice between these strategies will depend on the risk aversion of wind agents.

Thirdly, the possible impact of the participation of wind generation on the prices of tertiary regulation will be estimated. The following figure presents the contribution of wind generation to the tertiary regulation (upward energy in the graph above and downward energy in the graph below) in the year 2014 for each strategy.

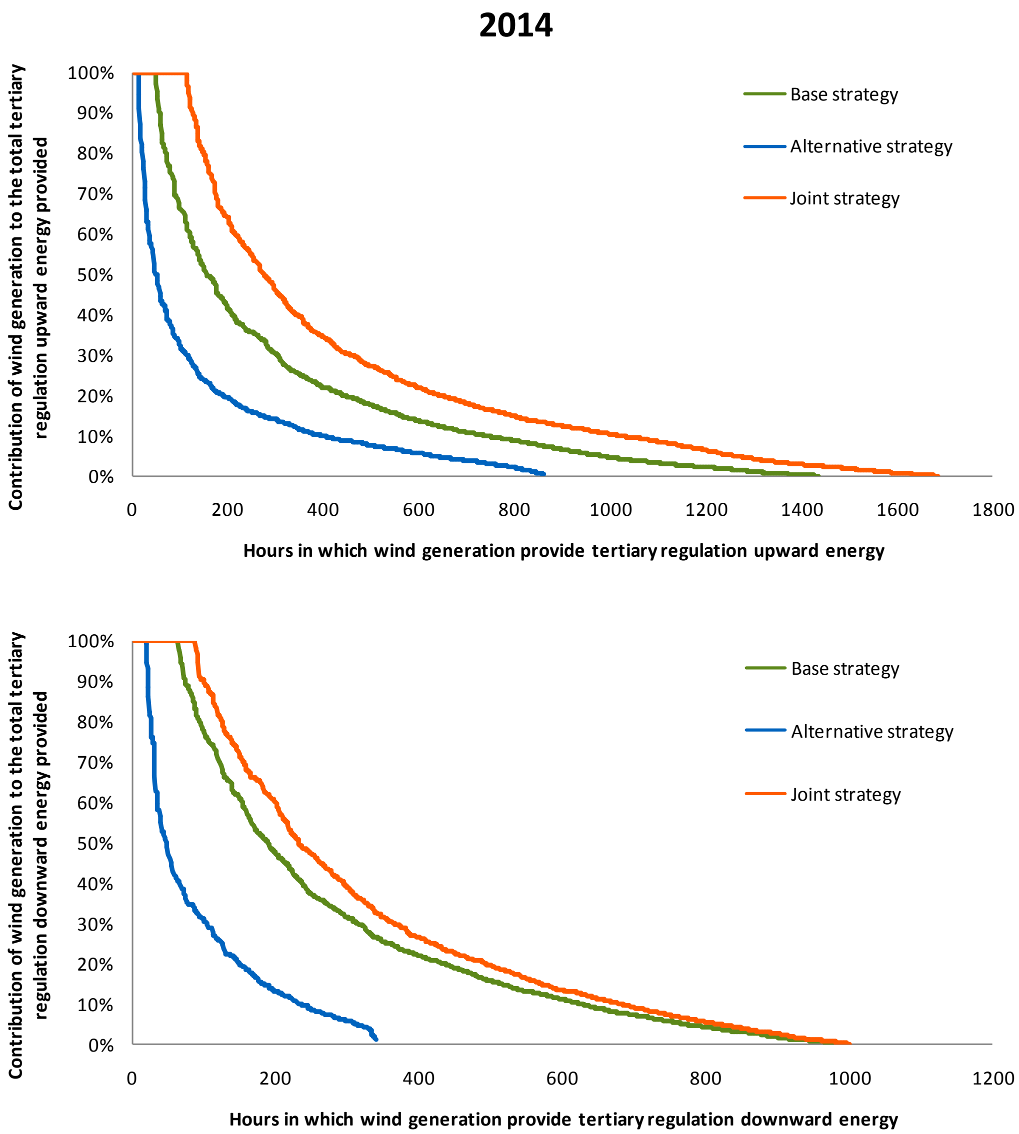

Figure 29: Comparison of the strategies: Contribution of wind generation to the total tertiary regulation energy provided in 2014.

The alternative strategy is the one in which wind generation participates in less hours in tertiary regulation. On the other hand, the joint strategy is the one in which wind generation provides more tertiary regulation. Although the percentage of the hours with a high contribution with respect to total hours in which wind energy provides tertiary regulation is similar for the three strategies, in the joint strategy is a bit lower than in the base strategy regarding tertiary regulation downward energy. Therefore, it is expected a higher impact on these prices if the joint strategy is implemented.

7.8 CONCLUSIONS

In this chapter a joint strategy that combines the advantages of the base strategy and the alternative strategy has been proposed. The joint strategy modifies the day-ahead schedule within the confidence interval in the same hours than in the alternative strategy. Later on, the wind production schedule is adjusted to the last forecast available before closing the tertiary regulation market in order to reduce the wind production deviations being committed to provide tertiary regulation energy.

The joint strategy allows capturing higher profits than the base strategy and the joint strategy. These profits could have amounted to more than 4 million € in each of the last three years and to around 1,3 million € in the first five months of the year 2015, figures that could be very attractive for the wind sector.

The number of hours in which the original profit would have been increased is also higher in the joint strategy than in the base strategy and the alternative strategy. Nevertheless, with the joint strategy the original profit would be reduced in some hours. However, the percentage of these hours with respect to the total hours of the year is small (lower than 10% in the years studied) and the high profits captured could justify this risk of incurring in a loss.

Finally, it should be pointed out that the joint strategy is preferable over the alternative strategy because it allows capturing high profits with lower risk. It would also be preferable over the base strategy if the low risk of obtaining negative profits in some hours is assumed in order to take advantage of the opportunity of capturing higher annual profits. Consequently, the choice between the joint strategy and the base strategy will depend on the risk aversion of wind agents.

Chapter 8 CONCLUSIONS

8.1 SUMMARY

The increased penetration of wind generation is posing increasing challenges to the planning and operation of power systems. Transmission System Operators usually take a cautious approach regarding massive penetration of wind energy into the grid arguing that wind power does not provide frequency and voltage control.

As far as the Spanish power system is concerned, renewable generation is currently not allowed to take part in ancillary services. However, the government is considering which should be the required tests to authorise renewable generation to participate in secondary and tertiary regulation, as well as deviations management mechanism. Therefore, it can be expected that renewables in general and wind farms in particular will be allowed to participate in ancillary services in the near future.

An extensive review of the literature has been carried out in order to know the most relevant studies related to the participation of wind power in frequency control. One of the main conclusions obtained is that modern wind turbines are technically able to provide such grid services. However, most of the active power controls involve an output power below the maximum available production, which implies a reduction in revenues. Nevertheless, in power systems with weak interconnections and/or high wind power penetration the provision of frequency reserves can be more valuable than maximizing the wind power production (Tarnowski et al., 2010). Furthermore, it should be pointed out that, although there are some studies that cover the participation of wind generation in secondary regulation (both from a technical and economical point of view), little attention has been paid to its possible participation in tertiary regulation. There is only a study from Denmark that suggests the reduction of wind production deviations though the participation in this grid service.

The aim of this Master Thesis is the economic assessment of the participation of wind generation in the Spanish ancillary services markets. Since primary regulation is not remunerated in Spain, the Master Thesis has focussed on the participation of wind generation in secondary and tertiary regulation, as well as on the deviation management service.

Firstly, a theoretical assessment of the most suitable circumstances for wind generation to participate in the mentioned ancillary services has been carried out. According to this assessment, the tertiary regulation has been identified as the most interesting market for wind generation to participate in.

To estimate the economic impact for wind agents of the participation of wind generation in tertiary regulation, in the second part of the Master Thesis three possible bidding strategies have been proposed: a base strategy, an alternative strategy and a joint strategy. These strategies differ in the hours in which wind generation will be interested in participating in tertiary regulation, as well as in the amount of tertiary regulation upward and downward energy it will be interested to provide.

For assessing the design of the three strategies, the profits received by wind agents if the strategies were implemented in the years 2012, 2013, 2014 and the first five months of the year 2015 have been estimated. To assess the results obtained, two main measures have been analyzed:

- The annual additional profits captured: the difference between the profits captured if wind generation had participated in tertiary regulation and its original profits (the actual ones, without being allowed to participate in it).

- The risk associated to reduce the original profit in some hours.

8.2 CONTRIBUTIONS

8.2.1 THEORETICAL ASSESSMENT OF THE MOST SUITABLE CIRCUMSTANCES FOR WIND GENERATION TO PARTICIPATE IN THE ANCILLARY SERVICES

Due to the impact of wind conditions on the prices of the day-ahead market and the different ancillary services markets, low, medium and high wind conditions have been distinguished to assess the most suitable circumstances for wind generation to participate in the ancillary services. The conclusion are summarised in the table below.

	Low and medium wind conditions	High wind conditions
	The price is high enough to motivate wind agents to produce	The price is low. Some wind generation can even have not been committed
Participation in secondary regulation	Not possible/ Not desirable	Under certain circumstances
Participation in tertiary regulation or deviation management	Desirable	Very desirable

Table 19: Theoretical assessment of the participation of wind generation in the Spanish frequency control services.

Due to the reliability required in secondary regulation, under low and medium wind conditions the participation of wind generation is not desirable (or even not possible) under current regulation, by which upward and downward reserves should be provided simultaneously. Under high wind conditions the participation of wind generation could be desirable in some cases. Nevertheless, it should be taken into account that additional investments would be required in order to design and implement the AGC mechanisms in the wind farms and the expected profits obtained for wind agents are not high.

The participation of wind generation in tertiary regulation or deviation management services can either keep the same situation as the current one (if wind generation is not committed) or improve it (if it is committed), benefiting wind agents, the system and thus the consumers, especially under high wind conditions.

Although deviations management mechanism presents similar features to tertiary regulation, this service is only demanded in specific circumstances that depend on the status of the system. The potential benefits that could be obtained will vary a lot depending on the year analysed; hence reducing the significance of the conclusions obtained.

Consequently, tertiary regulation seems to have the highest potential benefits for both wind agents and the system operation.

8.2.2 ESTIMATION OF THE ECONOMIC IMPACT OF THE PARTICIPATION OF WIND GENERATION IN TERTIARY REGULATION

8.2.2.1 Contributions of the base strategy

The base strategy consists of reducing the wind production deviations as if the tertiary regulation market was an additional intraday market where to adjust the wind production schedule. The main contribution made in the proposal of the base strategy is the suggestion of bidding the day-ahead price for the provision of tertiary regulation upward and downward energy. With this bid design the additional profits captured by wind agents would not be negative in any hour. Therefore, the security of increasing the profits of wind generation is ensured.

8.2.2.2 Contributions of the alternative strategy

The alternative strategy tries to detect trends in the system that imply a preference to provide upward or downward reserve. As any wind production forecast is made up of a mean value and an interval of confidence, the detection of these patterns may allow determining whether to modify the day-ahead schedule upwards or downwards, thus taking advantage of the opportunity cost of providing reserves within the confidence interval for participating in the tertiary regulation.

The whole design of the alternative strategy is a contribution of this Master Thesis, including the proposal of the amount of the day-ahead schedule that should be modified and the choice of the most suitable hours within a day to carry out this modification.

8.2.2.3 Contributions of the joint strategy

The main contribution of the joint strategy is its capability to combine the advantage of the base strategy of reducing the wind production deviations and the advantage of the alternative strategy of capturing additional profits modifying the current design of the bids submitted for the day-ahead market.

8.2.2.4 Results of the implementation of the strategies

The base strategy is preferable over the alternative strategy because it allows obtaining higher annual profits and increasing the original profits in more hours than the alternative strategy and without the risk of reducing the original profits in any hour.

The joint strategy allows capturing higher profits than the base and the alternative strategies. With its implementation, it has been estimated that the wind sector would have increased its annual profits in more than 4 million € in the years 2012, 2013 and 2014.

The number of hours in which the original profit would have been increased is also higher with the joint strategy than with the base strategy or the alternative strategy. Nevertheless, with the joint strategy the original profit would be reduced in some hours. However, the percentage of these hours with respect to the total hours of the year is small (lower than 10% in the years studied) and the high profits captured could justify this risk of incurring in a loss.

The joint strategy is preferable over the alternative strategy because it allows capturing high profits with lower risk. The choice between the joint strategy and the base strategy will depend on the risk aversion of wind agents. If the expected annual profits are prioritized over the risk of reducing the original profits in some hours, the joint strategy will be chosen. On the other hand, if wind agents are more cautious and they want to prevent the reduction of the original profit in every hour, the base strategy will be more suitable for them.

In conclusion, a regulatory change that enables wind generation to provide tertiary regulation is desirable because only with the base strategy the costs of deviations for wind agents will be reduced; hence decreasing the cost of deviations of the system which implies reducing the costs for the consumers.

8.3 SUGGESTIONS FOR FUTURE DEVELOPMENTS

In order to complement the assessment carried out in the Master Thesis, the following studies could be interesting:

- The analysis of the expected profits obtained by a wind agent with the strategies proposed using the measures of the wind production forecasts employed by the agent. It should be noted that the wind production forecast errors for a single agent are higher than the errors of the wind production forecast carried out by REE for the whole sector (the *Sipreolico errors* employed in this Master Thesis). Consequently, the profits obtained could be considerably different than the ones estimated in the Master Thesis.

- The assessment of the economic impact of the participation of wind generation in tertiary regulation on the profits earned by the owners of the other technologies (hydro power plants, coal power plants, combine cycles...).

- A quantitative assessment of the economic impact of the participation of wind generation in secondary regulation. Nevertheless, it should be noted that some authors have already carried out studies related to this topic focussing on the Spanish power system.

- A quantitative assessment of the economic impact of the participation of wind generation in the deviation management services.

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ANNEXES

Annex 1 BASE STRATEGY FOR THE YEARS 2012, 2013 AND 2015

In this Annex the hourly wind production forecast errors employed for the years 2012, 2013 and 2015, as well as the analysis of the hours with tertiary regulation of these years will be presented. All of these data and studies have been employed for the design and the assessment of the base strategy described in the Chapter 5. Furthermore, in this Annex the contribution of wind generation to the total tertiary regulation energy provided if the base strategy was implemented in the years 2012, 2013 and 2015 is included.

The analysis of all the data provided in Annex 1 has been explained with detail for the year 2014 in the Chapter 5. The analogous analysis would be carried out for the years 2012, 2013 and 2015.

HOURLY WIND PRODUCTION FORECAST ERRORS

The data for the years 2012 and 2013 have been obtained from Figure 12, in which the Sipreolico errors (the errors of the wind production forecast carried out by REE for the whole wind sector) are depicted.

2012

Hour	Last intraday market	Prediction horizon [hours]	Estimated wind production forecast error [%]
1	2	4	9
2	2	5	9,5
3	2	6	9,8
4	2	7	10,1
5	3	4	9
6	3	5	9,5
7	3	6	9,8
8	4	4	9
9	4	5	9,5
10	4	6	9,8
11	4	7	10,1
12	5	4	9
13	5	5	9,5
14	5	6	9,8
15	5	7	10,1
16	6	4	9
17	6	5	9,5
18	6	6	9,8
19	6	7	10,1
20	6	8	10,3
21	6	9	10,5
22	1	5	9,5
23	1	6	9,8
24	1	7	10,1
25	1	8	10,3

The forecast error employed for bidding before the tertiary regulation market closes corresponds to a prediction horizon of two hours (to be conservative). The value employed for the year 2012 is 7%.

2013

Hour	Last intraday market	Prediction horizon [hours]	Estimated wind production forecast error [%]
1	2	4	6,7
2	2	5	7
3	2	6	7,4
4	2	7	7,6
5	3	4	6,7
6	3	5	7
7	3	6	7,4
8	4	4	6,7
9	4	5	7
10	4	6	7,4
11	4	7	7,6
12	5	4	6,7
13	5	5	7
14	5	6	7,4
15	5	7	7,6
16	6	4	6,7
17	6	5	7
18	6	6	7,4
19	6	7	7,6
20	6	8	7,8
21	6	9	7,9
22	1	5	7
23	1	6	7,4
24	1	7	7,6
25	1	8	7,8

The forecast error employed for bidding before the tertiary regulation market closes is 5,4%.

2015

Since there is not data available regarding the hourly wind production forecast errors of the current year, the most recent data (the data form 2014) has been employed.

ANALYSIS OF THE HOURS WITH TERTIARY REGULATION UPWARD ENERGY

As it was presented in the Chapter 5, if wind generation participated in tertiary regulation in all the hours in which tertiary regulation upward energy was required the additional profits obtained would be positive in most of the hours (if the price of tertiary regulation upward energy is higher than the price of upward deviations).

2012

	Year 2012
Number of hours with TRUE [hours]	4042
Number of hours with TRUE [% of hours of the year]	46,0%
Number of hours with TRUE when $P_{TRUE} > P_{UD}$ [% of the hours with TRUE]	85,4%
Number of hours with TRUE when $P_{TRUE} < P_{UD}$ [% of the hours with TRUE]	13,2%

2013

	Year 2013
Number of hours with TRUE [hours]	4430
Number of hours with TRUE [% of hours of the year]	50,6%
Number of hours with TRUE when $P_{TRUE} > P_{UD}$ [% of the hours with TRUE]	88,7%
Number of hours with TRUE when $P_{TRUE} < P_{UD}$ [% of the hours with TRUE]	9,8%

2015

	Year 2015*
Number of hours with TRUE [hours]	1909
Number of hours with TRUE [% of hours of the year]	52,7%
Number of hours with TRUE when $P_{TRUE} > P_{UD}$ [% of the hours with TRUE]	95,0%
Number of hours with TRUE when $P_{TRUE} < P_{UD}$ [% of the hours with TRUE]	4,2%

*From January to May

ANALYSIS OF THE HOURS WITH TERTIARY REGULATION DOWNWARD ENERGY

As it was also presented in the Chapter 5, if wind generation participated in tertiary regulation in all the hours in which tertiary regulation downward energy was required the additional profits obtained would be positive in most of the hours (if the price of tertiary regulation downward energy is lower than the price of downward deviations).

2012

	Year 2012
Number of hours with TRDE [hours]	3446
Number of hours with TRDE [% of hours of the year]	39,2%
Number of hours with TRDE when $P_{TRDE} < P_{DD}$ [% of the hours with TRDE]	98,6%
Number of hours with TRDE when $P_{TRDE} > P_{DD}$ [% of the hours with TRDE]	0,5%

2013

	Year 2013
Number of hours with TRDE [hours]	3327
Number of hours with TRDE [% of hours of the year]	38,0%
Number of hours with TRDE when $P_{TRDE} < P_{DD}$ [% of the hours with TRDE]	90,4%
Number of hours with TRDE when $P_{TRDE} > P_{DD}$ [% of the hours with TRDE]	0,7%

2015

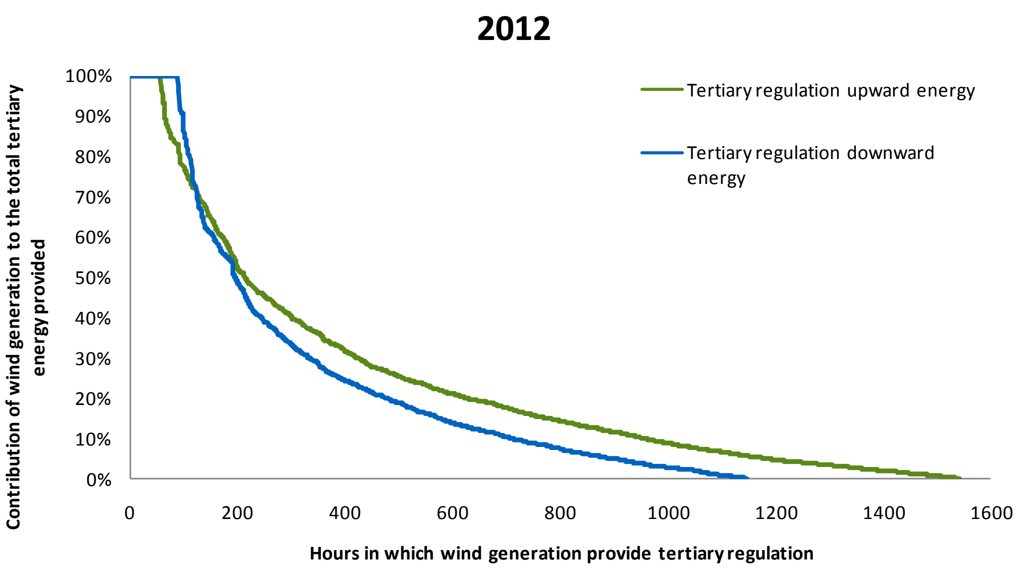
	Year 2015*
Number of hours with TRDE [hours]	1396
Number of hours with TRDE [% of hours of the year]	38,5%
Number of hours with TRDE when $P_{TRDE} < P_{DD}$ [% of the hours with TRDE]	99,9%
Number of hours with TRDE when $P_{TRDE} > P_{DD}$ [% of the hours with TRDE]	0,0%

*From January to May

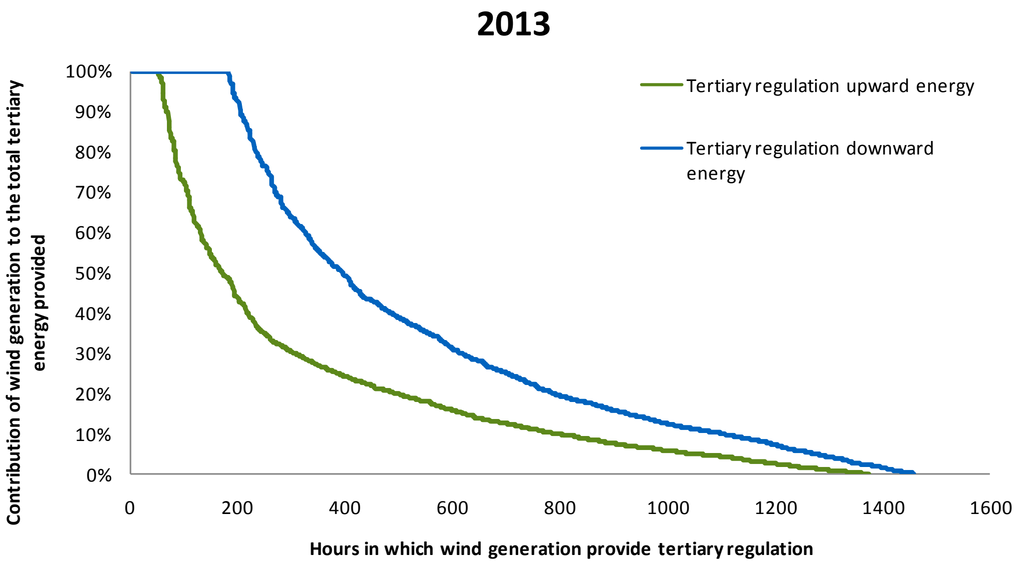
Contribution of wind generation to the total tertiary regulation energy if the base strategy is implemented

As it was explained in the Chapter 5, although in most of the hours in which wind generation participate in tertiary regulation its contribution is not huge, there is some hours in which it could even provided all the tertiary regulation required, being the marginal technology of such market.

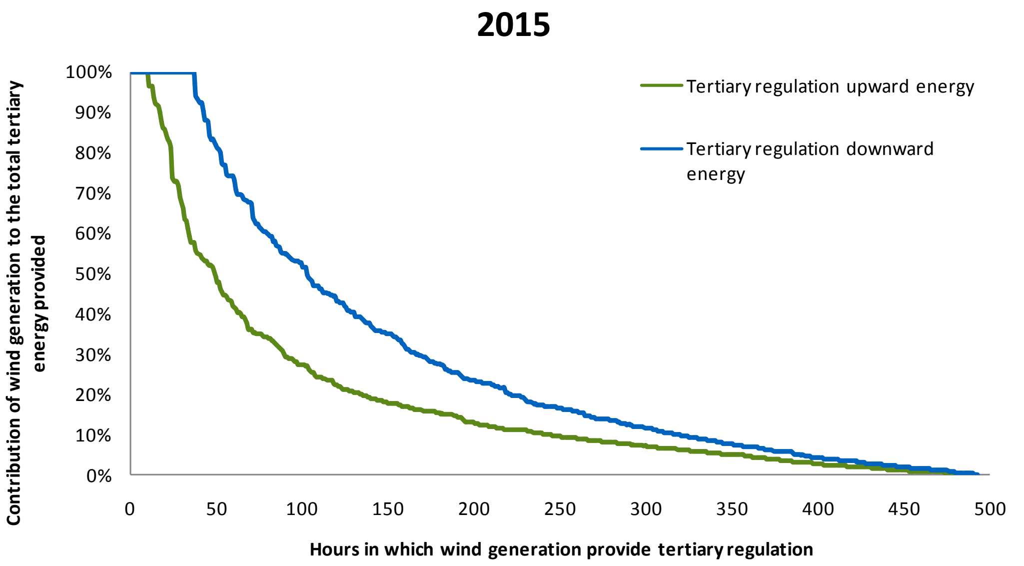
2012



2013


2013
Tertiary regulation upward energy
Tertiary regulation downward energy
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
200
400
600
800
1000
1200
1400
1600
Contribution of wind generation to the total tertiary energy provided
Hours in which wind generation provide tertiary regulation

2015


2015
Tertiary regulation upward energy
Tertiary regulation downward energy
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
50
100
150
200
250
300
350
400
450
500
Contribution of wind generation to the total tertiary energy provided
Hours in which wind generation provide tertiary regulation

Annex 2 ALTERNATIVE STRATEGY FOR THE YEARS 2012, 2013 AND 2015

In this Annex firstly the analyses carried out for the years 2012 and 2013 to detect trends in the system that imply a preference to provide upward or downward reserve within the wind production confidence interval will be presented. Secondly, the results obtained if the alternative strategy was implemented in the previous years, as well as in the first five months of the year 2015, will be included. Finally, the contribution of wind generation to the total tertiary regulation energy provided with the alternative strategy will be depicted.

The explanation of all the results presented in this Annex has been made in detail for the year 2014 in the Chapter 6. Since the conclusions obtained are similar, the explanation won't be repeated in the Annex.

POSSIBLE FACTORS TO BE CONSIDERED

2012

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	0 ≤ PDAM < 15	267	40,1%	21,7%	3714	13,91
	15 ≤ PDAM < 30	532	52,6%	21,8%	4102	7,71
	30 ≤ PDAM < 45	2096	40,5%	34,7%	-4995	-2,38
	45 ≤ PDAM < 60	4847	36,2%	50,1%	-28505	-5,88
	60 ≤ PDAM	1042	33,4%	54,4%	-8523	-8,18
TRDE	0 ≤ PDAM < 15	267	31,5%	55,1%	-5.029	-18,84
	15 ≤ PDAM < 30	532	28,2%	66,2%	-4.627	-8,70
	30 ≤ PDAM < 45	2096	38,5%	53,4%	5.057	2,41
	45 ≤ PDAM < 60	4847	40,0%	39,7%	25.821	5,33
	60 ≤ PDAM	1042	36,6%	36,2%	5.107	4,90

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	0 ≤ Demand Coverage < 0,1	2062	43,8%	41,2%	-4.614	-2,24
	0,1 ≤ Demand Coverage < 0,2	3100	35,2%	47,7%	-15.370	-4,96
	0,2 ≤ Demand Coverage < 0,3	1965	35,0%	46,9%	-12.220	-6,22
	0,3 ≤ Demand Coverage < 0,4	1052	38,1%	43,1%	-4.908	-4,67
	0,4 ≤ Demand Coverage	605	42,1%	32,1%	2.904	4,80
TRDE	0 ≤ Demand Coverage < 0,1	2062	28,0%	49,5%	95	0,05
	0,1 ≤ Demand Coverage < 0,2	3100	38,6%	40,9%	13.198	4,26
	0,2 ≤ Demand Coverage < 0,3	1965	44,3%	43,0%	11.615	5,91
	0,3 ≤ Demand Coverage < 0,4	1052	45,3%	45,6%	4.738	4,50
	0,4 ≤ Demand Coverage	605	39,7%	50,7%	-3.318	-5,48

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Net Wind Demand Ramp < -2000	877	28,1%	56,2%	-6.925	-7,90
	-2000 ≤ Net Wind Demand Ramp < -1000	1203	24,6%	58,4%	-11.366	-9,45
	-1000 ≤ Net Wind Demand Ramp < 0	2628	29,9%	48,4%	-15.247	-5,80
	0 ≤ Net Wind Demand Ramp < 1000	2057	43,7%	37,4%	-2.369	-1,15
	1000 ≤ Net Wind Demand Ramp < 2000	1028	51,8%	35,2%	-89	-0,09
	2000 ≤ Net Wind Demand Ramp	990	58,4%	30,0%	1784	1,80
TRDE	Net Wind Demand Ramp < -2000	877	52,8%	33,5%	7.045	8,03
	-2000 ≤ Net Wind Demand Ramp < -1000	1203	54,0%	29,8%	11.114	9,24
	-1000 ≤ Net Wind Demand Ramp < 0	2628	42,5%	40,5%	11.516	4,38
	0 ≤ Net Wind Demand Ramp < 1000	2057	29,5%	52,4%	-1.427	-0,69
	1000 ≤ Net Wind Demand Ramp < 2000	1028	26,1%	54,7%	-755	-0,73
	2000 ≤ Net Wind Demand Ramp	990	25,9%	56,9%	-1158	-1,17

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Q1 Peak	1456	33,2%	53,0%	-10.428	-7,16
	Q2 Peak	1456	39,5%	44,0%	-5.995	-4,12
	Q3 Peak	1472	34,7%	53,6%	-9.761	-6,63
	Q4 Peak	1472	44,6%	39,5%	-3.349	-2,28
TRDE	Q1 Peak	1456	42,8%	37,8%	8.977	6,17
	Q2 Peak	1456	38,3%	44,6%	4.623	3,17
	Q3 Peak	1472	40,1%	37,0%	7.992	5,43
	Q4 Peak	1472	35,1%	49,4%	1.364	0,93

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Q1 Off-peak	727	44,0%	30,0%	677	0,93
	Q2 Off-peak	728	33,1%	43,4%	-3.418	-4,69
	Q3 Off-peak	736	27,0%	47,6%	-3.764	-5,11
	Q4 Off-peak	736	48,0%	31,1%	1.878	2,55
TRDE	Q1 Off-peak	727	32,2%	59,4%	-1.060	-1,46
	Q2 Off-peak	728	40,7%	41,9%	3.197	4,39
	Q3 Off-peak	736	41,0%	39,4%	3.202	4,35
	Q4 Off-peak	736	32,9%	57,2%	-2.023	-2,75

2013

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	0 ≤ PDAM < 15	988	26,0%	17,6%	8276	8,38
	15 ≤ PDAM < 30	831	50,2%	22,7%	5922	7,13
	30 ≤ PDAM < 45	1740	51,0%	27,8%	-2297	-1,32
	45 ≤ PDAM < 60	3761	43,6%	40,9%	-15863	-4,22
	60 ≤ PDAM	1440	43,5%	44,9%	-8625	-5,99
TRDE	0 ≤ PDAM < 15	988	24,5%	32,2%	-9.028	-9,14
	15 ≤ PDAM < 30	831	36,0%	61,3%	-5.402	-6,50
	30 ≤ PDAM < 45	1740	34,1%	60,1%	4.257	2,45
	45 ≤ PDAM < 60	3761	33,7%	47,6%	15.412	4,10
	60 ≤ PDAM	1440	33,2%	46,8%	6.471	4,49

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	0 ≤ Demand Coverage < 0,1	1355	47,2%	37,0%	-3.150	-2,32
	0,1 ≤ Demand Coverage < 0,2	2619	41,7%	39,9%	-12.170	-4,65
	0,2 ≤ Demand Coverage < 0,3	2226	41,8%	35,4%	-6.359	-2,86
	0,3 ≤ Demand Coverage < 0,4	1518	45,8%	30,7%	698	0,46
	0,4 ≤ Demand Coverage	1042	45,2%	22,1%	8.392	8,05
TRDE	0 ≤ Demand Coverage < 0,1	1355	24,1%	54,7%	802	0,59
	0,1 ≤ Demand Coverage < 0,2	2619	32,9%	47,1%	9.669	3,69
	0,2 ≤ Demand Coverage < 0,3	2226	36,4%	47,6%	7.600	3,41
	0,3 ≤ Demand Coverage < 0,4	1518	35,0%	50,7%	745	0,49
	0,4 ≤ Demand Coverage	1042	33,9%	51,2%	-7.105	-6,82

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Net Wind Demand Ramp < -2000	782	32,6%	47,8%	-4.715	-6,03
	-2000 ≤ Net Wind Demand Ramp < -1000	1198	29,5%	46,7%	-8.902	-7,43
	-1000 ≤ Net Wind Demand Ramp < 0	2731	36,0%	38,2%	-9.705	-3,55
	0 ≤ Net Wind Demand Ramp < 1000	2093	48,0%	27,9%	931	0,44
	1000 ≤ Net Wind Demand Ramp < 2000	1034	58,1%	26,4%	4.316	4,17
	2000 ≤ Net Wind Demand Ramp	921	68,4%	21,1%	5519	5,99
TRDE	Net Wind Demand Ramp < -2000	782	51,5%	35,9%	5.932	7,59
	-2000 ≤ Net Wind Demand Ramp < -1000	1198	48,9%	36,1%	9.204	7,68
	-1000 ≤ Net Wind Demand Ramp < 0	2731	36,5%	44,5%	7.740	2,83
	0 ≤ Net Wind Demand Ramp < 1000	2093	24,3%	54,7%	-2.552	-1,22
	1000 ≤ Net Wind Demand Ramp < 2000	1034	19,8%	61,8%	-4.533	-4,38
	2000 ≤ Net Wind Demand Ramp	921	19,5%	68,2%	-4128	-4,48

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Q1 Peak	1440	39,8%	43,9%	-5.740	-3,99
	Q2 Peak	1456	39,4%	40,6%	-5.375	-3,69
	Q3 Peak	1472	50,7%	33,3%	-2.902	-1,97
	Q4 Peak	1472	48,4%	36,3%	-2.266	-1,54
TRDE	Q1 Peak	1440	36,4%	44,7%	4.546	3,16
	Q2 Peak	1456	37,6%	40,8%	5.155	3,54
	Q3 Peak	1472	28,3%	54,8%	2.655	1,80
	Q4 Peak	1472	30,8%	51,4%	2.518	1,71

	Additional profit					
	Conditions for changing the day-ahead schedule	Number of hours/ MWh modified	Number of hours with positive additional profit [%]	Number of hours with negative additional profit [%]	Additional profit [€]	Additional profit [€/MWh]
TRUE	Q1 Off-peak	719	42,3%	24,2%	3.106	4,32
	Q2 Off-peak	728	35,3%	28,6%	-1.146	-1,57
	Q3 Off-peak	736	44,0%	28,4%	-285	-0,39
	Q4 Off-peak	736	45,5%	25,8%	2.063	2,80
TRDE	Q1 Off-peak	719	30,9%	50,8%	-2.765	-3,85
	Q2 Off-peak	728	33,8%	45,6%	1.039	1,43
	Q3 Off-peak	736	28,7%	60,2%	-457	-0,62
	Q4 Off-peak	736	35,6%	54,1%	-1.024	-1,39

RESULTS AS A FUNCTION OF THE PERCENTAGE OF THE DAY-AHEAD SCHEDULE MODIFIED

As it was explained in the Chapter 6, the annual profits captured are higher if the percentage of the day-ahead schedule modified is bigger. Nevertheless, the number of hours with negative profits decreases, as well as the profit obtained per MWh modified.

2012

	Percentage of the day-ahead schedule		
	1%	2%	3%
Hours in which the day-ahead schedule would have modified [% of hours of the year]	23,9%	23,9%	23,9%
Hours with positive additional profit [% of hours of the year]	13,6%	13,1%	12,8%
Hours with negative additional profit [% of hours of the year]	4,3%	4,5%	4,9%
Annual additional profits [€]	1.138.130	2.128.207	2.916.202
Annual additional profits [€/MWh modified]	9,4	8,7	8,0
Tertiary regulation upward energy provided by wind generation [% of TRUE]	1,2%	2,4%	3,5%
Tertiary regulation downward energy provided by wind generation [% of TRDE]	1,2%	2,4%	3,4%

2013

	Percentage of the day-ahead schedule		
	1%	2%	3%
Hours in which the day-ahead schedule would have modified [% of hours of the year]	29,1%	29,1%	29,1%
Hours with positive additional profit [% of hours of the year]	15,2%	14,5%	13,8%
Hours with negative additional profit [% of hours of the year]	4,9%	5,3%	5,6%
Annual additional profits [€]	1.849.737	3.361.924	4.507.098
Annual additional profits [€/MWh modified]	10,1	9,2	8,2
Tertiary regulation upward energy provided by wind generation [% of TRUE]	1,7%	3,4%	5,0%
Tertiary regulation downward energy provided by wind generation [% of TRDE]	1,8%	3,4%	4,8%

2015

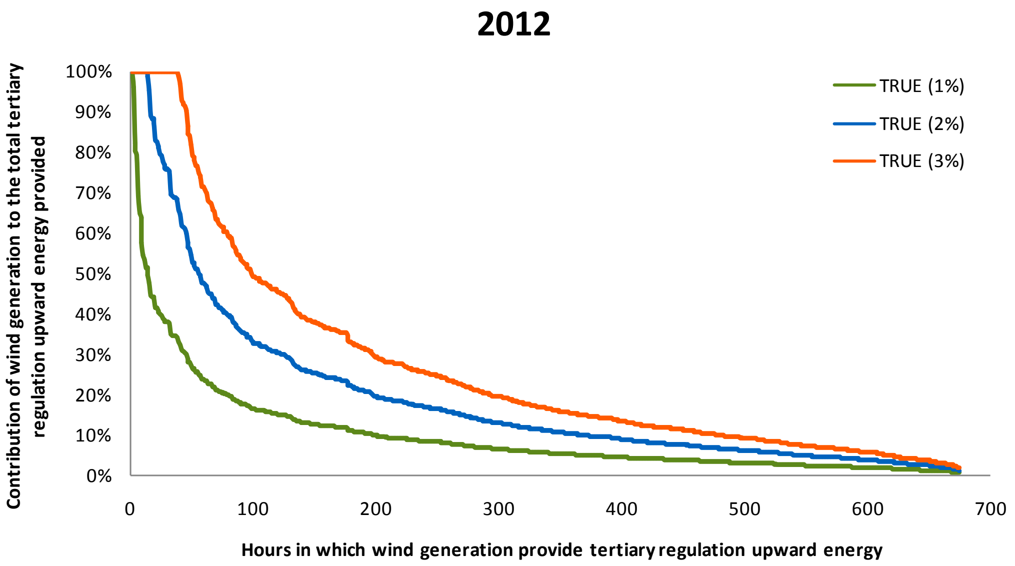
	Percentage of the day-ahead schedule		
	1%	2%	3%
Hours in which the day-ahead schedule would have modified [% of hours of the year]	24,1%	24,1%	24,1%
Hours with positive additional profit [% of hours of the year]	12,4%	11,2%	10,1%
Hours with negative additional profit [% of hours of the year]	7,5%	8,5%	9,1%
Annual additional profits [€]	349.372	517.657	461.692
Annual additional profits [€/MWh modified]	5,4	4,0	2,4
Tertiary regulation upward energy provided by wind generation [% of TRUE]	1,7%	3,4%	4,9%
Tertiary regulation downward energy provided by wind generation [% of TRDE]	1,1%	2,0%	2,6%

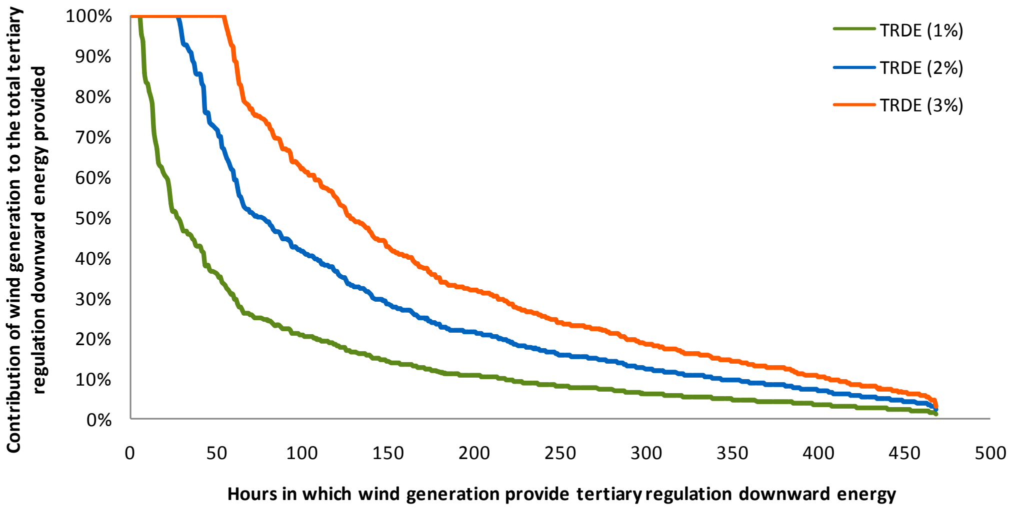
*From January to May

CONTRIBUTION OF WIND GENERATION TO THE TOTAL TERTIARY REGULATION ENERGY AS A FUNCTION OF THE PERCENTAGE OF THE DAY-AHEAD SCHEDULE MODIFIED

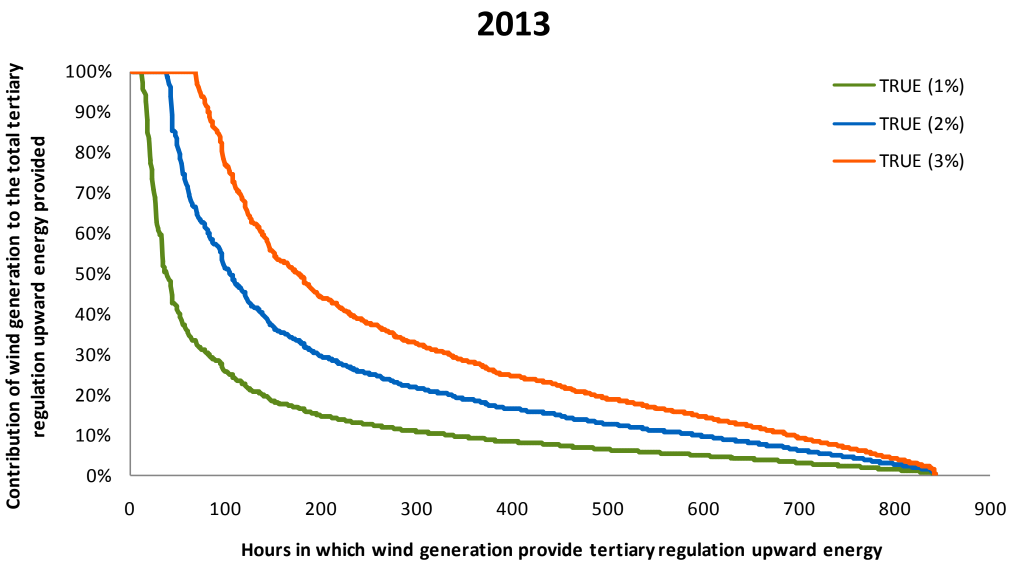
The contribution of wind generation to the total tertiary regulation energy provided increased as the percentage of the day-ahead schedule modified increases.

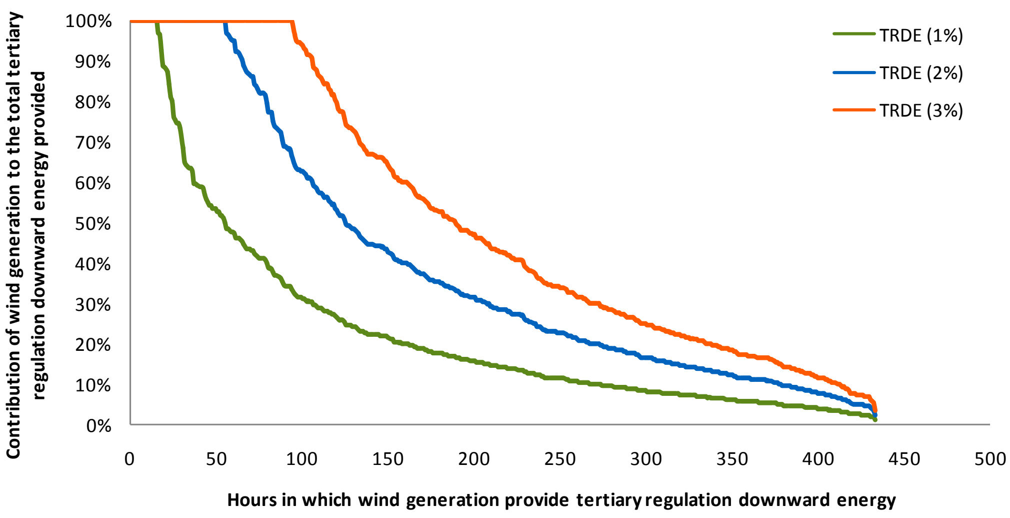
2012


2012
Contribution of wind generation to the total tertiary regulation upward energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
700
Hours in which wind generation provide tertiary regulation upward energy
TRUE (1%)
TRUE (2%)
TRUE (3%)

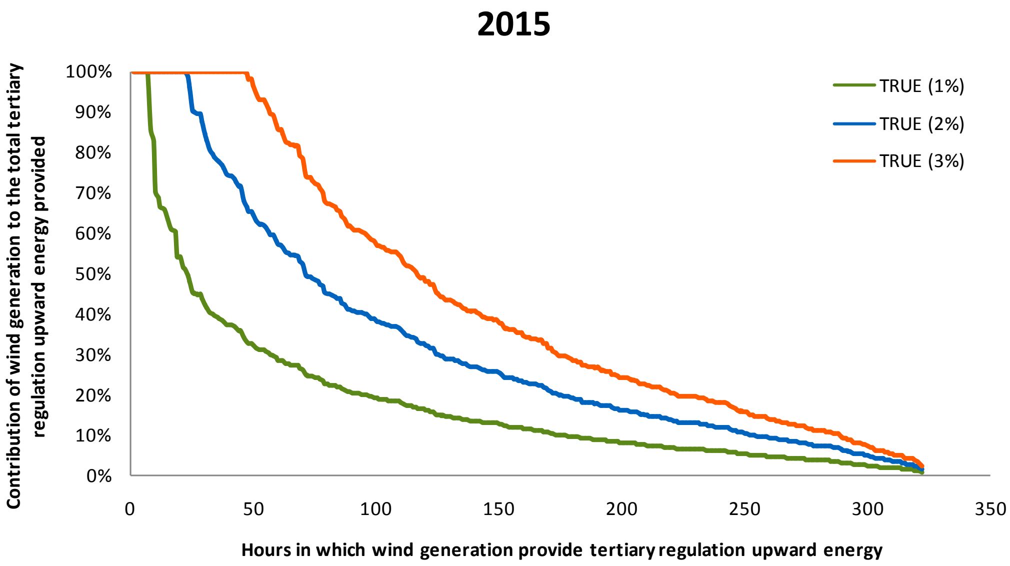

Contribution of wind generation to the total tertiary regulation downward energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
50
100
150
200
250
300
350
400
450
500
Hours in which wind generation provide tertiary regulation downward energy
TRDE (1%)
TRDE (2%)
TRDE (3%)

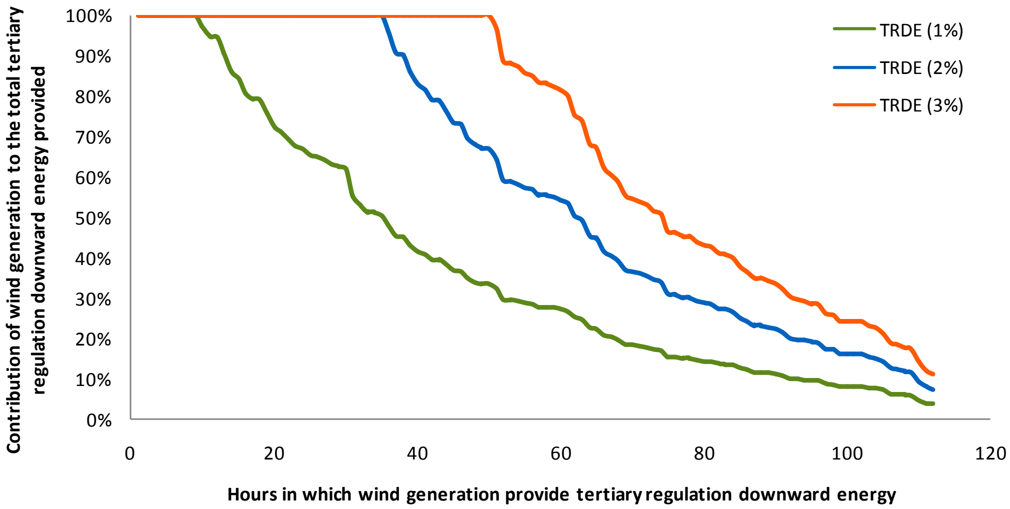
2013


2013
Contribution of wind generation to the total tertiary regulation upward energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
700
800
900
Hours in which wind generation provide tertiary regulation upward energy
TRUE (1%)
TRUE (2%)
TRUE (3%)


Contribution of wind generation to the total tertiary regulation downward energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
50
100
150
200
250
300
350
400
450
500
Hours in which wind generation provide tertiary regulation downward energy
TRDE (1%)
TRDE (2%)
TRDE (3%)

2015


2015
Contribution of wind generation to the total tertiary regulation upward energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
50
100
150
200
250
300
350
Hours in which wind generation provide tertiary regulation upward energy
TRUE (1%)
TRUE (2%)
TRUE (3%)

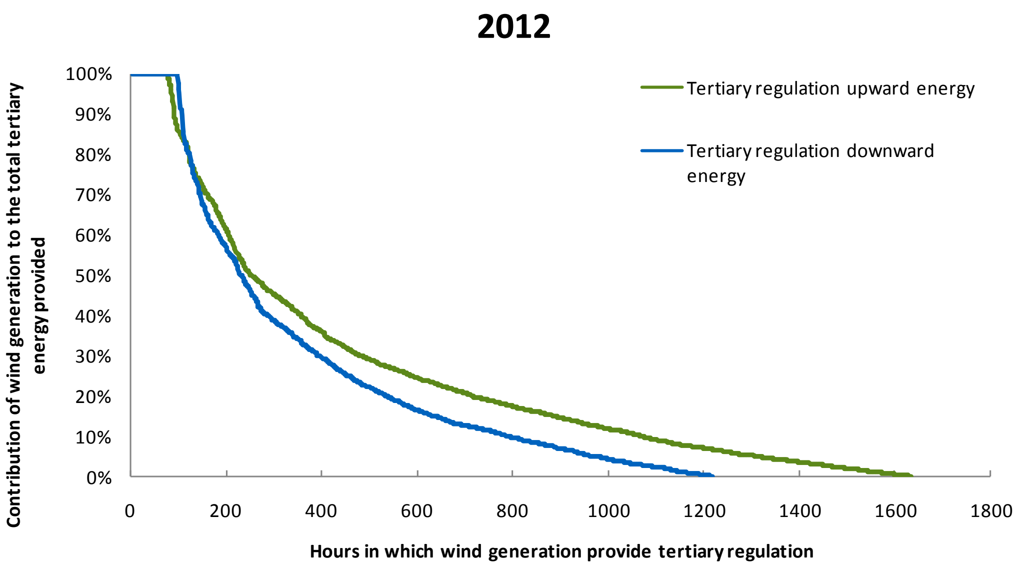

Contribution of wind generation to the total tertiary regulation downward energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
20
40
60
80
100
120
Hours in which wind generation provide tertiary regulation downward energy
TRDE (1%)
TRDE (2%)
TRDE (3%)

Annex 3 JOINT STRATEGY FOR THE YEARS 2012, 2013 AND 2015

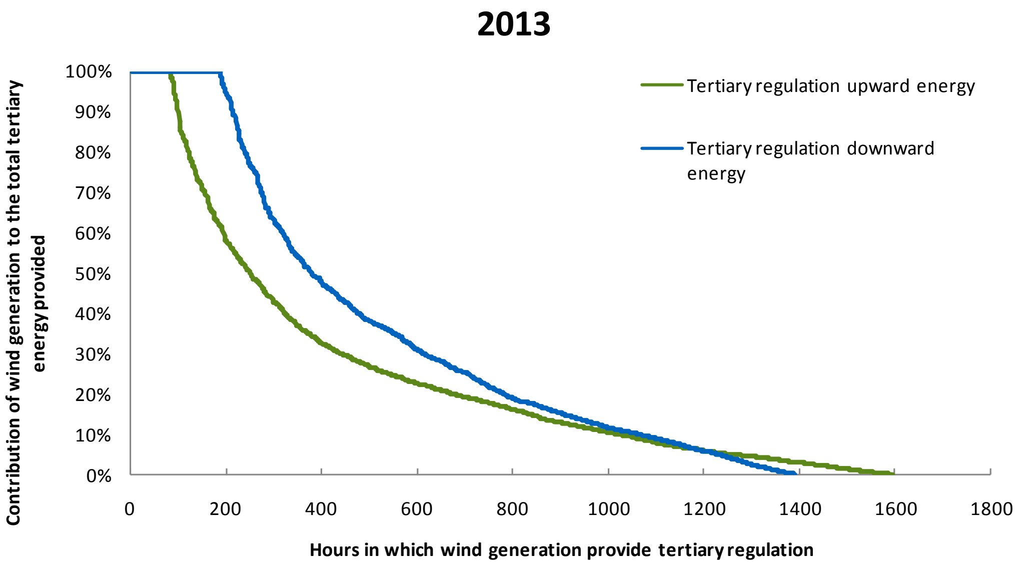
In this Annex the contribution of wind generation to the total tertiary regulation energy if the joint strategy was implemented in the years 2012, 2013 and 2015 will be presented. The conclusions obtained are similar to the ones presented in the Chapter 7 for the year 2014.

CONTRIBUTION OF WIND GENERATION TO THE TOTAL TERTIARY REGULATION ENERGY IF THE JOINT STRATEGY IS IMPLEMENTED

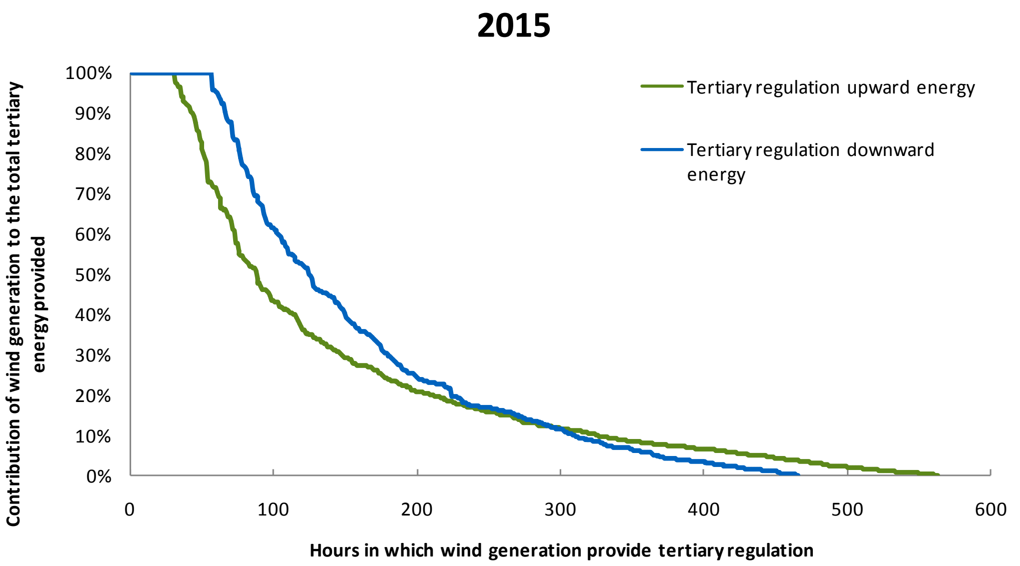
2012



2013


2013
Tertiary regulation upward energy
Tertiary regulation downward energy
Contribution of wind generation to the total tertiary energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
200
400
600
800
1000
1200
1400
1600
1800
Hours in which wind generation provide tertiary regulation

2015


2015
Tertiary regulation upward energy
Tertiary regulation downward energy
Contribution of wind generation to the total tertiary energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
Hours in which wind generation provide tertiary regulation

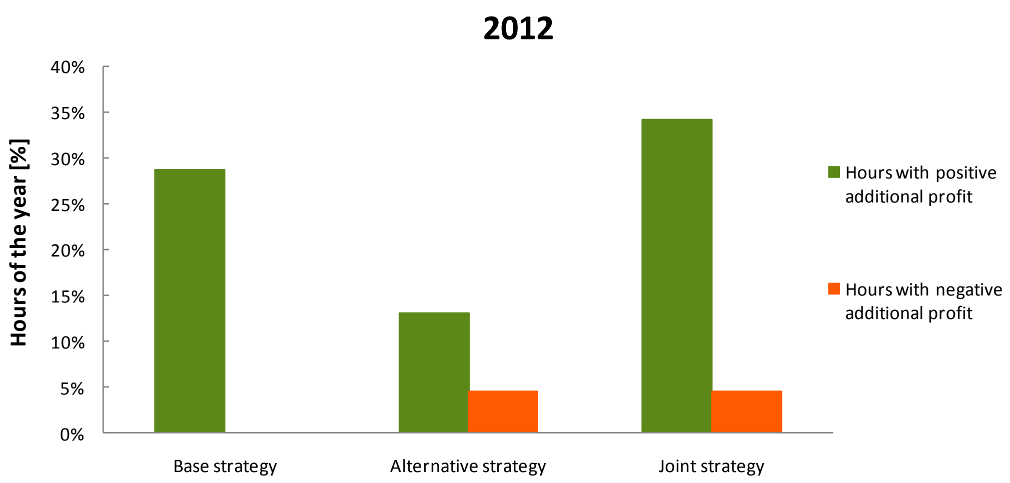
Annex 4 COMPARISON OF THE STRATEGIES

In this Annex the three strategies proposed in the Master Thesis will be compared in terms of the number of hours in which positive and negative additional profits have been obtained, as well as depending on the contribution of wind generation to the total tertiary regulation provided. These comparisons will be made for the years 2012, 2013 and the first five months of the year 2015. The conclusions obtained would be analogous to the ones presented in the Chapter 7 for the year 2014.

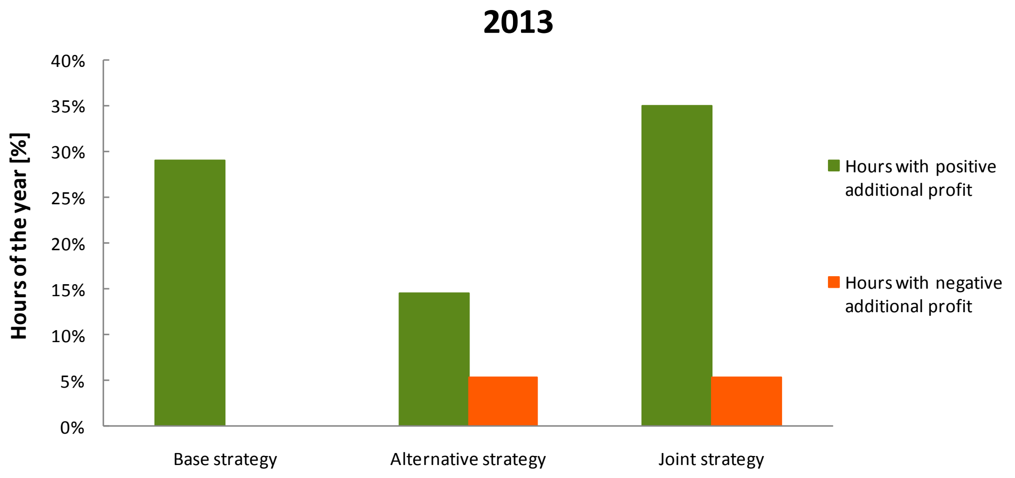
NUMBER OF HOURS WITH A HIGHER AND LOWER PROFIT THAN THE ORIGINAL ONE

As it was explained in the Chapter 7 the joint strategy allows increasing the original profits in more hours, while the main advantage of the base strategy is that it does not reduce the original profits in any hour.

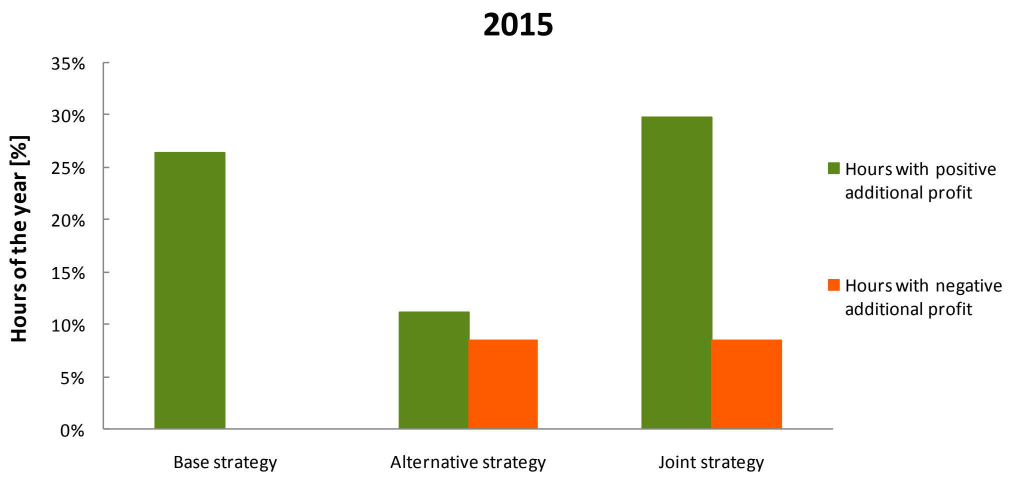
2012



2013


2013
Hours of the year [%]
40%
35%
30%
25%
20%
15%
10%
5%
0%
Base strategy
Alternative strategy
Joint strategy
Hours with positive additional profit
Hours with negative additional profit

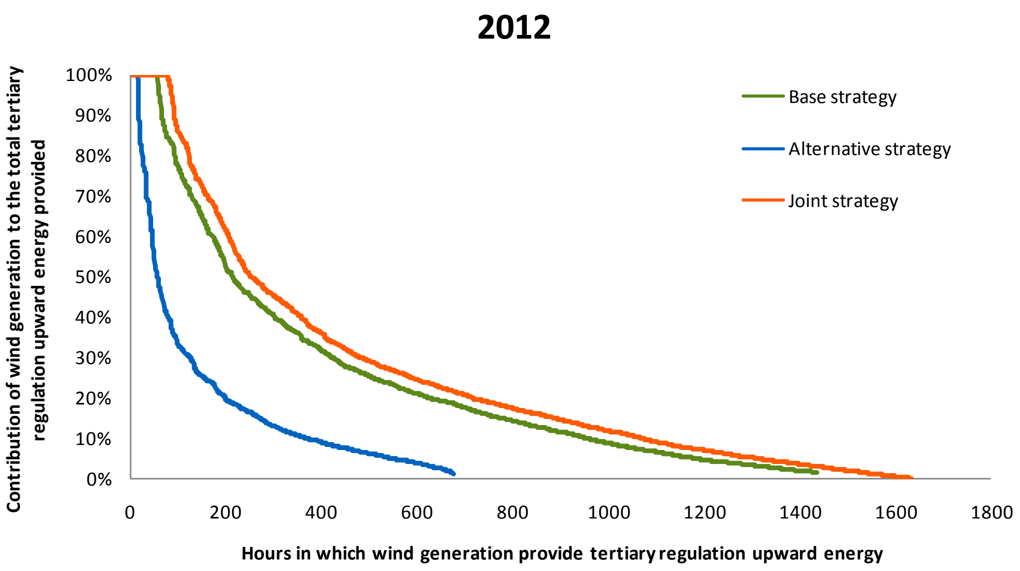
2015

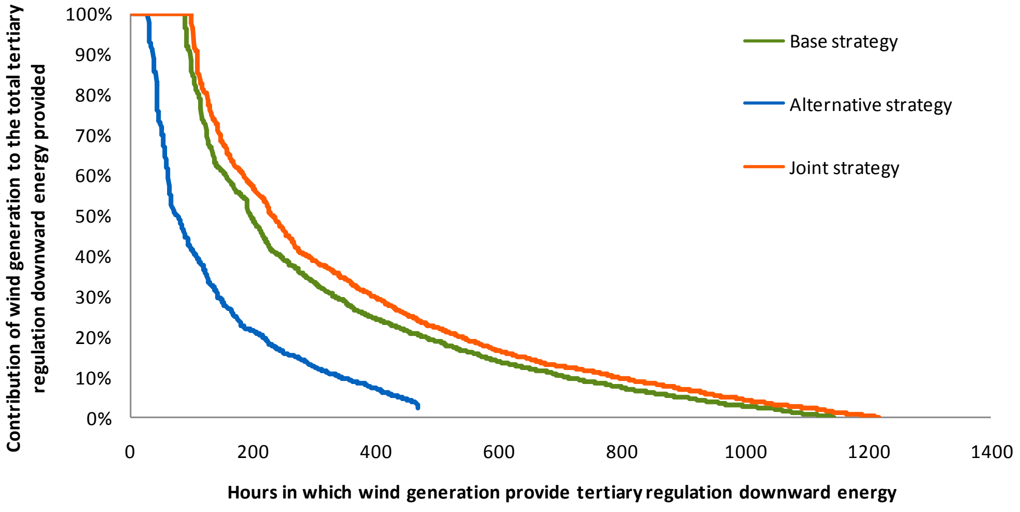

2015
Hours of the year [%]
35%
30%
25%
20%
15%
10%
5%
0%
Base strategy
Alternative strategy
Joint strategy
Hours with positive additional profit
Hours with negative additional profit

CONTRIBUTION OF WIND GENERATION TO THE TOTAL TERTIARY REGULATION ENERGY PROVIDED

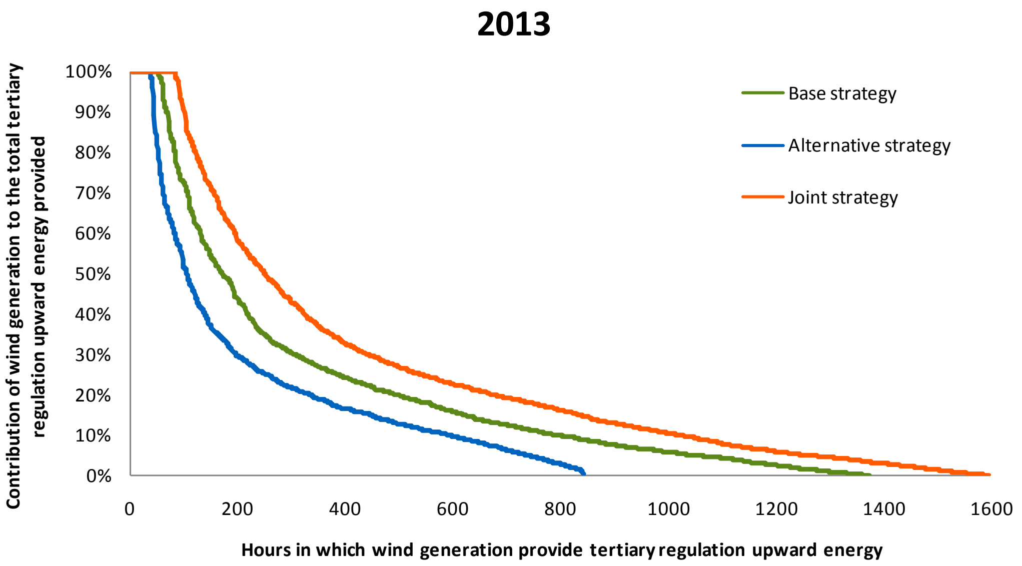
The number of hours in which wind generation would have provided tertiary regulation upward and downward energy are usually similar in the base strategy and the joint strategy and this number of hours exceed the number of hours in which wind generation would have participated with the alternative strategy. There are always some hours in which wind generation would have provided all the tertiary regulation required, being the marginal technology and thus affecting the prices of the tertiary regulation.

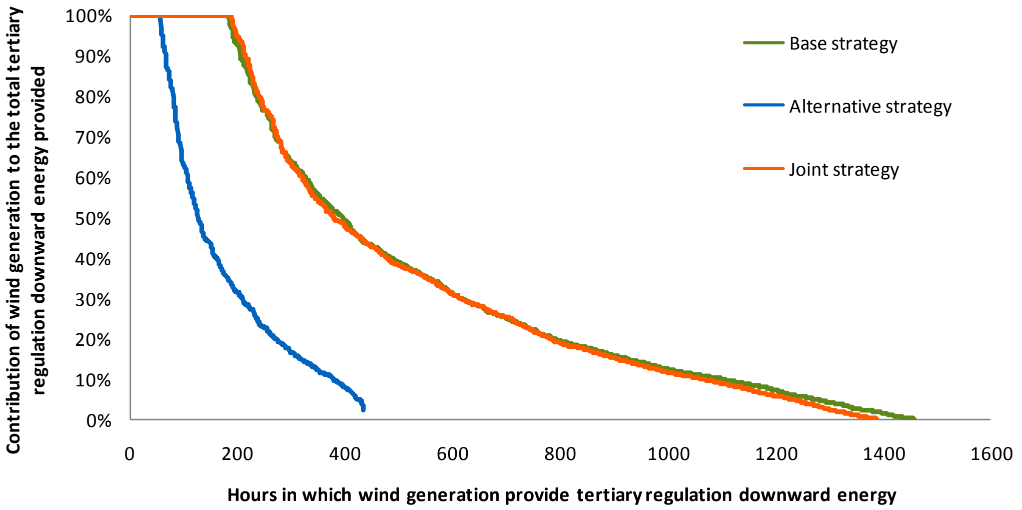
2012





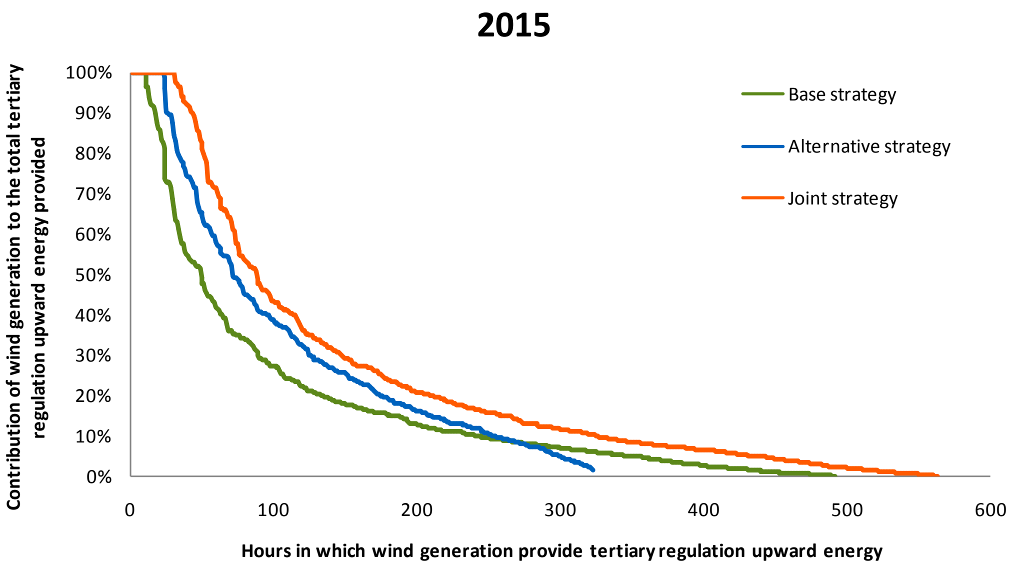
2013

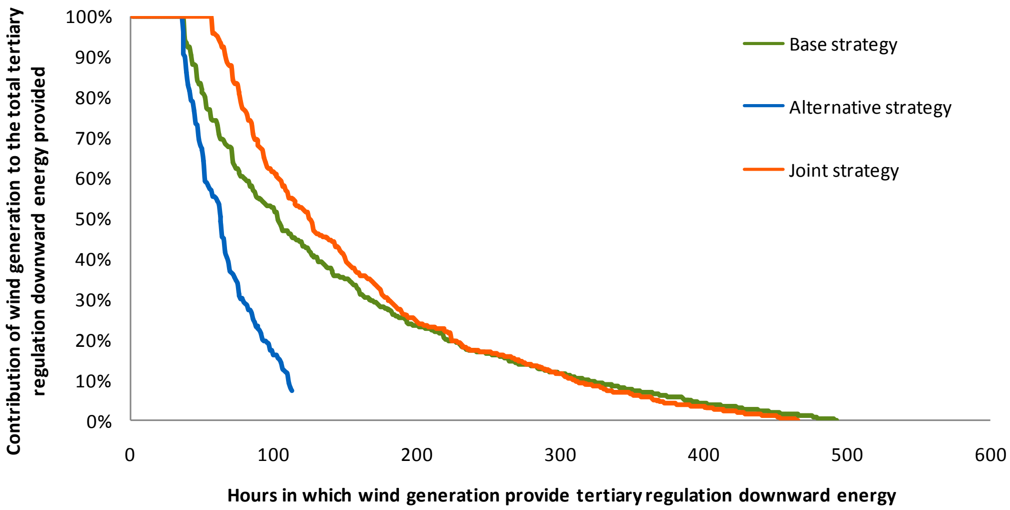




2015

It should be noted that in the first five months of the year 2015, the contribution ofwind generation with the alternative strategy would have been higher than in other years. Nevertheless, the rest of the months of the years would be needed to be analysed to properly assess the results of this year.


2015
Contribution of wind generation to the total tertiary regulation upward energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
Hours in which wind generation provide tertiary regulation upward energy
Base strategy
Alternative strategy
Joint strategy


Contribution of wind generation to the total tertiary regulation downward energy provided
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0
100
200
300
400
500
600
Hours in which wind generation provide tertiary regulation downward energy
Base strategy
Alternative strategy
Joint strategy