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ELECTRIC POWER INDUSTRY

Master's Thesis

EUROPEAN CROSS-BORDER EXCHANGE OF BALANCING ENERGY: SIMULATION AND ANALYSIS

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Abstract

Over the last two decades Europe's Energy policy has moved towards achieving a well-integrated Internal Energy Market. A big number of efforts have been made recently by European institutions. Binding European Rules, referred as *Network Codes*, are being developed and increasingly applied as an attempt to harmonized legal framework at European level. Meanwhile, several European TSOs have decided to begin an early implementation of a number of projects to contribute to faster delivery of the Internal Energy Market.

Balancing markets have greater importance for the annual results of utilities therefore forecasting their behavior is crucial for their economic results. This calls for an attempt to prepare themselves for future scenarios and assess the impact delivered from regulatory changes, such as the real implementation of pilot projects. This thesis aims to pave the way for the adaptation of Endesa to a new environment resulting from the real implementation of one of the cross-border Electricity Balancing Projects, known as TERRE (Trans-European Replacement Reserves Exchanges).

A forecasting tool, based on the principles established by TERRE pilot project, was designed in order to provide economic results for the system delivered from the real implementation of this platform. Additionally t is able to determine detailed information about physical power plants of Endesa, which would deliver this service in the future. The designed tool has demonstrated to be flexible and robust enough to provide the expected results when cross-border trade is allowed and when the capacity of interconnections increased considerably, among others. Additionally, the tool was left sufficiently open for the inclusion of further improvements once the platform becomes a reality.

Resumen

En las últimas dos décadas las políticas energéticas europeas han ido encaminadas hacía la formación de un mercado energético europeo. Las instituciones europeas han llevado a cabo un gran número de esfuerzos. Entre ellos destaca el desarrollo y puesta en marcha de una serie de reglas obligatorias, conocidas como *Network Codes*. Al mismo tiempo varios Operadores del Sistema Europeos han decidido comenzar a implementar una serie de proyectos piloto con el propósito de acelerar la formación de un mercado energético europeo.

Dado que los servicios complementarios tienen un gran impacto en los resultados anuales de las compañías eléctricas, es de vital importancia realizar previsiones futuras para hacer una estimación de los resultados económicos futuros. Este impacto invita a los departamentos de gestión de energía de las compañías eléctricas a prepararse para futuros escenarios resultantes cambios regulatorios, como es la puesta en marcha de los comentados proyectos piloto. La presente tesis tiene como objetivo facilitar el proceso de adaptación a Endesa a un nuevo contexto resultante de la implementación de uno de los proyectos piloto para el intercambio transfronterizo de energías de balance, conocido como TERRE (Trans-European Replacement Reserves Exchanges).

Se ha diseñado una herramienta de previsión que, basada en los principios establecidos en la fase de diseño del proyecto piloto TERRE, aportará resultados económicos para los sistemas eléctricos y para las unidades de producción de Endesa que participen en este servicio. La herramienta diseñada ha demostrado ser lo suficientemente robusta y flexible para obtener los resultados esperados cuando se produce un intercambio transfronterizo de energía o cuando se incrementa la capacidad física de intercambio de las líneas de interconexión, entre otros. De igual manera, la herramienta se ha dejado lo suficientemente abierta para futuras mejoras tras la puesta en funcionamiento de la plataforma en el futuro.

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1. Introduction

The present Master's thesis has been developed in one the leading companies of the electricity sector in Spain, Endesa. Concretely, the author of the present thesis has been working in a group called *Strategic Short-term Planning and Ancillary Services* which forms part of the energy management business line of the company. Among the several tasks carried out by this team the most important ones are the development and monitoring of models aimed to do market and competition analysis and forecast, both in the power and ancillary services markets. These market models are a necessary tool in the elaboration of fundamentals in order to support power plants optimization, scheduling, management of the power and fuel portfolio etc.

This thesis is focused on the development of a long-term forecasting tool of a future hypothetic European market for the cross-border exchange of Replacement Reserves. Once the European platform is implemented the tool will replace the existing one that is currently used to analyze and forecast the real-time energy balancing in the Spanish system, called *LPRM (Largo Plazo Resto Mercados)*. All algorithms will be coded in VBA (Visual Basic for Applications) and results will be presented in several Excel sheets.

Given that the market under study is not implemented yet, the developed tool will provide very valuable information, both from the theoretical and business point of view. Regarding the first one, the forecast tool will help to perform a qualitative and quantitative assessment of the benefits and some other consequences resulting from the interconnection of electricity systems. Secondly, the model will help the company to adapt and prepared their strategies to future circumstances.

1.1 Motivation

European Power System is in the midst of a transformative change. Among all the changes pursued, the most important one is the development of an internal energy market for Europe. This trend has started a few years ago with the approval of some directives that defined common rules for the launching of European markets. But also with the establishment of new common institutions such as the European Network of Transmission System Operators (ENTSO-E) and the Agency for the Cooperation of Energy Regulators (ACER).

Interconnection between systems provides them with some advantages, such as the contribution of security of supply and the reduction in cost of services. Thanks to electricity exchanges it is possible to use the most efficient technologies available. When cross-border capacity allows it, energy flows would go from where it is cheaper to where it is more expensive. Additionally, the implementation of European platforms for energy trading will increase the number of players thus the degree of market competitiveness as it will be demonstrated all the work presented through this thesis.

Nowadays there are some pilot projects under development whose aim is to achieve a fully interconnected system in Europe from the point of view of the market but also from the point of view of the operation and security of the systems. Among all the initiatives started a few years ago the thesis will be focused on one pilot project called TERRE (Trans-European Replacement Reserves Exchanges) set up by the ENTSO-E. The main purpose of TERRE is gaining experience from cross-border exchanges of balancing energy between TSOs in compliance with the future Electricity Balancing Guideline[1]. This project is studying and developing issues related to the procurement, exchange and settlement of balancing energy. The following figure represents in a simplified manner the functioning of the proposed platform for cross-border balancing energy exchanges. It can be seen that TSO will have still an important role in their countries as they will represent their units in the European market.

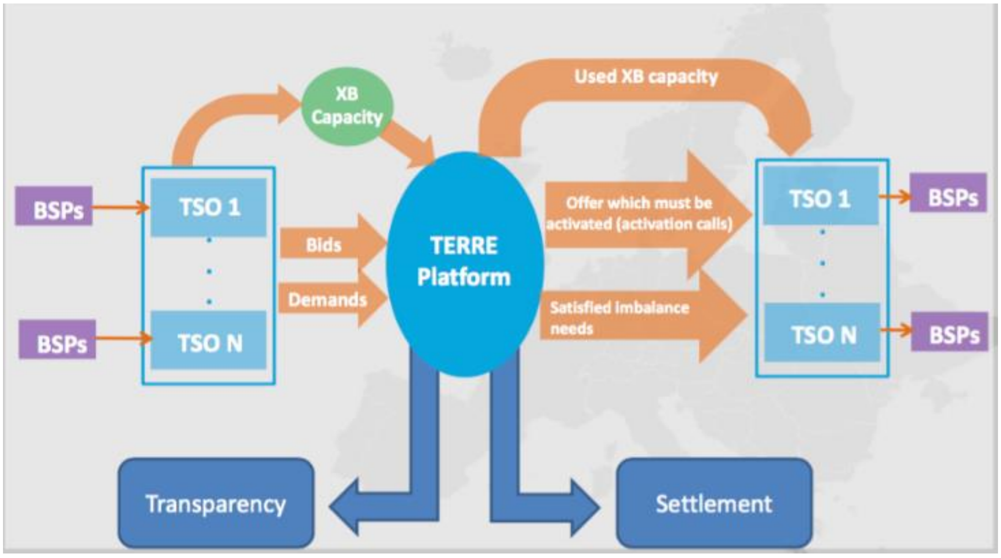

Figure 1.1-1. Functioning scheme TERRE platform

[1] Electricity Balancing Guideline aims at providing a solid framework for the integration of national balancing markets and the achievement of the single European electricity balancing market.

All changes introduced below are closed to its real implementation, hence, utilities must prepare themselves for futures scenarios. The main purpose of the model is then to help Endesa in this preparatory path. In the short-term the tool will help the Department to understand the consequences and implications of the future playing field which has moved from a national scope towards a cross-border exchange with other European players. However, highest utility of the tool will take place in the long-term when the model will substitute the one used to forecast and analyzed the tertiary reserve and deviation management markets.

1.2 Objectives

The following objectives apply to define the scope of the present Master's thesis:

1. Development of a sufficiently robust tool able to provide:
    a. Capacity available from Endesa units in MWs, based on the results delivered by forecast tools devoted to previous markets (Secondary Reserve).
    b. Hourly Upwards and downwards bidding curves.
    c. Two clearing process, one for the market for upwards activations and the other for downwards activations. They must provide a market solution (marginal price) using the following data:
        i. Hourly bidding curves.
        ii. Hourly imbalance needs for each one of the three system considered.
    d. Initial and final cross-border capacity.
    e. Information about market results of Endesa units.
        i. Hourly Energy provided.
        ii. Market share.
        iii. Incomes.
        iv. Profits.
    f. Aggregation of total results by country.
2. Perform a study based on historical data about marginal prices and imbalance needs of current Replacement Reserve's markets of Portuguese and French power systems, in order to obtain:
    a. A forecast of hourly imbalances needs
    b. Competition patterns for both upwards and downwards activations

3. Once the model is demonstrated to work according to the initial requirements, run several scenarios based on future expected situations and carried out a qualitative and quantitative assessment.

1.3 Organization of the document

The first chapter serves as an introduction to the Master's Thesis, explaining the context of the model, its main objectives and the principal reasons that have led the department to ask for the development of a forecast tool with these characteristics.

All the contents presented in the second chapter aims to describe to the reader the starting point of the model. Including in this regard the European current situation in terms of cross-border energy exchanges, and a summary of current and future energy policy framework. This chapter will also explain the methodology proposed by stakeholder for the functioning of the power exchange platform under study, TERRE.

The third chapter is the core part of the thesis. It presents the methodology applied in the principal subroutines of the forecast tool developed in this thesis. Likewise, it includes material about the different studies that were carried out to obtain input data related to French and Portuguese systems.

The fourth chapter includes results and explanations of some scenarios that have been proposed in order to determine to what extent interconnections and the behavior of agents influence the market results.

The fifth chapter is dedicated to conclusions and future developments.

2. Background

The scope of this thesis is to develop a model that simulates the functioning and provides market results of a European platform for cross-border exchange of balancing energy, concretely what is known as Replacement Reserves. In order to understand the methodology applied as well as the foremost assumptions, it is necessary to devote part of the document to explain the current situation regarding cross-border exchanges of energy flows and balancing energy, different mechanisms that every System Operator under study applies in its power system and finally the proposed methodology for the functioning of the TERRE.

2.1 European energy market

A well-integrated energy market is a pre-requisite to achieve the two main objectives of the European Union: energy affordable, competitively priced, environmentally sustainable and secure for everybody.

Over the last decades EU countries have made a big effort to achieve these goals. Cross-border trade has increased and so has the use of interconnectors, however it is nowhere near its full potential yet. Physical interconnections have to be reinforced, but also main obstacles for cross-border trade has to be removed. In this regard, regulatory framework instead of growing nationally have to grow according to EU-wide and regional initiatives, transposing into national legislation European directives.

Among all the efforts that have been made recently, the development of Network Codes and Framework Guidelines have had special importance. Both aim at providing harmonized rules for cross-border exchanges of electricity. The drafting of these documents involves the European Commission, ACER and ENTSO-E. Through this initiatives TSO and energy regulators want to promote a fully interconnected system from the point of view of the market but also from the point of view of the operation and security of the system.

From the point of view of wholesale market integration one should be aware of the already implemented initiative known as Price Coupling of Regions (PCR). Throughout PCR seven European Power exchanges, including the ones under the scope of this thesis, have developed a single price coupling solution-an algorithm called Euphemia- to be used to calculate electricity prices across Europe, and implicitly allocate cross-border capacity on a day-ahead basis. It brings several electricity markets managed by different entities into one market area and at the same time maintains the independent nature of each market. Nonetheless, when congestions occur several prices areas are formed as it is happening now.

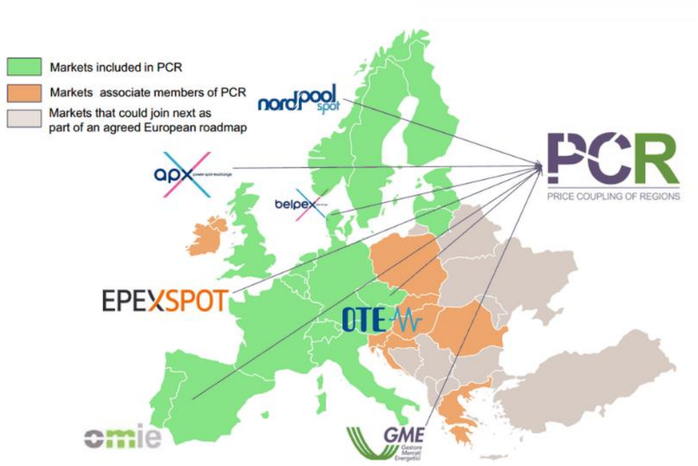

Figure 2.1-1. PCR participants

With respect the operation of the system, ENTSO-E has been working on the development of a Balancing Guideline which is currently under the revision process of the European Commission. The target of this Balancing Guideline is to establish an integrated European balancing market through a step-wise, regional approach for several balancing process such as Imbalance Netting (IN), Replacement Reserves (RR) or Manual Frequency Restoration Reserves (mFRR).

In order to meet the ambitious target deadlines in the guidelines, ENTSO-E has established a number of early implementation initiatives, such as the formation of building blocks (geographical areas) for the development of the European Integration Model for balancing, called Coordinated Balancing Areas (CoBAs). ENTSO-E is currently working in the first proposals for CoBAs, which are based on the definition of different CoBAs configuration depending on the balancing product considered.

One of the measures that are currently been developed is the standardization of balancing products. This is necessary because balancing products have traditionally been developed only to fit the local physical system (generation types, grid, balancing philosophy etc.) and do not consider a wider scope. The standardization process has been started through seven cross-border pilot projects with the purpose of test the feasibility of the European Model and evaluate the associated implementation impact.

2.2 Balancing reserves

In order to understand the principles of the model it is very important to understand the management and characteristics of the products traded in the market under study. These products are known as balancing reserves or Replacement Reserves. Like any other technical aspect of the electricity sector, they are managed and controlled by TSOs, entity in charge of the technical operation of the system.

The main feature of electricity is that it cannot be storage, therefore demand and production has to be equal at every single moment so as to maintain the frequency within the standard thresholds. In most of the cases, TSOs use balancing markets to redispatch generators in order to correct energy imbalances. In these markets energy bids are submitted by agents according to their energy availability and production costs. There are several products used to maintain the stability of the system which are traded in the previously mentioned markets; these products differ mainly on its activation time, ramp characteristics and gate closure.

Among all balancing products, the proposed platform (TERRE) is designed to allocate Replacement Reserves through a market basis. Replacement Reserves are operating reserves used to restore the required level of operating reserves in the categories of Frequency containment and Frequency Restoration reserves, such as Secondary Regulation, due to their early usage. It includes operating reserves with an activation time from 15 minutes up to an hour.

2.2.1 Replacement Reserves in Spain

In Spain this kind of energy regulation is divided into two services: tertiary regulation and deviation management. Tertiary regulation is provided by the tertiary reserve, which is defined as the maximum variation of power generation that a generating or pump storage unit can experience within a maximum of 15 minutes' dynamic time and which can be maintained for at least two consecutive hours. The objective of tertiary regulation is to recover the Secondary Regulation reserve that has already been used to solve short term deviations between generation and demand.

Every unit licensed to provide this service must bid all the upward and downward tertiary capability in the market. The market uses a minimum cost criterion to select the bids when they are needed. The settlement mechanism of this market used a marginal pricing criteria, differentiating between the upwards and downwards mobilized reserves. The following figure represents schematically how the marginal price is set in this market.

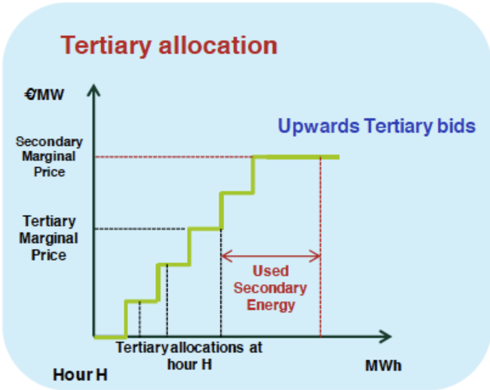

Figure 2.2-1. Scheme allocation mechanism for Tertiary Reserve in Spain

On the other hand, deviation management mechanism aims to resolve the expected deviations between generation and demand which could appear in the period between the end of one intraday market session and the beginning of the next intraday market horizon. In order to accomplish this, deviations are assessed ahead for each hour. If expected deviations above 300 MWh are identified, the TSO can trigger a deviation management market session. Participant have 30 minutes to submit their offers after the gate closure of the last intraday session. A particularity of this market is that agents are allowed to include in their offers complex conditions such as indivisibility conditions, among others.

The allocation is based on the bids presented in the corresponding market session by licensed agents. Selected bids are priced and settled at marginal pricing of the allocated bids in each time period. This service provides a link function between intraday markets and tertiary regulation, offering the TSO with a service managed through competitive market mechanism, and with more flexibility to resolve imbalances between generation and demand that could be identified after the closure of the last intraday market session.

2.2.2 Replacement Reserves in Portugal

Portuguese TSO, REN (Redes Energéticas Nacionais), manages this kind of reserves using market mechanisms. All balancing areas, which are composed by a set of physical units, with available reserves are obliged to present offers for the provision of this service. The offers must be sent up to 50 minutes before the beginning of the delivery period to which the intraday session is related or 10 minutes after the publication of the hourly schedule of the units (known and “PHF”) when this occurs 75 minutes after the closure of the intraday market session.

As is any other system, every hour TSO compares the demand-supply situation and evaluates the need to contract regulation reserve. In real time, if the amount of Secondary Reserve is not enough to meet system’s needs, TSO shall use regulation reserve to reconstitute the Secondary Reserve.

REN calculates the amount of energy that is needed to solve the imbalances and assigns it from a merit order list, taking into account the dynamic parameters of the involved physical units. Since it is a marginal price market, the last offer assigned defines the price of the regulating reserve energy used in the same direction in the hour.

2.2.3 Replacement Reserves in France

French System Operator, RTE (Réseau de Transport d’électricité) uses a similar mechanism known as Balancing Mechanism. Throughout this services RTE ensures the real time balancing between production and consumption and deals with network congestions on the French electricity system. This mechanism is a permanent call for tender open to everyone who wants to provide real-time reserve of power that can be used for balancing either upwards or downwards. When offers are required in order to solve imbalances, RTE activates them based on economic precedence and their usage conditions, taking into account the system operating conditions. In contrast to the mechanism used in Portugal and Spain, the serviced is remunerated pay-as-bid.

Participants have to submit, modify or withdraw offers for the current day at one of the gate closures, which are: 4 pm, 10 pm, 11 pm on the day before and the 9 pm of the current day.

2.3 Cross-border Electricity Balancing Projects

Energy policy in Europe is driving the sector towards a new situation in which renewable energy occupies a fundamental pillar along with the totally integration of European energy markets. Latest regulatory trends attempt to develop the highly concentrated and diverse national balancing markets into one robust integrated scheme accessible by all market agents.

Although balancing markets represent only 2-3% of the total volume traded in day-ahead wholesale markets they still represent a cost that consumers has to consider when paying their electricity bills. ENTSO-E has shown, throughout several studies, the potential gains for balancing resources to be effectively shared between countries, enhancing the security of supply and reducing cost while using resources more efficiently.

The main barrier for this integration is that nowadays there is not a single scheme for the management of balancing energy by TSO across Europe. Firstly, it would be necessary to establish a common legal framework, through Framework Guidelines and Network Codes at EU level that establish methodologies, terms and conditions for balancing energy. Meanwhile, capacity allocation tools are also following clear target models and rules which have been set out in the binding guidelines of Capacity Allocation and Congestion Management (CACM) and the Network Code on Forward Capacity Allocation. Next step will be the approval of the future Network Code on Electricity Balancing which will lay out the processes for developing market based co-operation and implementing the steps towards European Integration.

At the same time some pilot projects have been developed to guarantee strong Pan-European dimension and compliance with legal framework under development whilst ensuring stakeholders involvement. These projects are proposed to gain experience of products definition and pricing mechanism, and to identify and overcome barriers during its implementation related to regulatory issues. They also aim to provide and insight into which aspects are to be harmonized and two what extent, in order to achieve easily the real implementation of the project.

Nonetheless, some project related with cross-border trade of balancing energy have been already implemented, like the case of BALIT project where the three countries included in the model are involved.

2.3.1 BALIT project

Balancing Intern TSO, whose acronym is BALIT, corresponds to a bilateral solution between TSO for the exchange of balancing energy. TSOs of the South West Region (France, Spain and Portugal) are involved in this project. They exchange balancing energy using the cross-border capacity available after the intraday markets.

The current mechanism allows TSOs to present offers of the surplus available balancing reserve offers to their neighbor country. This means that every TSO will calculate the reserve needed for each hour and for each market unit, and will offer to the neighbor

TSO the bids that will not be needed in the close future. The offers must be activated and confirmed 30 minutes before the real time, and will be traded in a common IT platform that gathers surpluses of balancing energy (upwards and downwards).

All bids traded within this platform have a capacity of 50 MW, a duration of 1 hour and an activation time of 30 minutes. Although there is just a single platform, cross-border exchanges are bilateral therefore they are made between REE-REN and RTE-REE.

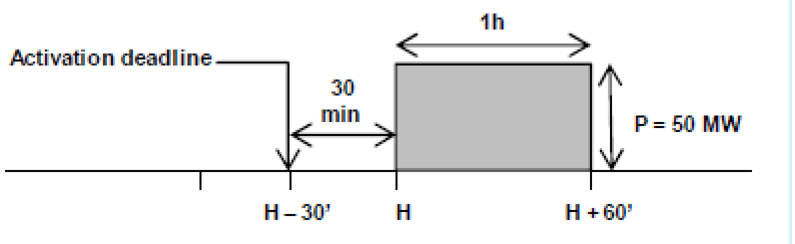

Figure 2.3-1. BALIT product definition

Figure below shows the market sequence followed by this bilateral mechanism between TSOs.

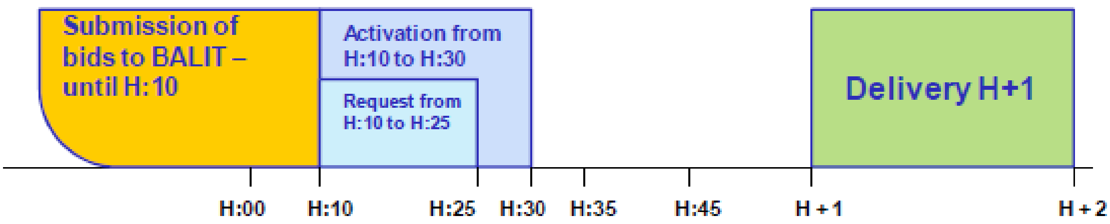

Figure 2.3-2. BALIT market sequence

2.3.2 Trans European Replacement Reserves Exchange project

Trans European Replacement Reserve Exchange, hereafter TERRE, is a pilot project for cross-border Replacement Reserves exchanges. It aims to enhance the experience of the current BALIT bilateral solution explained in previous sections. The project involves eight TSOs from UK to Greece, whilst two European TSOs are observes.

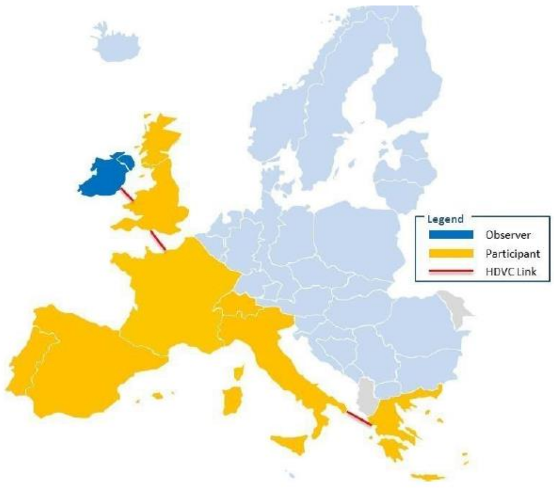

Figure 2.3-3. TERRE project participants and observers

Although the design phase is coming to a close, its implementation is not expected till at least the year 2018. This chapter explains the main principles of this platform regarding its markets rules, products and time frames. This information is very relevant in order to understand the scope of the model as well as its main simplifications.

Throughout this platform agents and TSO would be able to trade Standards Products for Replacement Reserves, whose shape is shown in Figure 2.3-4. Note that the final product exchanged through TERRE will be the blue box represented in the figure, excluding the energy associated with the increasing and decreasing power ramps (represented with red lines).

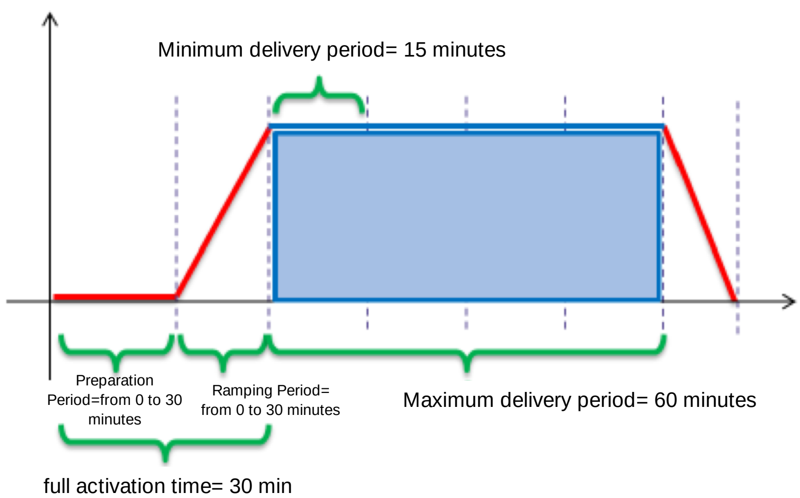

Figure 2.3-4. TERRE cross-border product shape

The Common Merit Order list accepts offers of several kinds. As in any other market mechanism there are divisible offers which can be accepted partially in terms of energy; however, the same quantity must be accepted for the whole delivery period. Block offers also consists of a single quantity and a single price with the difference that the algorithm can accept either the whole quantity of the block offers or nothing. There are some other types of offers, however, they are not going to be explained in the document because they are out of the scope of the thesis as it will be shown later.

Like Euphemia the TERRE algorithm was designed for the optimization of the social welfare, since it guarantees and enhances the efficiency of the market. The main novelty of this platform is that upwards and downwards offers/needs are gather together into one single market. There will be two Common Merit Order list: one for positive imbalance Need bids and downwards offers and one for negative Imbalance Needs and upwards offers.

It will be a marginal market, therefore marginal price will be given by the intersection between the selling and buying curve in the TERRE Common Merit Order list. Note that as downwards and upwards offers are treated in the same optimization problem there are not different prices for downwards and upwards activations. As the minimum duration period is 15 minutes, there will be a marginal price every 15 minutes.

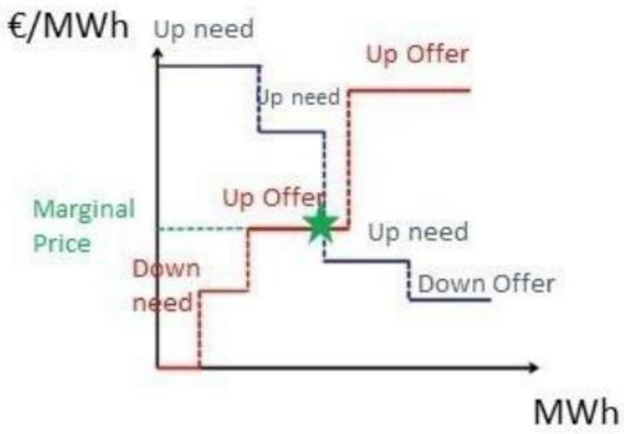

Figure 2.3-5. Determination of Marginal Price in TERRE platform

Another important aspect of the proposed methodology is that Imbalance needs decided by TSO are not any more just inelastic. Instead they will be submitted to the platform as any other balancing offer whose volume, price and delivery period characteristics are well defined. Nonetheless, offers submitted by TSO can remain inelastic when imbalance need volume is absolutely required by the TSO, in those case offers will be priced at the maximum instrumental price that does not affect the settlement. Notice that elasticity help TSO to deal with uncertainties when defining its imbalance volume. The reasoning beneath this design is that it allows and simplifies the introduction of a netting process, which is going to be explained in next sections.

Once offers are submitted, the algorithm will clear the market in a one-stage clearing process where there is not differentiation between the netting of imbalance needs and the activation of downward/upward offers in order to satisfy the demand of a TSO. Therefore, the main functionality of the algorithm is to determine the activated energy offers which satisfies the imbalance need bids of TSOs, taking into consideration the possibility of netting the imbalance needs in order to maximize the welfare of TERRE regions.

The social welfare is defined as the surplus of connecting TSOs (represented by their imbalance needs) minus the agents' production cost (represented by their imbalance energy offers). In simple terms, the social welfare is the red area represented below.

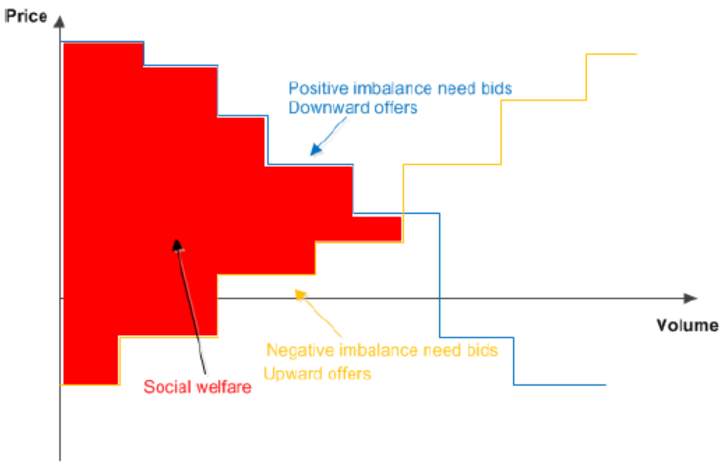

Figure 2.3-6. Social Welfare representation of TERRE regions

It was mentioned above that the submitted balancing energy may have different delivery periods and formats. The decision about which offer will be activated is based upon which offers maximizes the social welfare, looking at the whole market clearing time period. Therefore, the solution seeks to maximize the social welfare in one hour. Furthermore, the algorithm has a second objective which is the minimization of energy flows: if two solutions result in the same social welfare, the solutions leading to the minimum cross-border flows would be accepted.

In order to understand the functioning of this platform one should have a clear concept of how the netting methods works. Netting is the action of matching two imbalance needs of opposite directions, thus transfer energy from a zone that has a negative imbalance need to a zone with a positive imbalance need. Netting leads to a result in which less balancing offers needs to be activated.

The same scheme can be applied for balancing offers; in this case, it is called counter-activations. The algorithm allows for the simultaneous activation of an upwards and a downwards offers with the purpose of increasing the social welfare. Counter-activations could occur if some downward bid had higher prices than some downward bid. That is when an agent is willing to pay higher prices to reduce their production than the price other agent would be willing to receive to increase their production.

The lack of cross-border capacity might lead to situations in which cross-border lines are not able to simultaneously accommodate all the cheapest transactions, resulting in unavoidable suboptimal solutions. In these situations, TSO must satisfy its imbalance needs using offers that are more expensive than the optimal ones. Similarly, congestions might have an impact of netting; two imbalance needs may not be netted due to congestions, and therefore, TSOs have to activate balancing energy offers. Like in any other market, network congestions result in different prices among the congested areas.

3. LPRM-TERRE Model

The aim of this chapter is to explain the context of the model, which has been made within a Spanish utility called ENDESA, and its main features. Specifically, the model has been developed in the energy management department where several long-term market forecasting tools are run in a monthly basis in order to determine the most accurate provisions for the rest of the current year and for the following ones.

The model will be used within the Department at the moment the real platform starts functioning on a monthly basis, and up to that time to provide any forecast beyond the year 2018. Therefore, it is very important for the reader to understand the context of the model in order to understand its structure and main assumptions.

3.1 Endesa's long-term forecasting tools

The model developed under the scope of this thesis was designed to replace one of the existing tools that are run in a monthly basis by Endesa's Energy Management, concretely, Strategic Short Term planning and Ancillary Services Department. Models follow a temporal sequence, which coincides with the temporal sequence of the operational markets managed by REE.

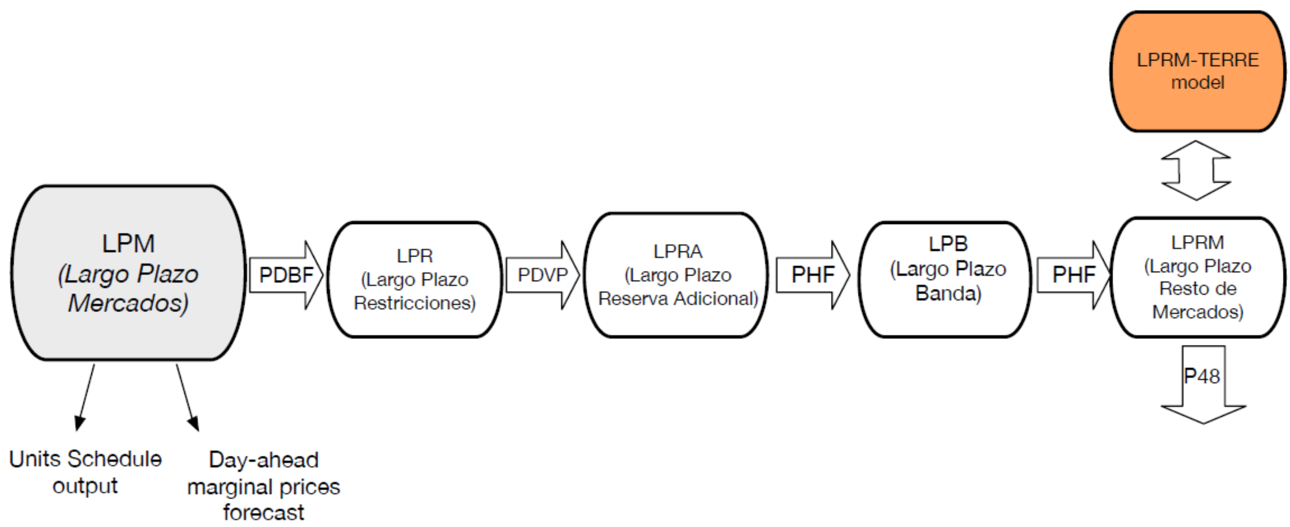

Figure 3.1-1. Long-term forecasting tools sequence

The sequence starts with the LPM, a model that uses econometric techniques to forecast the price of the day-ahead market together with all Endesa's power plant programs. This model feeds data to the LPR, which resolves the technical restrictions by redispatching UOF's[2]. Next is the LPRA, which commits new units that were not previously dispatched in the PDVP, Spanish acronym for Provisional Viable Daily Program, in order to fulfill the TSO's spinning reserve requirements. Then comes the LPB, which obtains a forecast of Secondary Reserve prices and commitments. The sequence closes with a tool devoted to obtain relevant information about the Spanish tertiary reserve and deviations management market, which is labeled as LPRM.

Considering that the model was designed to replace the existing tool called LPRM, the author of the thesis decided to call it using the same acronym but adding at the end the name of the pilot project under study, which will be presumably the real name of the platform once is implemented. Therefore, hereafter the model core of this thesis will be called LPRM-TERRE model.

3.2 The LPRM-TERRE model initial assumptions

The main purpose of the model is the development of a tool able to forecast the market resulted from the implementation of the TERRE project, which has been explained in previous chapter. Additionally, the model needs also to provide results for every power plant owned by Endesa and that are currently providing ancillary services for the Spanish and Portuguese electricity systems. As in each one of forecasting tools used within the Department, it must provide total annual results related with cost, incomes, market share etc.

Taking into account the proposals that has been made by stakeholders of TERRE for the methodology followed by the hypothetical platform, along with the features that a forecast tool have to comply with concerning the demands of the department and the resources available; the following assumptions will be made:

Three-system model: Spain, Portugal and France

TERRE platforms aims to gather TSO from eight different areas plus to observers together into one single platform, where they will be able to trade what is known as Replacement Reserves. However, given the cross-border capacity between France and Spain -which has demonstrated that in most of the cases Spain and Portugal are isolated

[2] UOF is the Spanish acronym for "Unidad de Oferta". UOF is the code associated to every physical unit when participating in the market.

from the rest of Europe- it seems reasonable to make a simplification and just take into account in the model systems of Spain, Portugal and France. The last one will be a representative of the rest of European systems. Furthermore, this simplification seems very reasonable given that Endesa just have generating units located in Portugal and Spain.

Consideration of net value for imbalances

Nowadays imbalances can occur in electricity systems in different directions (upwards and downwards) during the same hourly period. In those cases TSOs needs mobilize in the same hourly period upward reserves and downward reserves. This situation is possible due to the definition of balancing products, which can last less than an hour. However, in order to make the model simpler, it will just consider a net position for the imbalances either upward or downward for the same hour.

Separately clearing processes for upwards and downwards needs

It was explained in second chapter that there TERRE will be just consider one optimization algorithm and two common merit order list for upward energy and downward, therefore upwards and downwards offers/needs will be treated jointly. Buying and selling bidding curves will meet in one-stage clearing process. Although this approach is expected to further optimize the market, it is very different from the market mechanism that has been used up to now by most of European power systems. Furthermore it allows the introduction of elastic imbalances need’s offers. Given that there is not any previous real information to be considered as a reference for comparisons or market analysis the tool will consider TSO imbalance need as inelastic. Consequently there will be two clearing process for both energy directions, upwards and downwards. The clearing process will follow the same principles as the Spanish or Portuguese approach although there will be a big difference in the details given that now three electric systems are involved.

Consideration of hourly blocks and simple bids

The TERRE basic product is a 15 min scheduled block that can be activated for a fixed quarter hour or a multiple fixed quarter hour, being the full activation time 30 minutes. Once the bid is activated the delivery period goes from 15 minutes to one hour. In order to simplify the model in terms of calculations and information about future imbalance needs. It will just consider hourly blocks supposing that once an offer is activated it is activated for the whole delivery period. Besides, it will allow using more adequacy the input data that comes from the current situation of the real time markets in Spain, which are based on an hourly scheme.

Additionally, the model will just contemplate the existence of simple bids. This simplification results from the lack of information regarding the behavior of agents and TSO and the size and temporal scope of the model.

Not introduction of the netting method and counter-activations

One of the novelties that TERRE project has introduced in its design is the introduction of the possibility of netting imbalance needs or using counter-activations. As mentioned above, netting is the action of matching two imbalance needs of opposite directions from two different balancing areas. The more netting occurs, the fewer imbalance remains, and hence, fewer offers have to be activated. However, still a lot of information is missing for modeling this situation, as it has never been implemented in the electric systems considered.

With respect to counter activations, the procedure is very similar: they can occur if a downward offer had higher price than an upward offer, in this case both offers would simultaneously activated as it would result in a higher social welfare. Although this scheme seems very interesting in terms of cost and improvements with respect to current situation, it will not be introduced in the code due to the same reasons explained in previous paragraphs: there is not any information about the monetary price TSO would introduce to their imbalance needs.

3.3 Structure of the Model

The structure established for the model is greatly influenced by its context, which has been explained in the first point of this chapter. It has to be organized according to the same principles applied in other models used within the Department. Likewise, it was required the model to show the final results in the same format as the rest of the tools in order to have everything harmonized.

LPRM-TERRE follows a fundamental approach, where a detailed representation of the system is considered by different variables introduced as input data. In general terms the price is obtained as a results of the following drivers:

1. Imbalance needs of Spain, Portugal and France

2. Variable cost of thermal units
3. Cost and availability of hydro and pumping units
4. Competition patterns

LPRM-TERRE is composed by several sub-routines, which are run always following the same sequence. Figure 3.3-1 shows schematically the different sequential steps followed when running the model. The structure of this chapter is based on the model sequence, starting from the input data and finishing with the aggregation of market results.

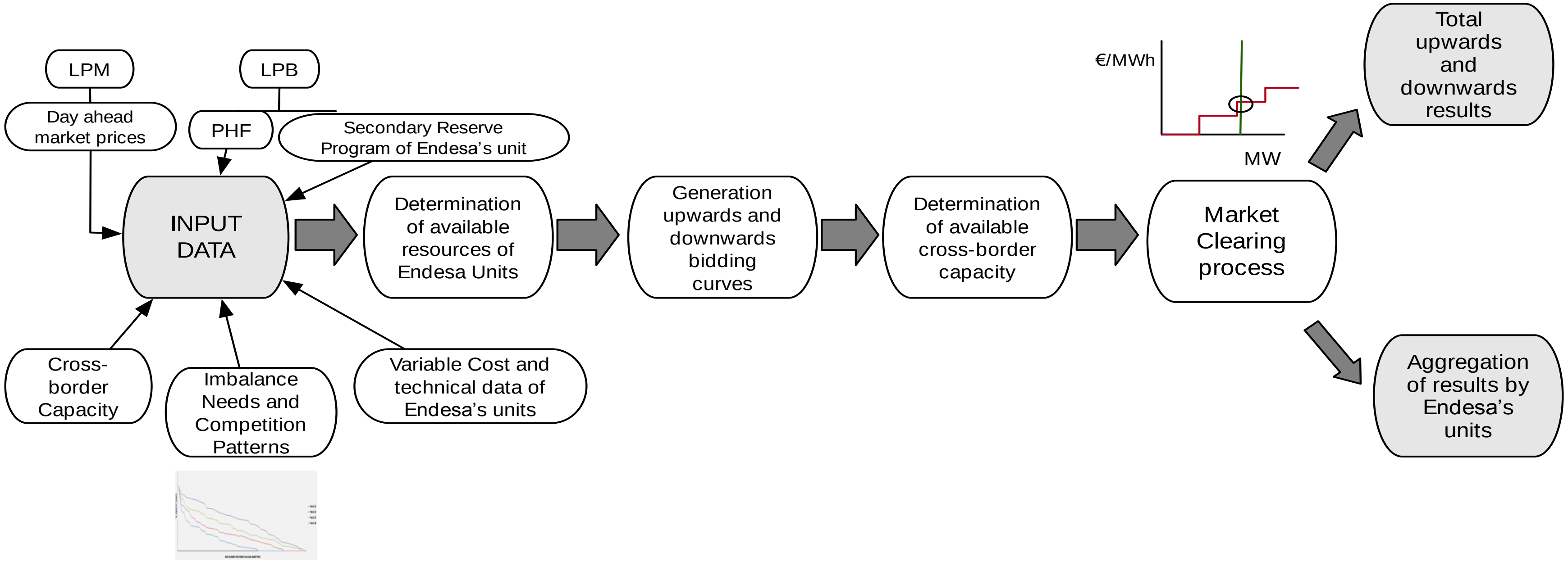

Figure 3.3-1.Sequential Structure of LPRM-TERRE model

3.4 Input Data

Determining the input data has had great importance during the design process. Existing long-term forecasting tools also follows a fundamental approach, however they are focus in the Spanish market and does not contemplate an international approach. Forecast tools use as input data imbalance needs and competition patterns of the Spanish markets, which from an intense study made by specialist from the IIT (Institute for Research and Technology) of Universidad Pontifícia Comillas. Given that they are the only resources available they were considered as a starting point when determining similar data about French and Portuguese power systems.

The principal idea was,based on these studies and historical information, to determine an approximation of the imbalance needs and competition patterns of the Portuguese and French systems.

3.4.1 Determination of French and Portuguese imbalance needs

This research was not based in the available data for the Spanish system but in historical data of Portuguese and French imbalance needs for the years 2014, 2015 and the first quarter of 2016. For the code to work correctly, input data about imbalance needs of the three European systems has to be introduced as showed below:

PT	VORKING DAYS											
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12
JAN	486	312	259	175	159	146	146	-160	-176	-432	-436	-469
FEB	473	315	313	302	263	249	237	147	-191	-308	-341	-336
MAR	461	363	348	280	298	282	241	-181	-311	-344	-225	-219
APR	319	213	203	203	169	221	223	179	-189	-189	-159	-260
MAY	105	201	140	131	236	263	269	-177	-176	-190	-199	-222
JUN	272	259	296	288	280	282	274	0	-177	-187	-157	-191
JUL	292	239	263	251	261	268	262	-171	-160	-168	0	0
AUG	100	100	100	100	100	100	100	-165	-198	-235	-211	-237
SEP	100	100	100	100	100	100	100	-147	-154	-173	-140	-144
OCT	100	100	100	100	100	100	100	-225	-275	-277	-253	-274
NOV	100	100	244	255	266	200	272	-159	-220	-224	-209	-266
DEC	100	100	100	100	100	100	272	-213	-243	-339	-289	-262

PT	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24
JAN	-430	-345	-379	-412	-369	-395	-319	0	191	314	338	353
FEB	-325	-305	-331	-342	-361	-341	-242	-149	0	162	166	176
MAR	-180	-195	-273	-232	-235	-338	-354	-415	-213	239	253	259
APR	-289	-254	-279	-270	-249	-344	-356	-340	-283	-142	190	266
MAY	-211	-180	-291	-292	-322	-333	-245	-209	0	0	167	163
JUN	-185	-169	-177	-204	-213	-230	-203	-211	-186	0	150	242
JUL	0	0	0	0	0	-150	-156	-166	-142	251	260	283
AUG	-245	-249	-284	-293	-307	-318	-277	-262	-197	240	276	242
SEP	-148	-159	-199	-183	-188	-217	-194	-218	-193	262	300	291
OCT	-261	-234	-258	-215	-203	-205	-216	-281	-233	100	100	100
NOV	-285	-253	-273	-254	-226	-237	-239	0	0	100	100	100
DEC	-266	-290	-354	-329	-312	-340	-338	-226	-234	100	100	100

Figure 3.4-1. Input data introduction of system's Imbalance Needs

The previous table establishes the distribution of hourly needs (upwards and downwards) among the 24 hours of working days for each of the twelve months of the year. There are also included in the data sheet identical tables considering Saturdays and Sundays.

The study was carried out considering the format of the table as a binding requirement. For each one of the years two identical table were filled out, one with average values of the hourly upward needs and other with average values of the hourly downward needs. Each cell had to comply with the condition established by their position within the table.

This means that a cell located in the first row of the first column includes the average value of the first hour hourly needs of the first month of the year under study.

Once the average imbalance needs for each one of the years and for both energy directions is determined, it is time to decide whether the final imbalance need for each position is either upwards or downwards. For this purpose, it was imposed that if the upward need is 100MW higher than the downward value the direction of the imbalance need is upward else it will be downward. Once the net direction of the imbalance is established, the value included in each one of the cells is the average value of the historical imbalance needs for the same direction and for the same characteristics regarding the position within the table. An identical methodology was applied for the Portuguese and French systems, using historical data for the years 2014, 2015 and the first quarter of 2016.

3.4.2 Determination of Portuguese and French competition patterns

Determining the behavior of competitors requires a more deeply study base on clustering techniques. Through these techniques a big number of hourly bidding curves are gathering together when its shape can be considered as similar taking into account some tolerances. The results from clustering are a set of four curves driven by the variation of the bid price with respect the day-ahead market prices and the percentage of market share. Figure 3.4-2 and Figure 3.4-3 represent the shape of these curves for upward and downward reserves markets. One can see that for upwards activations the first pattern labeled as 1S is the most aggressive one, as price increases more sharply than the other ones, as a result agents are asking for higher prices at the first steps of the curve. On the other hand, pattern 4S is the less aggressive as the price increment steps are made slower. The same reasoning applies for downwards activations.

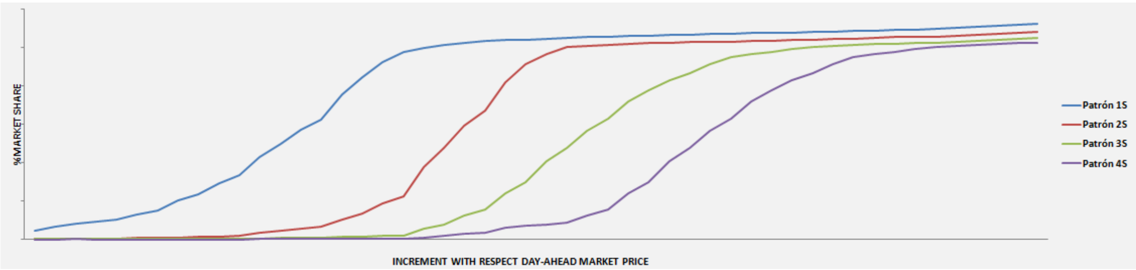

Figure 3.4-2. Patterns profile for upwards activations

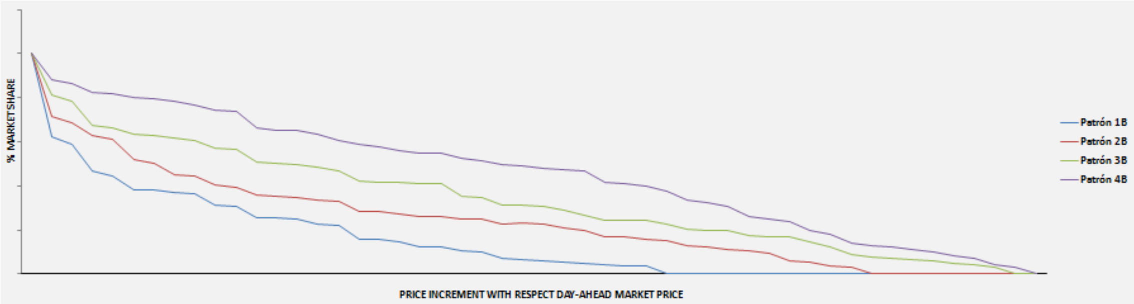

Figure 3.4-3. Patterns profile for downwards activations

These curves have to work together with a table similar to the ones showed for imbalance needs. But this time the table allocates the four already established patterns among the hours of the year under study. Noticed that this table is highly related with the table which includes the needs for each hour; depending on the direction of the energy an upwards or downwards pattern will be applied for model the behavior of competitors.

	LABORABLES																							
	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18	H19	H20	H21	H22	H23	H24
ENE	B2	B2	B2	B3	B3	B2	B3	B2	B2	B2	B2	B3	S3	B3	S3	B3	B3	B1	B1	B1	B2	B2	B2	B3
FEB	S3	S3	S3	B3	B3	B2	B2	S4	S4	S4	S3	S3	S3	S3	S3	S3	B3	B2	B1	B1	B2	B2	B2	B3
MAR	S3	S3	B3	B3	B3	B2	B2	S4	S4	S4	B3	B3	S3	B3	B3	B3	B3	B2	B1	B1	S2	B2	B2	S3
ABR	S3	S3	B2	B2	B2	B2	S3	S4	B1	B1	B2	S3	B3	S3	B2	B3	B3	B3	B2	B2	B2	B2	B2	S2
MAY	S2	S2	S2	B3	S3	S2	S3	S3	S3	S4	S3	S4	S3	S3	S3	B3	S3	S3	S3	S3	B2	S2	S2	S2
JUN	S3	S3	B2	B3	S3	B3	B3	B2	S2	B2	B2	S4	S4	B3	B2	B3	B3	S4	S4	S3	B3	S3	S4	S3
JUL	B1	B2	B2	B3	B3	B3	B3	B2	B2	B2	B2	S3	B2	B2	B2	B2	B2	B1	B1	B1	B1	S3	S4	B2
AGO	S3	S3	B2	B3	S3	S2	B2	B3	B2	0	0	0	B2	B2	B2	B2	B2	B2	B1	B1	B1	S3	S3	S3
SEP	S3	S3	B2	B3	S3	B2	B2	B2	0	0	B3	B2	B3	B3	B2	B2	B2	B2	B2	B2	B1	B2	B2	S3
OCT	S3	B2	B2	B3	B3	B3	B3	B2	B2	B2	S3	S3	S4	B2	B2	B2	B2	B2	B2	B1	B1	B2	B2	S3
NOV	B1	B2	B2	B2	B2	B2	B2	B2	S3	B2	B2	B2	B2	B2	B2	B2	B2	B1	B1	B1	B1	B1	B1	B2
DIC	B2	S3	B2	B2	B2	B2	B3	B2	B2	B2	B2	B2	S3	B3	B3	B3	B2	B1	B1	B1	B1	B2	B2	B2

Figure 3.4-4. Input data for the hourly distribution of patterns

Using the already known studies as well as historical data related to replacement reserves market prices, the behavior of French and Portuguese competitors was established. It should be kept in mind that these studies were performed once the model was totally finished because it was the only tool available to clear the French and Portuguese Replacement Reserves markets, however, in order to follow the real sequence of the model it is included in this section.

The methodology applied consists of changing the slope of the patterns used to model the Spanish agents and run the model without considering the availability of interconnections (isolated systems) until the results obtained are at least an approximation of the hourly real prices resulting from clearing those markets in previous years. But first it was necessary to fill out the table corresponding to the distribution of patterns along the year.

Replacement Reserves markets are real time markers that are mobilized once the day-ahead and intra-day market sessions closed, thus prices should be seen as a complement of preceding markets. Normally upwards hourly price resulting from this market is higher than the day-ahead market price for the same hour. Consequently, the behavior of competitors is based on the difference between upwards and downwards marginal prices with respect the price day-ahead price in the exactly same hour. This price difference is known as “spread”. Hours with high spread, around 50 €/MWh for instance, would mean that competitors have behaved followed the most aggressive pattern.

The study used as relevant data hourly day-ahead and replacement reserves prices for the year 2014, 2015 and the first quarter of 2016. The difference between day-ahead market prices and upward and downward replacement reserves market was determined for each one of the hours. The set of data was divided in four equal groups by using the quartiles[3] . In order to complete the table required by the data sheet, a similar procedure was carried out to obtain average values according to the conditions imposed by the table and considering the spreads from the time framework considered. A pattern will be allocated to every resulting value according to its position within each of intervals determine with quartiles. The allocation of patterns among the cells were done according to the table showed below:

Lower Extreme   Lower quartile   Median   Upper quartile   Upper extreme

S1	S2	S3	S4
B4	B3	B2	B1

Figure 3.4-5. Quartiles representation and consideration made to distribute them among hours

The reader should notice that most competitive patterns are the ones whose spreads are the higher ones, meaning that agents would like to obtain the maximum income from real time markets.

It was observed that French and Portuguese agents usually behave according to medium high level of aggressiveness. This appreciation seems accurate when one sees the real

[3] A quartile is a statistical term describing a division of observations into four defined intervals based upon the values of the data and how they are compare with the set of observations.

market prices, which are more expensive than the Spanish ones. In case of the French system, the pay-as-bid methodology used for remunerate these services seems the principal explanation for this fact.

3.5 LPRM-TERRE Model: algorithm and processes

Once the general structure has been explained along with the techniques applied to obtain the most accurate input data with the available resources, this sections seeks to explain down to the last detail the inside of the tool. It will be focused on the algorithms and considerations applied when developed the principal subroutines, which are the skeleton of the model.

3.5.1 Determination of available resources

One of the pillars of the model is the determination of specific results of Endesa power plants delivered from the participation in this hypothetic market, the same requirement asked for the rest of forecast tool within the department. The model should provide then specific results of each one of the units like the market share, incomes, profits and energy provided. Those values depend on the available resources of every unit, which are the capacity that has not been used previously in other markets.

Therefore, the model should have a subroutine able to determine the energy available from every Endesa's unit that is allowed to offer its remain capacity to this market. As a starting point, the algorithm uses the resulting programs from previously run models. In this case the market that has to be considered as the prior one is the Secondary Reserve market, whose associated forecast tool is called LPB (in Spanish, *Largo Plazo Banda*). The algorithm copies from the LPB to sheets; one with the PHF (Spanish acronym for hourly final program), which takes into account resulting programs from technical restrictions and the intra-day sessions, and another with information about hourly upward and downward band offered in the secondary market.

Available resources will consequently depend on the technology considered and the programs resulting from previous markets. Endesa has three types of technologies which make available its remain capacity and flexibility for balancing markets: thermal units, hydro units and pumping units. In order to determine hourly available resources, the algorithm need to be feed with the technical minimum and maximal output for every unit.

The formula employed to calculate the available capacity is highly dependent on the technology considered. But in general terms, upwards available energy would be the difference between the maximum output and the PHF and the upward secondary band; downwards energy would be determining the same way but considering the technical minimum and the downward secondary band.

3.5.2 Bid characteristics and Common Merit Order List

Like in any other market, bids will be characterized by three blocks:

- *Name*: in this case it was very important to include in the name the origin of the offer, thus the country where the energy will be generated: Spain, France or Portugal.
- *Capacity* (MW)
- *Price* (€/MWh)

Additionally, all the Spanish and Portuguese offers whose energy comes from a Endesa's unit, has to be very well specified with the name of the unit to make as easier as possible the aggregation of results.

Endesa's offers

The construction of Endesa's offers is based on the hourly available resources, their variable cost, the increment of price and strategy established for every unit. The methodology was decided by the members of the Department in an attempt to harmonize all forecasting tools regarding the modelling of market behavior of the company.

1			2		
Group	**Energy (MW)**	**Offer(€/MWh)**	**Group**	**Energy (MW)**	**Offer(€/MWh)**
ES EN TEES	10	**32**	ES EN GDLQ	10	**32**

Figure 3.5-1. Sample of two Endesa's offers corresponding to an upwards hourly bidding curve

The figure above shows an example of how several Endesa's offers are included in the offer's sheet. Notice that the same approach has been use for upward and downward offers.

Competitor's offers

The behavior of competitors is represented through the patterns presented in previous sections. However, these patterns had to be translated into another format which will be equal to the kind of offers explained above. Every pattern is a curve whose variables are the price increment with respect the day-ahead market price and the market share represent as a percentage of the hourly needs. The points that make up the curves are given in the data sheet. Each point is composed by two coordinates: one is the % of the imbalance need and the other is the increment with respect to the day-ahead market price. The two main characteristics of an offer from the competition (price and volume, will be calculated using the numerical data of every point of the curves and applying the following expressions:

$$Offer\ Price_n\left(\frac{€}{MWh}\right) = \Delta P(\%) \times MP_h(\frac{€}{MWh}) \tag{1}$$

$$Offer\ Energy_n\ (MWh) = BalancingNeedsShare(\%) \times ImbalanceNeed_h(MWh) \tag{2}$$

Notice that in these expressions $\Delta P(\%)$ and $BalancingNeedsShare(\%)$ are the values related with the competition patterns curves. The price ($MP_h(\frac{€}{MWh})$) and balancing needs ($ImbalanceNeed_h(MWh)$) applied correspond with the ones from the country of origin of the bid. An offer that belongs to a French market agent the day-ahead market price and hourly needs included in the formula will be the ones used as input data from the French electricity system. The same scheme is applied for offers coming from Spain and France.

It should be noticed that there will be hours where the country of origin has not balancing needs, meaning that for this hour the research made to determine the average imbalance needs has shown that at this hour TSO is not requiring any balancing reserve. Therefore the resulting quantity for the offer would be equal to zero. However, the agent could supply these services to a neighbor country. In those cases, the model will consider as balancing needs a standard value that represents the average available resources taken as valid for every system. This value depends on the installed capacity of the system and the energy that normally is available after the gate closure of day-ahead market. The figure below shows the table where these values can be modified in case they change it or for analyzing its sensibilities.

Average Balancing Needs		
Zone	Upwards(MW)	Downwards(MW)
Portugal	300	300
España	1200	1200
Francia	500	500

Figure 3.5-2. Adjusting parameters for average Imbalance Needs

Balancing offers from competitors are labelled with their origin system and the pattern that has been applied. The next figure shows a detail of two consecutive bids from competitors.

1			2		
Group	**Energy (MW)**	**Offer (€/MWh)**	**Group**	**Energy (MW)**	**Offer (€/MWh)**
FR S3	17	38	ES S2	24	38

Table 3.5-1. . Sample of two competitor's offers corresponding to an upwards hourly bidding curve

Once all the bids are generated, upwards and downwards offers has to be sorted out according to their price. For the upwards curve the bids with lowest price will occupy the first part of the curve and the most expensive ones the top of the curve. Downwards offers work in the opposite direction, the most expensive ones are placed at the beginning of the curve and the cheapest (more competitive) in the lowest part of the curve close to the axis.

This process is repeated of every simulated hour, having at the end two sheets, one for upward energy and other for downward energy, which gather sorted bidding curves for each hour. Both sheets are the starting point for the next sub-routines.

3.5.3 Determination of cross-border capacity

The potential benefits of TERRE project are limited by the unavailability of cross-border capacity. The lack of cross-border capacity can have a physical origin, meaning that the capacity of already built lines is not enough to carry all the energy that would have provided economic benefits to both interconnected systems; or because the remaining capacity after clearing the day-ahead market does not seem sufficient to let sequential markets play with the interconnection lines.

Spain-Portugal and Spain-France interconnection lines have been allocated trough long-term, medium-term explicit auctions, but especially most of the capacity is allocated implicitly when clearing the day-ahead market. Due to the lack of previous experiences in which the cross-border capacity would be continuously reallocated in real-time markets, it is not possible to introduce forecast data based on historical results. For that reason, it was necessary to introduce some assumptions to determine hourly available capacity in each of the lines that the model is working with.

The starting point is the current physical capacity of the lines. One should notice that this capacity can vary along the hours, days and months. When TSOs are carrying out maintenance activities in lines; or due to technical constraints or test in the network, some interconnections are off-line for a certain period of time and thus the capacity available is lower than the maximum figures. As mentioned above one of the first steps when running the model is bringing hourly forecast of exporting and importing cross-border capacity for each of the international interconnection. Having these values, the next considerations (showed in Figure 3.5-3) were introduced in the code to determine the availability of cross-border capacity after the day-ahead market.

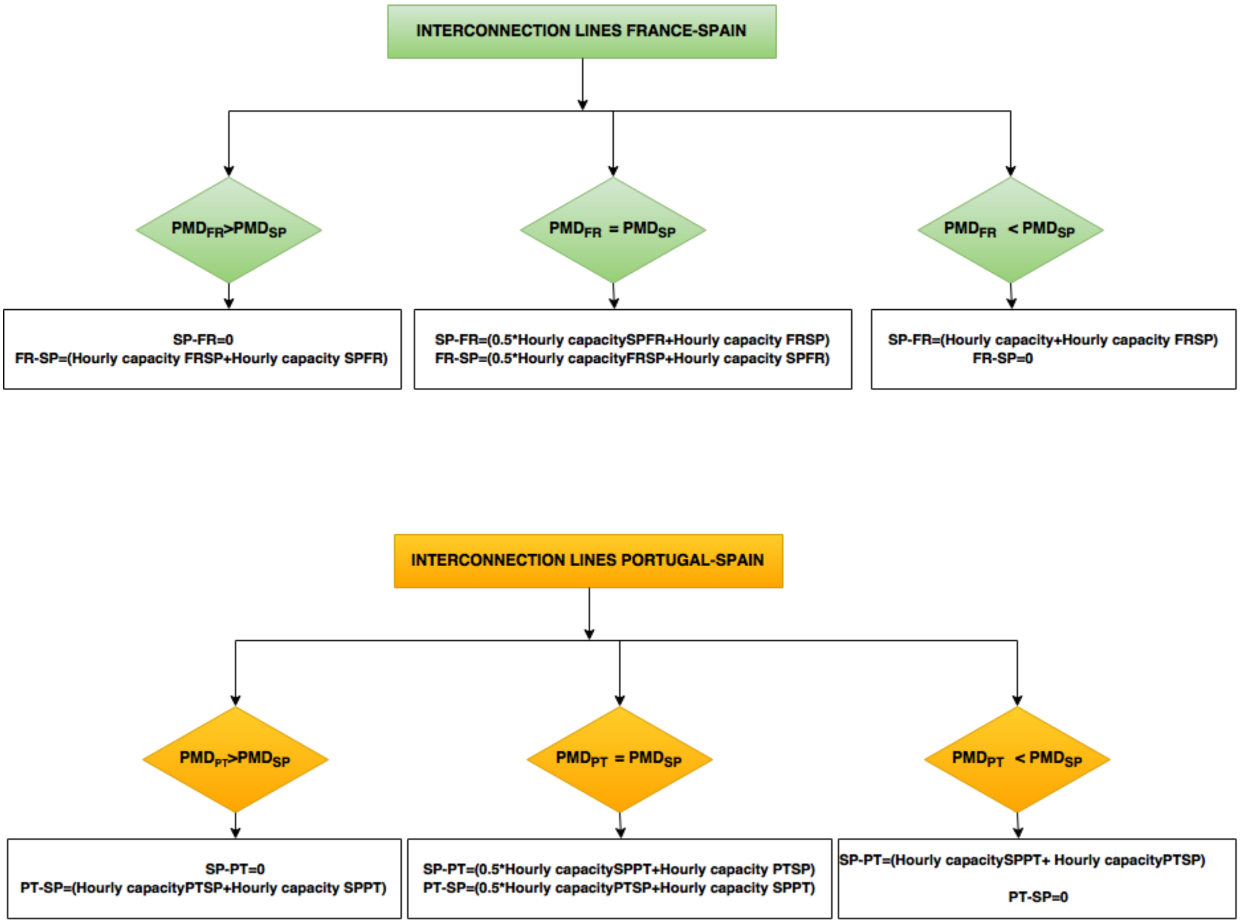

Figure 3.5-4. Designed algorithm for the calculation of hourly interconnections availability

The principle applied for these considerations in based upon the concept of market splitting in the day-ahead market. When two neighbor countries have two different market prices it means that their interconnections were congested and it was not possible to exchange all the energy that would have been economically feasible. The country with higher market price is the one that has imported resources from outside, thus its importing direction of the interconnection is congested. The exporting direction would be empty because it had not economic sense to bring more expensive resources to an area whose own resources are cheaper.

It is noteworthy that if there is enough capacity in one of the directions, because is not the economical one, there is the possibility to change the net position of the interconnection usage by additionally using the whole capacity of the opposite direction. Therefore, in those cases the total available capacity would be result of adding to the exporting capacity to the importing capacity. As represented in figure below, if the interconnection line was congested from Spain to France, the total available capacity to be used by this platform would be the sum of both directions.

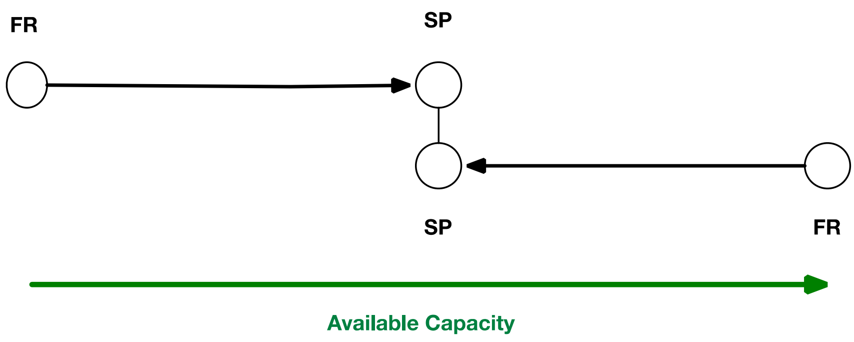

Figure 3.5-5. Example for the determination of cross-border capacity

In case hourly day-ahead market prices are equal in both areas, it has been considered that just half of the exporting capacity and half of the importing capacity has been used in previous markets. The same reasoning can be applied regarding the change in the net position of the interconnection.

Given that these assumptions could have a big influence in the results of the model, they have been introduced in the model as open variables that can be changed whenever the user thinks it is necessary. Furthermore, it allows to perform further simulations to study its sensibilities.

3.5.4 Market clearing algorithm

The development of an algorithm to clear such a complex market has been the most important contribution of the present thesis. Taking into account the main features established by the TERRE project the idea was to replicate as accurate as possible each one of them. Although some simplifications have been done at first stage, the fundamentals of the proposed algorithm still remain in line with the ideas of the project.

In order to simulate the clearing process of an international market for replacement reserves the algorithm needs as starting point the next hourly values:

1. Upward and downward imbalance needs of each of the areas (Spain, France and Portugal)

2. Spain-France/ France-Spain and Portugal-Spain/Spain-Portugal cross-border capacity[4]
3. Common Merit Order List for upward and downward bids

The process should aim to allocate the cheapest bids until fulfilling the imbalance needs of each of the three areas taking into account the availability of interconnections. It is possible to apply to equivalent approaches:

- *Two step process*: Firstly, clear the market without considering the restrictions imposed by interconnections; then, check if allocated offers comply with interconnections constrains, if not replace foreign bids with others whose origin is the same as the area of delivery.
- *One step process*: In this case, the economic merit order and the cross-border availability would be considered at the same time while clearing the market.

Both approaches where discussed during the design process, however, the second one seemed more appropriate because the algorithm would be simpler and faster to code.

The proposed algorithm aims simultaneously to allocate the cheapest balancing resources in order to meet the imbalance needs for every hour and to optimize the use of interconnections. Within this context, optimizing means to make use of interconnections lines with the cheapest energy that would be available at that moment. Both purposes are translated to the program by developing several subroutines that will be called depending on the origin of the offer. Firstly, the algorithm allocates the offers to its corresponding routine depending on its country of origin. One should notice that at this stage bids has been already sorted out according to prices, hence the economic optimization is achieved by following up this order.

[4] Notice that this values results from running first the subroutine for the determination of cross-border capacity, explained in previous point.

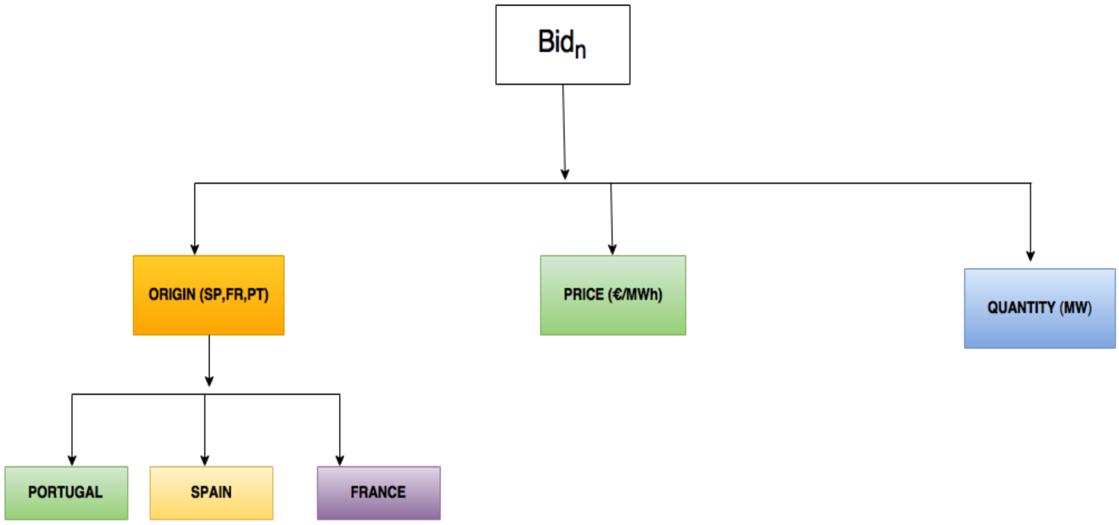

Figure 3.5-6. Bids Labels

Each procedure establishes several conditions, when an offer complies with first condition is allocated at first stage else it will continue until being allocated in the right place or being rejected. In all cases, the algorithm seeks at first stage to allocate the offer in its country of origin. In case there are not balancing needs at its origin country for this hour, the algorithm would try to allocate the offer in a foreign country who has imbalance needs but always taking into account the availability of cross-border capacity. The following schemes present the proposed procedures for the allocating of bids coming from Spain, France and Portugal.

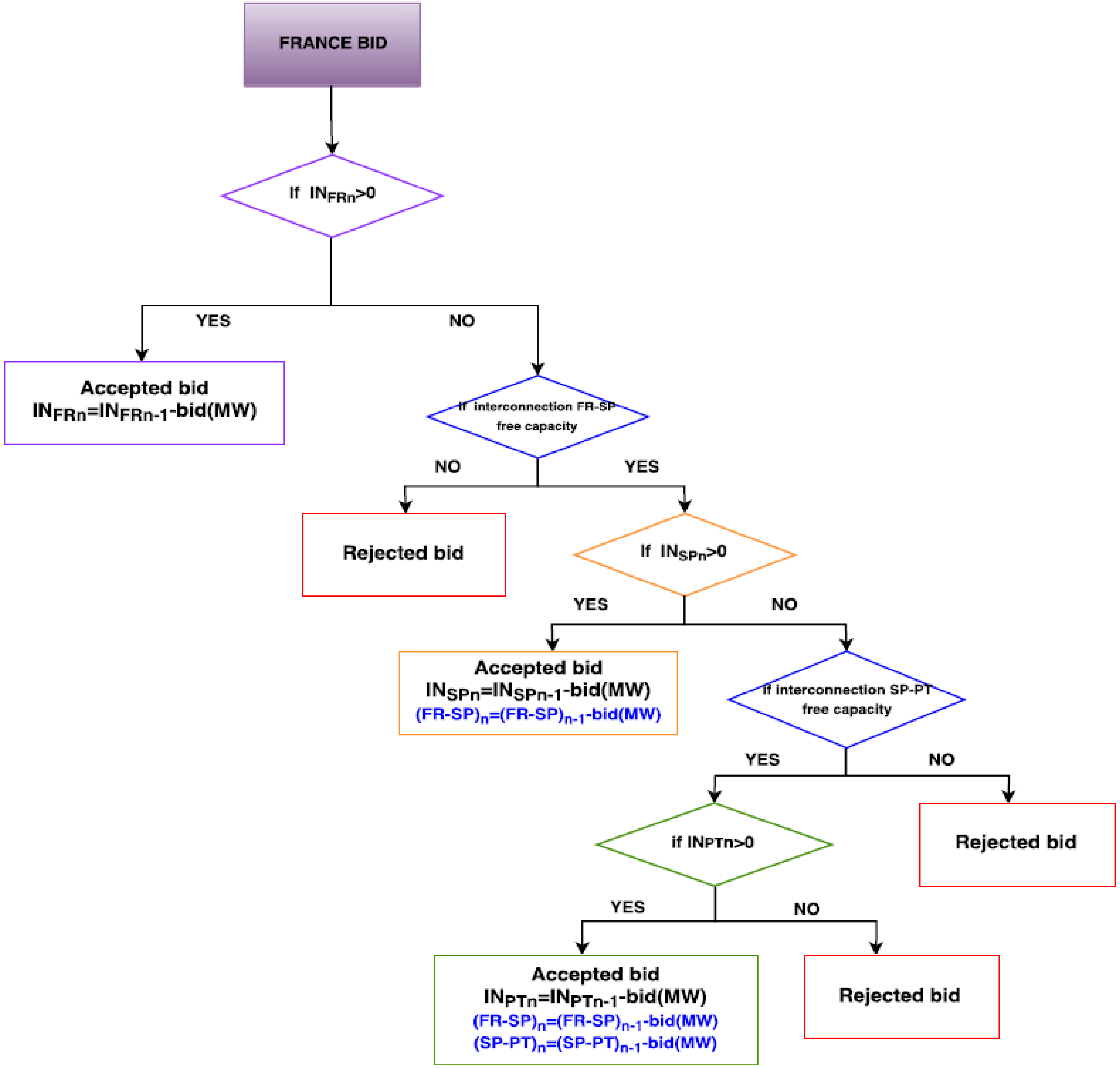

Figure 3.5-7. Algorithm for the allocation of French bids

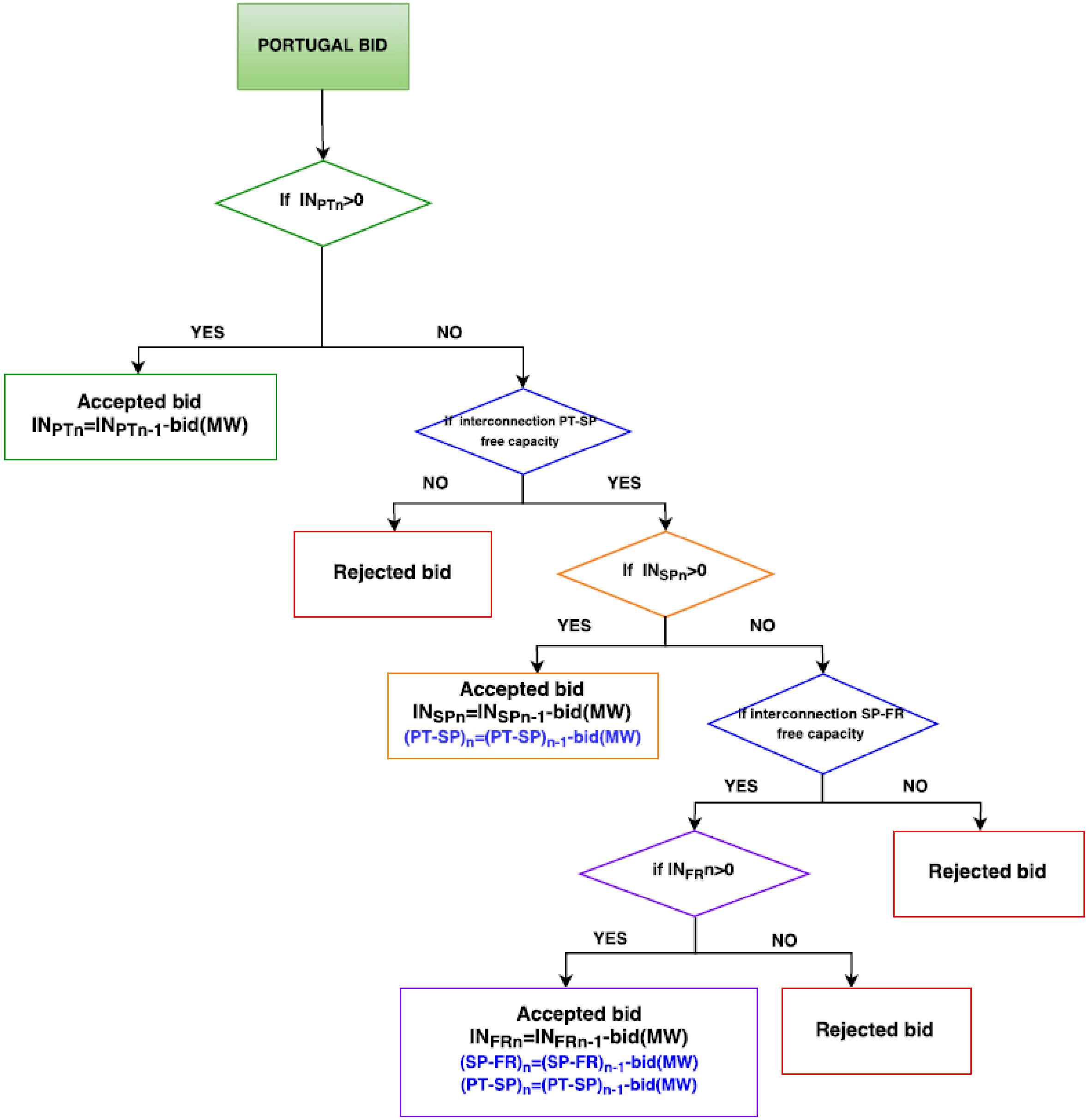

Figure 3.5-8. Algorithm for the allocation of Portuguese bids

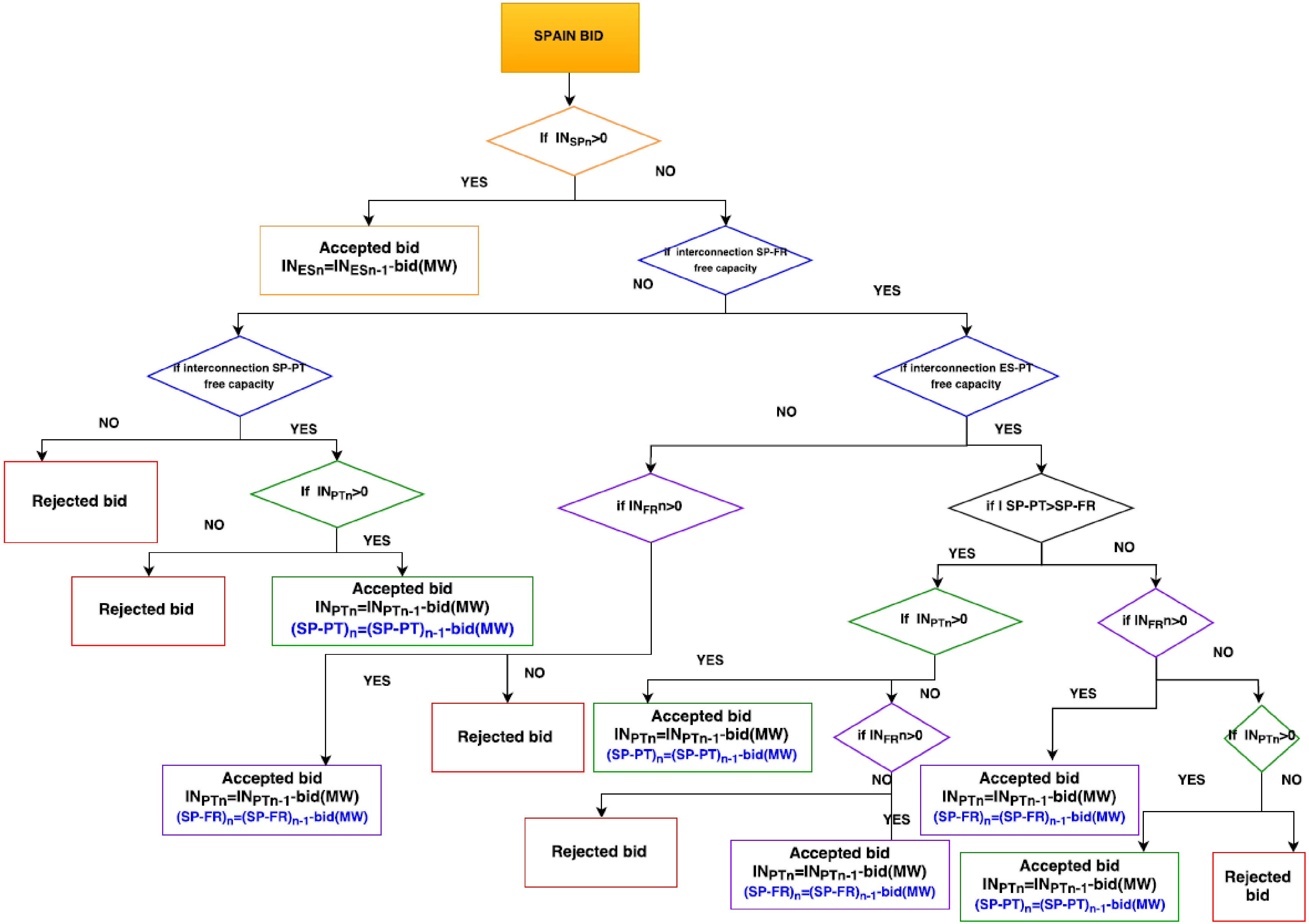

Figure 3.5-9. Algorithm for the allocation of Spanish bids

For offers whose origin is France or Portugal the process of allocating them outside its borders is clearer because there is just one choice to do so. A Portuguese offer can only be allocated outside Portugal using part of the Portugal-Spain interconnection line, when this direction is congested it will never be possible to move more energy from Portugal to Spain or France. The same situation occurs with French offers because the only possibility to allocate them outside is through the France-Spain interconnection. However, the case of Spanish offers has more complexities associated because there are two possibilities to move energy outside the borders. Then it was necessary to establish a condition to give priority to one of the interconnection lines: in case there is availability in Spain-France and Spain-Portugal interconnections bids will go through lines with higher cross-border availability.

The algorithm will be simultaneously determining the marginal price for each one of the bidding areas. If there was not any restriction in the interconnections prices would converge into a single one, however this scheme is really far from reality. The same principle applies in the day-ahead market, when lines are congested marginal prices in each part of the line are different. The last offer allocated in each area will set the marginal price of this bidding area. The origin of the offer will not have any influence the market works as a single one.

3.5.5 Determination of congestions rents

Price differences in two connected bidding areas has an associated income on the trading flow from the area with lower price to the area with higher price. This income is known as congestion rent.

Considering as an example a situation in which zone A has not imbalance needs but zone B has a certain amount. If the interconnection capacity between the two systems was infinite, both bidding curves would be join together into a single one and the market would be cleared in order to meet the balancing needs of zone B. However, when cross-border capacity is not enough to carry the energy flows resulting from previous dispatch, the common merit order curve will be split in two. One curve will correspond to the zone A (exporter) and the other one will corresponds to zone B (importer). Each of the bidding curves will be made up of the activated offers from its corresponding zone. Both curves are shown in Figure 3.5-10.

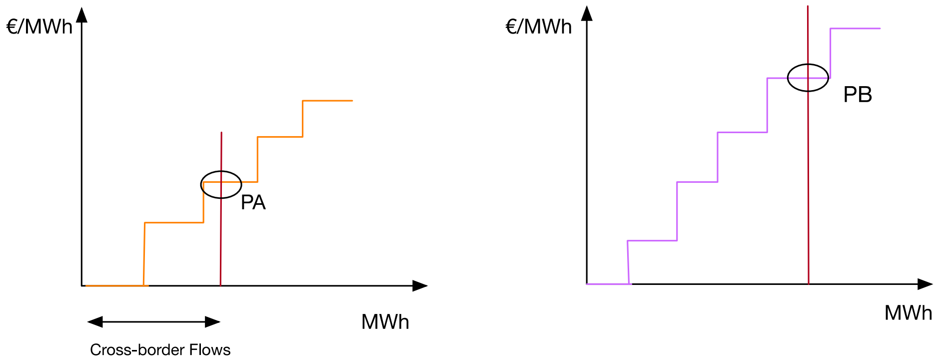

Figure 3.5-10. Congestion Rent definition

Marginal price in zone A is set by the last bid accepted to meet the balancing needs of zone B considering the restriction imposed by the interconnection. Price B is the marginal price in zone B, which considerably higher given that its resources are more expensive.

As a result, there will be different marginal prices at both sides of the interconnector. Marginal price in zone B is higher than marginal price in zone A. Consequently, the price that zone B is willing to pay for the exchanged balancing energy, in this case imported, is higher than the price that the zone A is willing to receive for the exporting energy. This price difference results in the following income:

$$TERRE\ congestion\ rent = TERRE\ schedule\ \times (PB - PA) \qquad (3)$$

One should notice that this is just the methodology applied in the designed algorithm but other approaches can be applied as well. Since congestion rents are potential revenues resulting from the real implementation of TERRE platform it would be very interesting to include them in the model, although the principal benefits will be demonstrated as a reduction in the total cost of service. In order to calculate them the model should capture all energy flows representing through offers. While clearing the market the model store cross-border offers considering the following groups, which are based on the origin and the destination of the offer:

- Origin: Spain; Destination: Portugal
- Origin: Spain; Destination: France
- Origin: France; Destination: Spain
- Origin: France; Destination: Portugal
- Origin: Portugal; Destination: Spain
- Origin: Portugal; Destination: France

The last offer allocated in each one of the groups in the marginal price and congestion rents are calculated according to it.

3.6 Presentation of results by system

Presentation of results consists of gathering monthly information for each of the system considered (Spain, Portugal and France). Information is presented in a table similar to the one showed in Figure 3.6-1.

	Upward Replacenemt Reserves Spain													
	Current execution	January	February	March	Aprl	May	June	July	August	September	October	November	December	Annual Total
Technical Results (MW - Totals GW)	Upward Balancing needs													
	Allocation ENDESA													
	Market share (%)													
Economic Results (k€ - Totals M€)	Average Price (l/MW)													
	Cost of Service													
	Margin													
	Incomes													

Figure 3.6-1. Model presentation of annual market results

Through this table the model gathers the most important results in order to have a general picture of the market forecasted and carried out a qualitative and quantitative analysis. One should notice that this is an example of the table corresponding to upward replacement reserves for the Spanish system therefore all information is related to it. But additionally the user has access to similar information but referred to downwards activations, like the one showed in Figure 3.6-2.

	DOWNWARD BALANCING RESERVES PORTUGAL													
	Current execution	January	February	March	Aprl	May	June	July	August	September	October	November	December	Annual Total
Technical Results (MW - Totals GW)	Upward Balancing needs													
	Allocation ENDESA													
	Market share (%)													
Economic Results (k€ - Totals M€)	Average Price (l/MW)													
	Cost of Service (incomes)													
	Margin													
	Incomes													

Figure 3.6-2. Model presentation of annual downwards market results

Looking at this figures the user should be able to carry out a general analysis that allows to determine whether the model has worked properly and whether the results provided are within the normal limits for a market with similar characteristics. One of the general trends for balancing markets are the monthly amount of energy called by TSOs and its associated average price. Balancing markets are a complement (extra income) of the day-ahead market then prices should be higher than the hourly marginal price in the day-ahead market, in case of upward energy, and lower in case of downward energy. The user could compare the resulting price with the daily prices to verify that the simulation has worked properly.

Another valuable information that should be included in a forecast tool is the total cost of the service for the system. Those units that provides real time upward energy have to be remunerated for it, hence upwards activations means a cost for the system. However, the situation for downwards activations is the opposite one, as units are reducing their output they have to pay for it considering that they are buying back their energy; in this case the system is receiving money which is an income rather than a cost.

All the information collected in this tables about Endesa units aims to provide a quick view of the market expectations for the company. For that purpose, each the table shows the resulting calculation of the monthly market share, margins and incomes. A detailed explanation of the calculation of the margin will be presented in the next point.

3.7 Aggregation of results by UOF

The model has an intrinsic purpose which consists of providing market results for every power plant of Endesa. Even though these results would be mainly a forecast, the user should have access to as much detailed information as possible. Under this context, detailed information means giving specific results about every thermal power plant or hydro reservoir, from now on OUF.

Detailed information is provided about the following aspects, for upwards and downwards balancing markets:

- Energy provided (MW)
- Incomes (€)
- Margin (€)
- Market share (%)

Data is collected in tables similar to the one showed below:

	CUOTA A SUBIR (%)													TOTAL BY TECHNOLOGY	ZONE
UOF	January	February	March	Apri	May	June	July	August	September	October	November	December	Annual Total		
CCO3														TOTAL THERMAL	TOTAL SPAIN
COM4															
COM5															
TER1															
TER2															
TER3															
LIT1															
LIT2															
PGR1															
PGR2															
PGR3															
PGR4															
BES3															
BES5															
COL4															
PGR5															
SROQ2															
EBRFEN														TOTAL HYDRO	
GDNA															
GDLQ															
SBEU															
TEES															
TERE															
GUIG														TOTAL PUMPING	
SLTG															
TJEG															
MLTG															
GUIB															
SLTB															
TJEB															
MLTB															
PEGO30														TOTAL THERMAL	TOTAL PORTUGAL
PEGO40															

Figure 3.7-1. Aggregation of results for market share in upwards balancing market

An excel sheet contains in total eight tables similar the previous one: four for upwards activations and other four for downwards activations. Energy delivery by every unit is calculated as the sum of the allocated energy in each hourly period of the month considered. Market share is calculated using the next expression, which applies for every unit *i*:

$$Monthly\ market\ share_i(\%) = \frac{\sum Allocated\ Energy_i}{\sum Spanish\ IN + \sum PortugueseIN + \sum French\ IN} \qquad (4)$$

With respect to the incomes, they are calculated as follows:

$$Income_i = \sum MP_h(\frac{€}{MWh}) \times Energy\ Provided_i\ (MW) \qquad (5)$$

Notice that the sum goes from the beginning to the end of the month. With respect to the margins, they are calculating taking into account the variable cost for every unit.

$$Margin_i = Energy\ Provided_i \times (MP_h\left(\frac{€}{MWh}\right) - VC\left(\frac{€}{MWh}\right)) \qquad (6)$$

Values introduced as variable cost are the ones coming from the data sheet, where detailed information for every unit is presented.

4. Analysis of Scenarios

LPRM-TERRE is a forecast tool that simulates a market that has not be implemented yet. Therefore, it is not possible to validate the model against real data. However, with a forecast tool of this characteristics it seems very interesting to run the model changing some of the variables that were introduced at first stage with the purpose of simulating several scenarios and making an assessment based on the economic results cross-border flows, even though they are just an estimation.

The analysis aims to compare the current situation, under which every system manages its imbalances with national markets, with each one of the scenarios. As mention in previous chapters the main benefit associated to the platform is the reduction in the total cost of service, hence, resulting total cost provided by the model will be compared. Furthermore, the analysis will include an assessment of the usage of cross-border flows by comparing the market share of foreign balancing energy, determining possible impacts for each one of the systems.

Every scenario will be run in a yearly basis in order to obtain results for the year 2017.

4.1 Scenario 0: Isolated Systems

This scenario corresponds to the current situation where TSO organize their imbalances using their own energy resources. Although REE, RTE and REN are currently exchanging some balancing offers through the BALIT project, those exchanges are not going to be taken into account as it is out of the scope of the thesis. Likewise, they do not represent a big volume of energy less than 5% of total imbalance needs.

Even though LPRM-TERRE has been designed to model the functioning of an international platform if one changes the available cross-border capacity and introduces a value of zero for every interconnection - Spain-France, France-Spain, Portugal-Spain and Spain-Portugal- it would be possible to obtain results corresponding to a situation in which every system is isolated in terms of balancing energy.

Based on the previous condition, the cost for upward energy and payments from downward energy for the year 2017 are the following ones:

	ISOLATED STSTEMS YEAR 2017				
	Volume of upward activations (GWh)	**Volume of downward activations (GWh)**	**Value of upward activations (M€)**	**Value of downward activations (M€)**	**Total (M€)**
PORTUGAL	831.8	-1,070.9	39.8	-31.6	8.1
SPAIN	4,146.8	-2,058.0	217.7	-68.4	149.3
FRANCE	1,682.0	-4,283.2	63.8	-96.7	-32.9
TOTAL	**6,660.7**	**-7,412.2**	**321.3**	**-196.8**	**124.5**

Table 4.1-1. Economic Results Scenario 0. Isolated systems

Future scenarios will be compare against these results with purpose of assess the impact in cost resulting from the implementation of TERRE platform. Notice that the total cost of the service is very influenced by the amount of balancing energy called by TSO along the year. Information available in Table 4.1-1 demonstrates the trends of imbalances in the systems under study. Spain usually ask for a bigger amount of upwards reserves overall whereas France and Portugal tend to have downwards imbalances, if one takes into account the size of the systems when making these comparisons.

4.2 Scenario 1: Default Scenario

This scenario is the one resulting from running the model keeping the default parameters. Therefore:

- Competence patterns are based on the current behavior obtained through some studies that has been already explained. Notice that this patterns are exactly the same ones as if the systems were isolated in terms of balancing energy.
- In those hours where day-ahead marginal prices are equal, thus the interconnection is not congested yet, the available cross-border capacity corresponds to a 50% for each direction. In this regard, in order to internalize the forecast error, a tolerance in prices was introduced. Price difference between two neighbor countries equal or lower than 0.5 €/MWh are permitted in order to consider both prices as equal thus there is capacity available in the

interconnection. This consideration will be kept in all the scenarios presented in this document.

- Input data of cross-border capacity corresponds to a forecast of physical capacity for the year 2017 which corresponds to the most accurate data available for the department. The proposed algorithm explained in previous sections determines remain capacity in interconnections to be used in this replacement reserve market.
- Input imbalance needs are the ones resulting from the performed study based on historical data. This values will remain equal in the rest of scenarios.

Taking into account previous considerations, the results obtained are the following ones:

	ISOLATED STSTEMS YEAR 2017				DEFAULT CASE YEAR 2017		BENEFITS		
	Volume of upward activations (GWh)	Volume of downward activations (GWh)	Value of upward activations (M€)	Value of downward activations (M€)	Value of upward activations (M€)	Value of downward activations (M€)	Upwards benefits (M€)	Downwards Benefits (M€)	Total Benefits (M€)
PORTUGAL	831.8	-1070.9	39.8	-31.6	35.3	-41.4	4.4	9.8	14.2
SPAIN	4146.8	-2058.0	217.7	-68.4	216.7	-68.5	1.0	0.1	1.1
FRANCE	1682.0	-4283.2	63.8	-96.7	61.1	-97.2	2.7	0.5	3.2
TOTAL	**6660.6**	**-7412.1**	**321.3**	**-196.8**	**313.1**	**-207.1**	**8.2**	**10.3**	**18.5**

Table 4.2-1. Economic Results. Scenario 1. Default scenario with TERRE

Table 4.2-1 demonstrates the expected benefits that would be obtained if the platform was implemented. Notice that this results does not consider any change in the behavior of agents, they are competing without considering the presence of foreign agents in their domestic markets. One can see that the biggest improvements occurs in Portugal, where benefits accounts for more than a 10% of current cost for upwards activations and more than 30% for the opposite direction. This is the result of the lack of competitiveness than can be found in this balancing markets in Portugal up to now. When looking at the market share of agents the results obtained are the ones shown in the following charts:

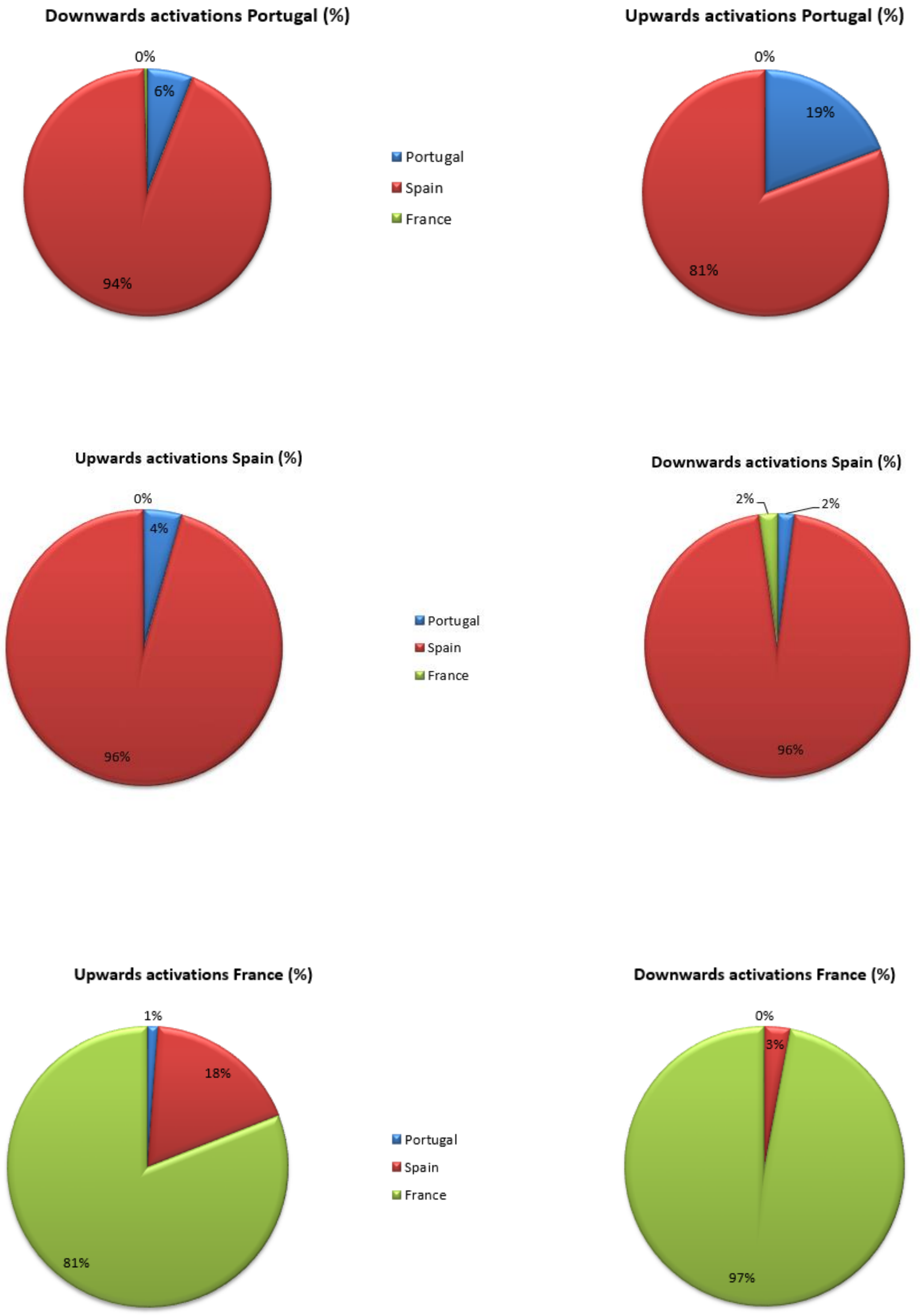

Table 4.2-2. Upwards and downwards market share for Portugal, Spain and France in Scenario 1

When looking at these charts one should notice the considerable amount of market share of Spanish agents in Portuguese power system. The reasoning for this issue is the shape of Portuguese patterns and their distribution among hours with respect the Spanish ones.

Both distribution and shape factors results in a situation in which Portuguese agents are less competitive than the Spanish ones. Nowadays marginal prices for balancing energy in Portugal are more expensive than the Spanish ones mainly due to their market concentration. While in Portugal there is just a main principal agent providing this kind of services in Spain there are at least four of five competing in most of the hours. It is also important to highlight that imbalances needs are complementary in both countries: in those hours where Spain is asking for upwards replacement reserves, Portugal is asking for reserves in the opposite direction. This imbalance situation incentivizes the effect previously explained.

Regarding the French system, the binding effect of interconnection is very significant. As mentioned in chapter three, interconnections were assumed to be congested when there is a difference in day-ahead market prices. Because market prices in France are usually lower than the Iberian ones, French agents are not allowed to export more energy. Due to the same effect, there is available capacity in the export direction and Spanish agents are taking advantage of the situation providing part of the French imbalance needs when their bids are cheaper than the French ones.

4.3 Scenario 2: Behavioral Response by Agents

When analyzing the second scenario it was observed that Spanish agents have a considerable high market share in Portuguese system. The explanation for this fact is the shape of Portuguese patterns as well as their distribution among the hours, being Portuguese agents less competitive than their neighbors. A response by market agents is expected once the market is implemented. Portuguese agents would need to change their strategies in order to compete against foreign agents to return to previous situation in which they have a considerable market share.

The competitiveness of Spanish agents in French system has a lower impact with respect to the Portuguese system due to the effect of interconnections. Day-ahead market price forecast does not foresee a considerable number of hours with market coupling.

In order the model to include the response made by agents it was necessary to introduce the following assumptions:

- The shape of bidding curve of agents from Portugal has been modified to make them more competitive with respect Spanish agents. The slope for upward bidding curve was decreased whereas the slope for downward bidding curves was increased. Then the slope of patterns curve is flatter.

- In those hours where there are imbalance needs with the same direction at both sides of the interconnections the pattern assigned to Portuguese agents will be exactly the same as the Spanish one allocated for the same hour. This assumption aims to introduce in the tool a high level of competitiveness in the market in which Portuguese agents adapt their behavior to the Spanish one.
- The competition patterns of French agents remains the same as previous scenario as this scenario is just trying to assess the adaptation of Portuguese agents to the new environment.

Regarding the total cost of the service, the results obtained are the following ones:

			ISOLATED STSTEMS YEAR 2017		RESPONSE BY AGENTS YEAR 2017		BENEFITS		
	Volume of upward activations (GWh)	Volume of downward activations (GWh)	Value of upward activations (M€)	Value of downward activations (M€)	Value of upward activations (M€)	Value of downward activations (M€)	Upwards benefits (M€)	Downwards Benefits (M€)	Total Benefits (M€)
PORTUGAL	831.8	-1070.9	39.8	-31.6	33.7	-44.2	6.1	12.6	18.7
SPAIN	4146.8	-2058.0	217.7	-68.4	214.0	-69.1	3.7	0.6	4.3
FRANCE	1682.0	-4283.2	63.8	-96.7	60.7	-97.5	3.1	0.8	3.9
TOTAL	**6660.6**	**-7412.1**	**321.3**	**-196.8**	**308.4**	**-210.8**	**12.9**	**14.0**	**26.9**

Figure 4.3-1. Economic Results. Scenario 2. Behavioral response by agents

Now the benefits resulting from the implementation of the platform increased considerably, both for the Spanish and Portuguese systems. There has been an increment in the competitive performance of Portuguese agents. Benefits are noticeable both for upward and downward replacement reserves.

When looking at the market share the resulting charts have changed to the following ones:

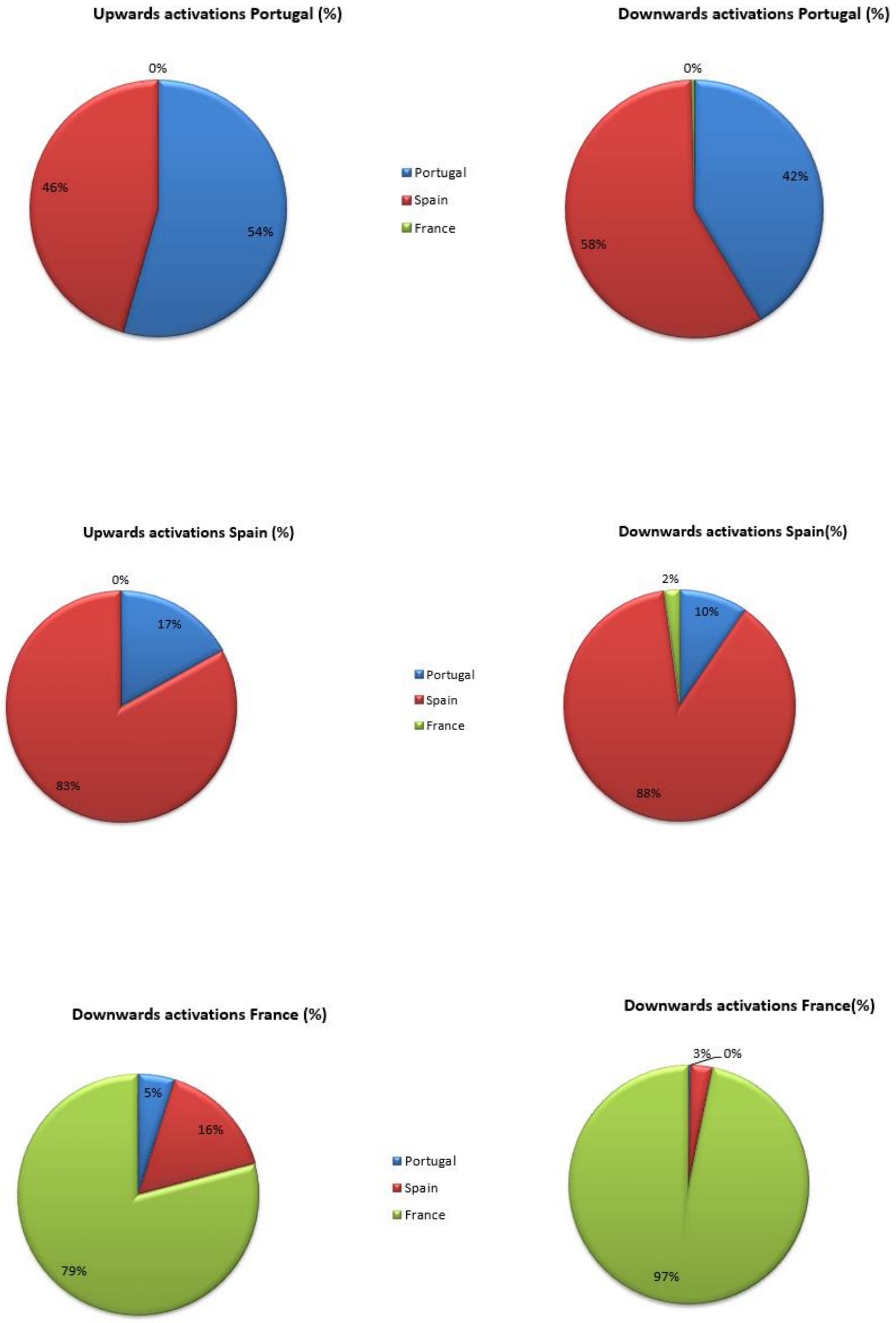

Figure 4.3-2. . Upwards and downwards market share for Portugal, Spain and France in Scenario 2

From these charts one can notice that Portuguese agents have regained partly their market share, which now accounts for more than 50%. This increment of market share can be seen also in the French systems, where Portuguese agents fulfill part of the yearly imbalance needs.

It worth noticing that this behavioral response is based on patterns with are modeled taking into account current prices that results from a different market mechanism with a very different level of competition. Therefore, this scenario is not far from reality, if playing field changes, a shift in the bidding curves of agents would be an expected reaction. Likewise, once the platform is implemented new study of competition should be carried out in order to simulate more accurately the behavior of market agents.

One should notice from this situation that the effect of interconnections is almost negligible in the Spain-Portugal case. It means that both systems are perfectly coupled in terms of interconnection. The opposite effect occurs in Spain-France interconnection lines; which economic sense is congested in a great percentage of the hours thus an increase in competitiveness in French system does not impact the results of the simulation.

4.4 Scenario 3: Equalization of Agents

The lesson learnt from previous scenarios is that the performance of agents has a big impact on resulting market share, whenever interconnection allows energy to flow where towards is more needed. One should expect that once the platform is well implemented agents would adapt their bids to the new situation but also market agents would play under the same level of competitiveness regarding extra cost imposed to generators. Although previous scenarios have demonstrated that the level of competitiveness is higher in the Spanish system there are still some taxes or mechanism that agents has to take into account when calculating the price of their bids.

This scenario aims to include the impact if some of the taxes paid exclusively or in a higher amount by Spanish generators were removed, thus the price of their bids will decrease as a response of these adjustments.

Nowadays in Spain there is tax imposed to generators equal to a 7% of the incomes. Additionally, they have to cope with what is called in Spanish as “céntimo verde” which supposes an additional charge to the consumption of fossil fuels such as coal and natural gas. This scenario tries to include also the differences in access tariffs to the gas network in Spain and Portugal. Although flexibilities in access tariff in Portugal are lower, Spanish access tariff to gas network is more expensive overall. One should notice that the impact of access tariffs in total cost of units would depend on the type of consumption made by agents, having special influences the flexibilities asked to the supplier. Finally, this scenario will include the impact in cost if the marginal payment associated with the use of the transmission network was removed. This cost is equal to 0.5€/MWh and it has to be paid by every generator connected to the network.

Due to the intrinsic characteristics of the model it would very complicate to include separately the influences of each of the issues already explained. Consequently, all extra cost will be grouped together into a single figure included into the model as a percentage in the reduction of generation cost. Variable cost of Endesa's units as well as the slope of the patterns will be reduced a 10% out of its total. Notice that for downward curves the slope has to be increased as now agents would be more competitive thus the slope of the curve.

The model was run again changing the profile of the bidding curves as well as the input variable cost of Endesa's units. The results obtained regarding the total cost of the service are the following ones:

	ISOLATED STSTEMS YEAR 2017				EQUALIZATION YEAR 2017		BENEFITS		
	Volume of upward activations (GWh)	Volume of downward activations (GWh)	Value of upward activations (M€)	Value of downward activations (M€)	Value of upward activations (M€)	Value of downward activations (M€)	Upwards benefits (M€)	Downwards Benefits (M€)	Total Benefits (M€)
PORTUGAL	831.8	-1070.9	39.8	-31.6	32.0	-45.4	7.8	13.8	21.6
SPAIN	4146.8	-2058.0	217.7	-68.4	194.4	-73.3	23.3	4.9	28.1
FRANCE	1682.0	-4283.2	63.8	-96.7	58.9	-97.7	4.9	1.0	5.9
TOTAL	**6660.6**	**-7412.1**	**321.3**	**-196.8**	**285.3**	**-216.4**	**36.0**	**19.6**	**55.6**

Figure 4.4-1. Economic Results. Scenario 3, equalization of agents

The impact of these changes is especially noticeable in Portugal, who under this situation the amount paid to generators providing upward balancing reserves is lower than the amount paid by those agents providing downward balancing reserves to the system. If this situation was real in the future, TSOs would receive a surplus of more than 10 M€. However, this is just an approximation which includes all forecast mistakes and simplifications included in the tool. In Spain the assessment is similar, because now units have reduced the price of their bids the cost of the services has decreased according to this reduction approximately a 10%. Regarding the distribution of energy flows among bidding areas, the results obtained are represented in the following charts:

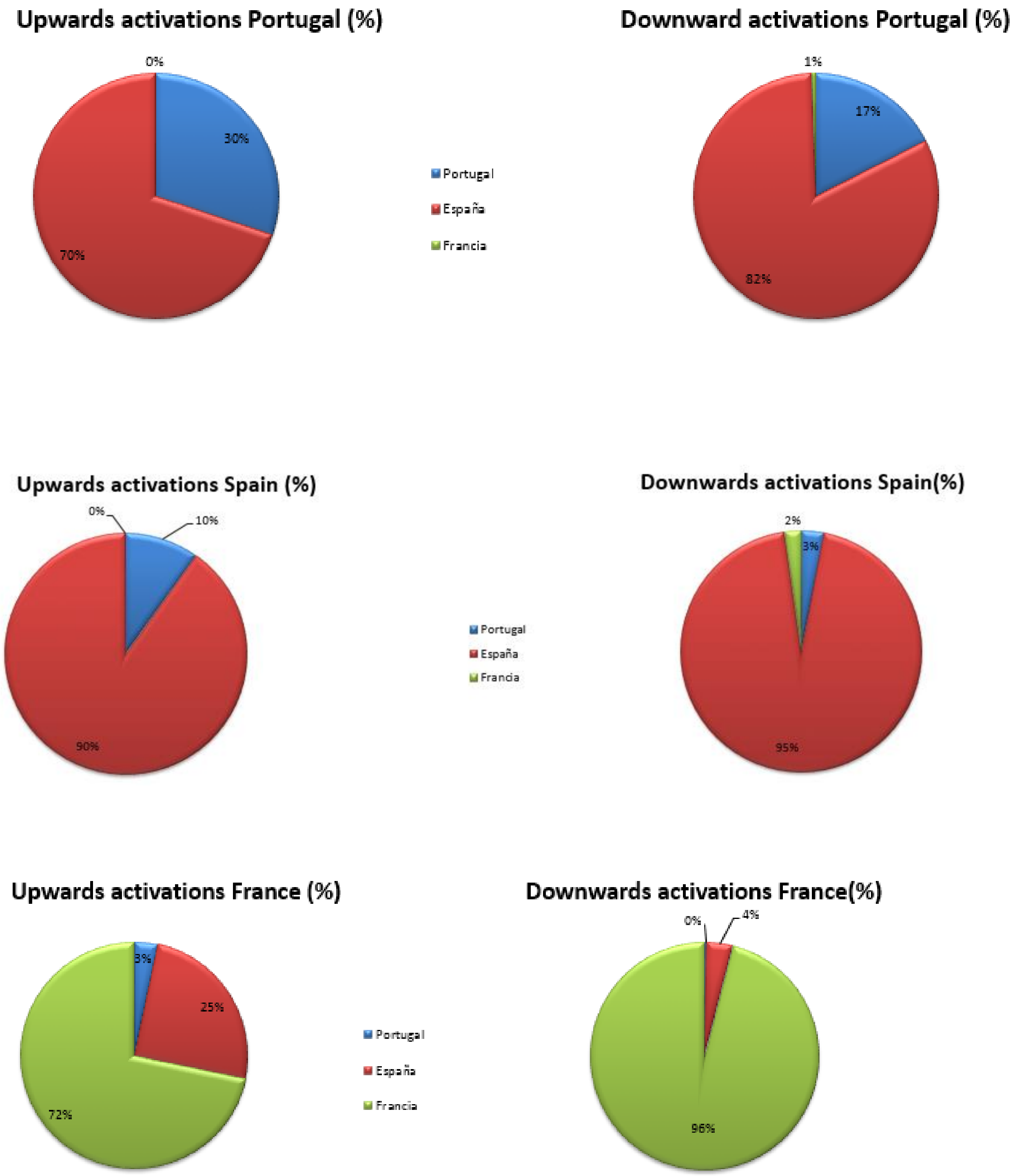

Figure 4.4-2. Upwards and downwards market share for Portugal, Spain and France in Scenario 3

Within this hypothetic environment Spain is less dependent of imports, as expected. Thanks to a reduction in generation cost their units has become more competitive with respect ones corresponding to its neighbors. Due to the same reasoning the allocation of Spanish bids in both French and Portuguese system has increased considerably, Spanish market share in French market has increased a 10%. Notice that if agents would respond to this situation they would probably be more competitive in order to maintain their market share. However, any further response made by agents would be difficult to quantify, hence, this possibility remains opened to future studies.

These charts again demonstrate the impact of Spain-France interconnection when clearing the market. Due to the lack of interconnection capacity produced by price differences, France is isolated from the rest of the systems and it is not allowed to export its cheap resources. This demonstrates that lack of interconnection capacity would be the main barrier for the development in this market in the future.

4.5 Scenario 5: Increase of Interconnection Capacity

Previous scenarios have shown that due to the lack of capacity in the lines that connects Spain with France, the last system is isolated from the rest of market participants. Day-ahead marginal prices resulting in the French bidding area are in a considerable number of hours lower than the ones corresponding to the Spanish bidding area. This price difference has an intrinsic effect: France-Spain interconnection lines are at full capacity; hence it is not possible to use them for consecutives markets such as the one considered in this thesis.

Lack of cross-border capacity is the main barrier that prevents this market from obtain larger benefits thus reduction in cost of service. Then it seems necessary to run a new scenario in which hourly capacity of the lines is increased considerably. This scenario has an additional outcome that is the assessment of whether the benefit obtained from this market justify the construction of new lines in the future.

However, this scenario has associated several complexities that has to be taken into account as accurate as possible when introducing input data in the tool. The main aspect that has to be introduced in the model is the impact in day-ahead prices that an increment in cross-border capacity would produce. If more interconnection lines were build Spain would stop being an island in terms of interconnections and consequently more energy would flow towards the Iberian Peninsula. If the capacity of new lines were considerably high the Iberian market would be coupled with France and the rest of Europe. Market splitting would not occur anymore and the Iberian market would shift towards lower prices similar to the current ones in France.

Therefore, the input data related to day-ahead market prices had to be modified so as to provide the model with representative values of this hypothetic market situation. With the purpose of simplifying the task, forecast day-ahead market prices for France increased a 5% were introduced as they were the corresponding ones for the three systems under study. Furthermore, input data related to the forecast scheduled output of Endesa's units was changed with the corresponding one which was computed considering that Spanish and Portuguese market prices were equal to the French ones.

Results delivered from this scenario are the following ones:

	ISOLATED STSTEMS YEAR 2017				INCREMENT INTERCONNECTIONS YEAR 2017		BENEFITS		
	Volume of upward activations (GWh)	Volume of downward activations (GWh)	Value of upward activations (M€)	Value of downward activations (M€)	Value of upward activations (M€)	Value of downward activations (M€)	Upwards benefits (M€)	Downwards Benefits (M€)	Total Benefits(M€)
PORTUGAL	831.8	-1070.9	39.8	-31.6	22.5	-40.1	17.3	8.5	25.8
SPAIN	4146.8	-2058.0	217.7	-68.4	157.4	-64.2	60.3	-4.2	56.1
FRANCE	1682.0	-4283.2	63.8	-96.7	51.9	-146.0	11.9	49.3	61.1
TOTAL	**6660.6**	**-7412.1**	**321.3**	**-196.7**	**231.8**	**-250.3**	**89.5**	**53.6**	**143.0**

Figure 4.5-1. Economic Results. Scenario 4, increment of interconnections

The highest benefits are delivered from this scenario. This demonstrates that an increment of interconnection capacity would double the benefits delivered from the implementation of this platform. Even though is Spain payment obligations are lower within this scenario due to the decrement of market prices, it is compensated by the considerable decrement in the amount pay for upwards activations.

This amount of benefits should be considered when determining a cost benefit analysis for the construction of new interconnection lines between France and Spain. Although the highest savings will be achieved in the day-ahead market, this amount has to be taken into account because this services represent also a cost for the system.

Under this possible environment market share are better distributed in each of the systems as represented in the chart below:

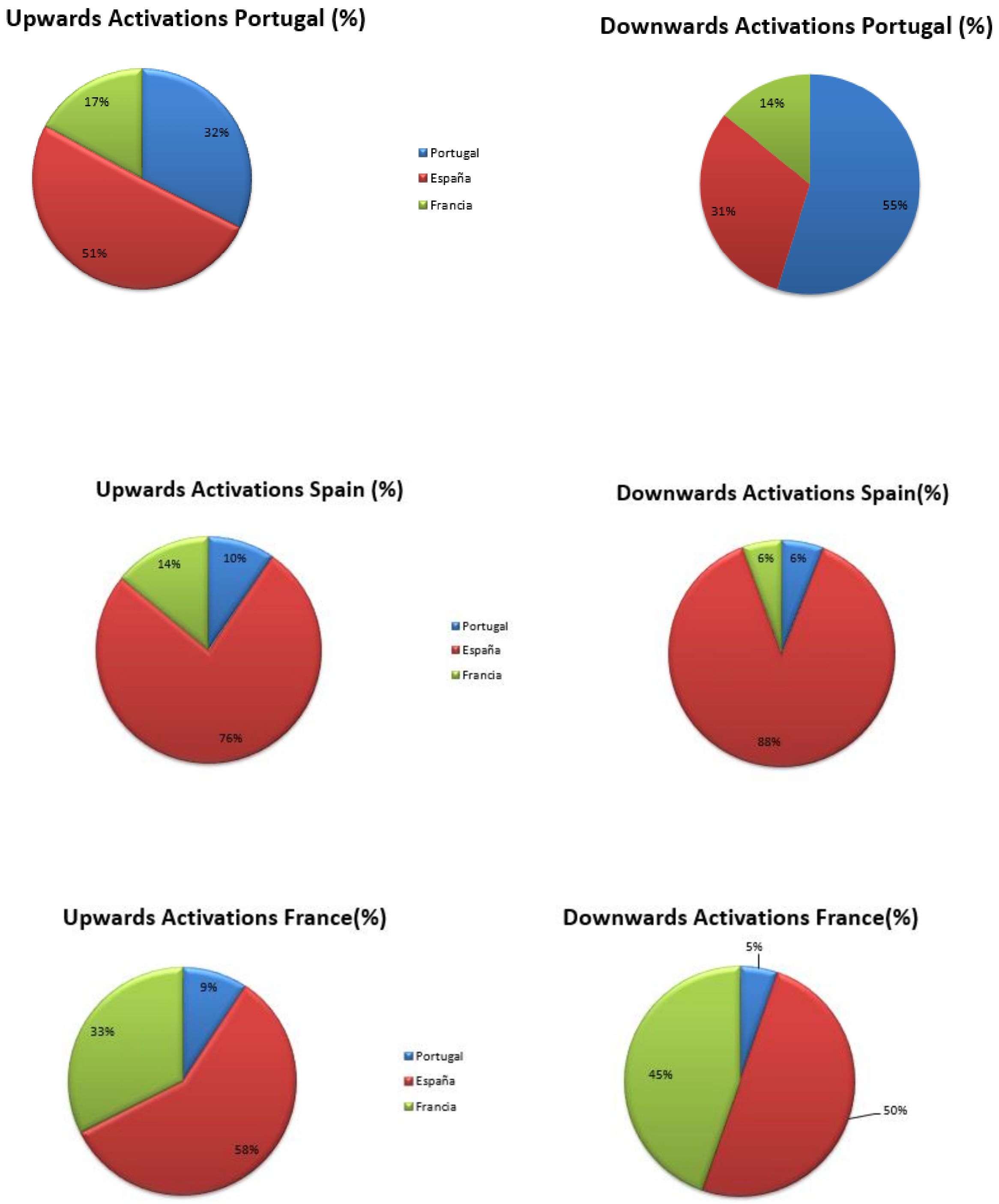

Figure 4.5-2. Upwards and downwards market share for Portugal, Spain and France in Scenario 4

Note that under this situation Spanish agents provide a large share of balancing energy. Probably in reality this affect would be softer as it is due the methodology applied for determining the bids of competitors. The size of the bid is the result of multiplying the pattern factor by the hourly imbalance needs, which accounts for a higher amount in the Spanish system.

4.6 Comparison of scenarios

Once all scenarios have been computed it is time now to make a qualitative and quantitative analysis in order to compare the results. Although the model is able to provide a large number of information (marginal prices, usage of interconnections, market share, congestions rents etc.) the analysis will be based on a comparison of total reduction in cost of the service, making a differentiation between upwards cost and downward payments.

			DEFAULT CASE YEAR 2017		RESPONSE BY AGENTS YEAR 2017		EQUALIZATION YEAR 2017		INCREMENT OF INTERCONNECTIONS YEAR 2017	
	Cost of upward activations (GWh)	**Payments of downward activations (GWh)**	**Benefits of upward activations (GWh)**	**Benefits of downward activations (GWh)**	**Benefits of upward activations (GWh)**	**Benefits of downward activations (GWh)**	**Benefits of upward activations (GWh)**	**Benefits of downward activations (GWh)**	**Benefits of upward activations (GWh)**	**Benefits of downward activations (GWh)**
PORTUGAL	39.8	-31.6	4.4	9.8	6.1	12.6	7.8	13.8	17.3	8.5
SPAIN	217.7	-68.4	1.0	0.1	3.7	0.6	23.3	4.9	60.3	-4.2
FRANCE	63.8	-96.7	2.7	0.5	3.1	0.8	4.9	1.0	11.9	49.3
TOTAL	**321.3**	**-196.8**	**8.2**	**10.3**	**12.9**	**14.0**	**36.0**	**19.6**	**89.5**	**53.6**

Figure 4.6-1. Aggregation of total benefits delivered from scenarios

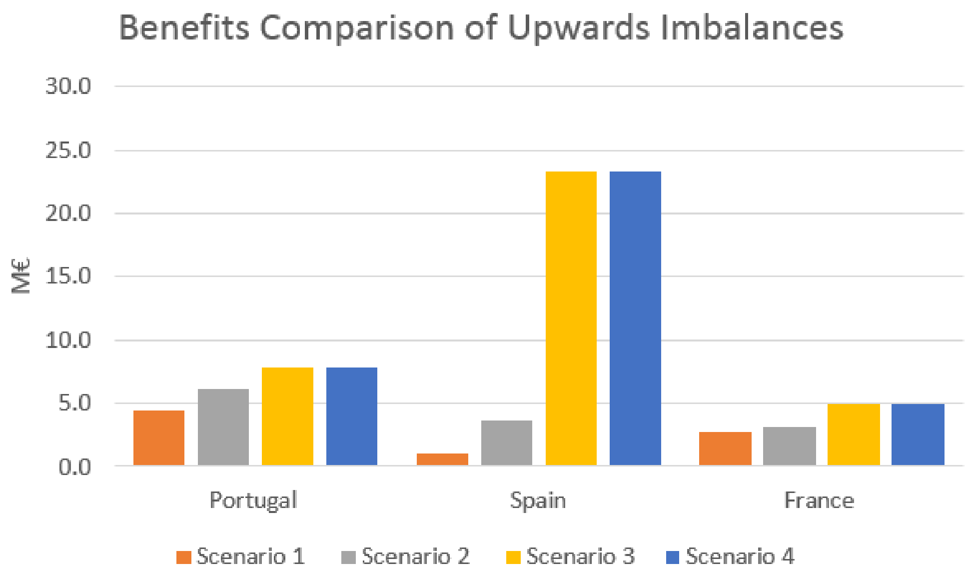

Figure 4.6-2. Economic Benefit comparison for upwards activations

It can be seen that in every county, the cost of satisfying the upwards imbalance needs is reduced with TERRE. This reduction in cost is traduced into benefits for the system, as now payments for agents are lower. Specially, this chart demonstrates that largest savings or benefits occurs when the capacity of interconnection lines is increased. Under this scenario, interconnection does not entail a barrier for the cross-border flows thus at every hour the cheapest offers can be allocated. Likewise, when a bigger number of participants are gather together into a single market the level of competition increased accordingly and therefore the total cost for the system. However, one should have in mind that this scenario has an intrinsic additional cost, which is are the investments needed to build new interconnection lines.

Regarding the other three scenarios, there is also a reduction in total cost for the system produced firstly by the share of capacity (cheaper bids) between countries and secondly due to the fact that agents have to adapt to this new environment, changing their initial strategies in order to be competitive against foreign agents.

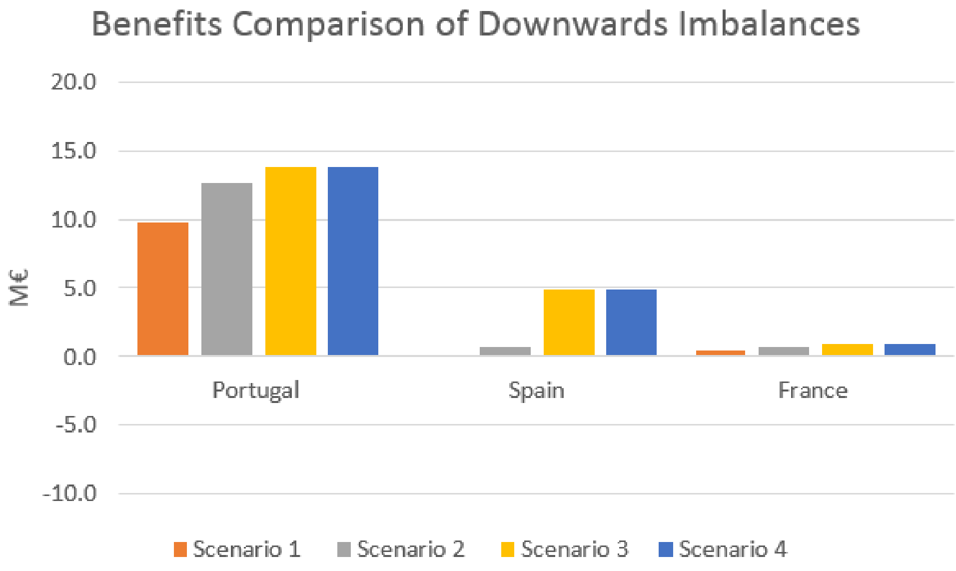

Figure 4.6-3. Economic benefit comparison for downwards activations

Figure above shows the total increment of payments that balancing agents have to pay to TSOs when they provide downward balancing energy. If TERRE was implemented an overall increment of these payments would be expected in most of the cases. Again, highest benefits occur if the last scenario when they interconnection capacity allows for the coupling of the three systems under study. Although it worth noticing that the third scenario entails a considerable benefit for the Spanish system as under the proposed situation Spanish are excepted of paying some additional cost attached to their production.

5. Conclusions

Throughout this Master's thesis a model for European cross-border exchange of balancing energy has been developed from scratch. The tool provides a considerable amount of information (marginal prices, quotas, cross-border flows…) in a reasonable running time. In spite of the initial assumptions and simplifications made at first stage, due to the initial complexity of the market, the results that the user can obtain from the model are realistic if one compares them with prices and volumes that Spanish, French and Portuguese markets are presenting nowadays.

Due to the fact that the model simulates a hypothetic balancing market which has not been implemented yet, it not possible to validate the results against real values. However the model has shown to be a flexible tool in the sense that some of the input values are left open in order to let analyst adapt them in the future in order to adjust the tool to reality.

Most of the weak points that have arisen during the design process, due to uncertainty reasons among others, have been identified and addressed successfully either by introducing some corrections or by leaving them open for future corrections once the real platform is implemented. In this regard, the designed market clearing algorithm has demonstrated to be robust enough to take into account at the same time cross-border constraints and economic efficiency which are the pillars the market under study.

The research and analysis carried out in order to obtain data about competiveness and volumes of imbalances needs in both French and Portuguese system was sufficiently accurate taking into account the resources available. The basic trends regarding imbalances needs volumes for each one of the three system are evident in the results provided by the tool.

The results delivered from the execution of several scenarios have demonstrated to be under the expectations. For example, an increment in the physical cross-border capacity or in the competitiveness of the agents has led to an increment in the economic benefits. This has a very important implication which is the flexibility of the tool to be adapted to future situations just by changing the input data.

Finally the model complies with all the requirements established for forecasting tools within the department. It provides relevant specific data about every power plant of Endesa that the user can look up in a friendly interface.

5.1 Future developments

Given that the tool simulates a European platform which has not been implement yet, uncertainty was presented in all the stages of the process. Consequently future developments have to be focus on substitute assumptions and simplifications with, if possible, real data more accurate considerations.

The following work is opened to be performed in the future:

1. Once the project comes a reality, introduction of priced TSO imbalance needs into the upwards and downwards bidding curves, based on real market data.
2. Development of a new market clearing algorithm in which upwards and downwards offers/imbalances needs meets together.
3. Introduction of netting imbalance and counter activations in the algorithm.
4. Once there is sufficient market data resulting from the implementation of TERRE, carrying out further studies and analysis in order to take into account the change of behavior in the model

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List of abbreviations

ACER: Agency for the Cooperation of Energy Regulators

BALIT: BALancing Inter TSO

ENTSO-E: European Network of Transmission System Operators for Electricity

FR: France

IIT: Instituto de Investigación Tecnológica

IN: Imbalance Needs

LPB: *Largo Plazo Banda*- Long-term (secondary regulation) Band

LPM: *Largo Plazo Mercado*- Long-term (Day-ahead) market

LPR: *Largo Plazo Restricciones*- Long-term constraints

LPRA: *Largo Plazo Reserva Adicional*- Long-term Additional Reserve

LPRM: *Largo Plazo Resto de Mercados*- Long-term other markets

P48: Hourly Operating Dispatch after horizon programming

PCR: Price Coupling of Regions

PDBC: *Programa Diario Base de Casación* – Base Clearing Daily Program.

PDBF: *Programa Diario Base de Funcionamiento* – Base Functioning Daily Program.

PDVD: *Programa Diario Viable Definitivo* – Final Feasible Daily Program.

PDVP: *Programa Diario Viable Provisional* – Provisional Feasible Daily Program.

PHF: Programa Horario de Funcionamiento – Functioning Hourly Program

PMD: Precio Mercado Diario (*Daily-ahead market Price*)

PT: Portugal

REE: Red Eléctrica de España

REN: Redes Energéticas Nacionais

RR: Replacement Reserves

RTE: Le Réseau de Transport d’électricité

SP: Spain

TERRE: Trans-European Replacement Reserves Exchanges

TSO: Transmission System Operator

UOF: *Unidad de oferta-* Offer unit