UNIVERSIDAD PONTIFICIA COMILLAS

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

OFFICIAL MASTER'S DEGREE IN THE
ELECTRIC POWER INDUSTRY

Master's Thesis

CROSS BORDER BALANCING ENERGY EXCHANGE: ANALYSIS OF A MARKET DESIGN BASED ON OPTIMIZATION

Author: **Antonio Useros García**

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Madrid, January 2015

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SUMMARY

The integration of balancing markets has been identified as a key process to achieve a true Internal Energy Market, which in turn is essential to attain the European Union energy policy objectives: security of supply, sustainability and competitiveness.

It is not easy indeed, since, the closer to real time in electric systems operation, the more differences there are in the approaches and criteria used in the existing market-based mechanisms.

On the grounds of the target model that ACER, in its Framework Guidelines on Electricity Balancing, and ENTSO-E, in its corresponding ongoing Network Code, have developed on the matter, i.e. a TSO-TSO model with a common merit order list, the goal of this work is: to design a regional market for balancing energy procurement based on optimization techniques for its clearing; to implement the design on a platform to run simulations; and to analyze its performance with respect to the available transmission capacity in the interconnections and the bidding rule.

The standardization of the balancing product, the definition of the optimization problem objective function and constraints, the pricing methodology and settlement rules, and the link and impact of this regional market on the national ones, are the design key elements.

A regional mechanism that reflects the real costs of the purchased balancing energy and means an incentive to the market players to be balanced, focused on balancing services while putting aside commercial transactions, and in which exchanges follow the economic signals, along with a sound mathematical formulation, are the underlying principles all over the model.

Several simulations reveal the importance of the interconnections in this market integration process and the necessity to remove barriers preventing energy to freely flow; as well as the advisability of adopting of a common merit order list, sharing all the available balancing resources in the region, to get efficient results.

RESUMEN

La integración de los mercados de servicios de balance ha sido identificada como uno de los elementos clave para la creación de un verdadero Mercado Interior de la Energía, lo que a su vez es imprescindible para alcanzar los objetivos de la Unión Europea en política energética: seguridad de suministro, sostenibilidad y competitividad.

No es tarea fácil, puesto que, cuanto más cerca del tiempo real en la operación de sistemas eléctricos, más diferencias existen en los enfoques y criterios utilizados en los mecanismos de mercado existentes.

Tomando como base el modelo que a este respecto han desarrollado ACER, en su Framework Guidelines on Electricity Balancing, y ENTSO-E, en el correspondiente Network Code en curso, es decir, un modelo TSO-TSO con orden de mérito común, el propósito de este trabajo es: diseñar un mercado regional para el intercambio de energía de balance basado en técnicas de optimización para la asignación de ofertas; implementar el diseño en una plataforma que permita hacer simulaciones; y analizar su comportamiento con respecto a la capacidad de intercambio disponible en las interconexiones y a la forma en que se comparten los recursos de balance.

La definición de un producto de balance estandarizado, de la función objetivo y restricciones del problema de optimización, de la metodología empleada para la formación de precios y liquidación, y la unión de este mercado regional con los correspondientes mercados nacionales, son las piezas angulares del diseño.

Un mecanismo regional que refleje los costes reales incurridos en la adquisición de energía de balance, que proporcione incentivos a los agentes para mantener sus programas, que se centre en servicios de balance y deje al margen transacciones comerciales, y en el que los intercambios sigan las señales económicas, junto con una sólida formulación matemática, son los principios que subyacen en todo el modelo.

Diversas simulaciones ponen de manifiesto la importancia de las interconexiones para una integración real de mercados y la necesidad de eliminar barreras a la circulación de energía; así como la conveniencia de implementar un orden de mérito común, mediante el que se compartan todos los recursos disponibles en la región, para obtener resultados eficientes.

CONTENTS

CHAPTER 1
INTRODUCTION

It is well-known that electricity cannot be stored, at least, on a large —national system— scale. That is why generation must continuously equal demand. This feature has a huge impact both in the technical and economical management of electric power systems, being TSOs responsible for keeping this balance between injections and withdrawals through the procurement of the so-called balancing services, namely:

- Capacity [MW] —also known as reserves. Ahead of real time, TSOs gain access to power capacity.

- Balancing energy [MWh]. Close to and in real time, energy is activated form these reserves and/or other available resources for TSOs to balance the system.

In the realm of electrical engineering, i.e. from a technical perspective, this process is known as P-f control, through which TSOs maintain the system frequency within a predefined range. All these actions and processes, lying at the core of system operation, define the balancing function, absolutely essential for a due electricity supply.

These two services are purchased by means of market-based mechanisms, bilateral contracts or legal obligations.

Moreover, the regional integration[1] of national balancing markets is regarded at European level as a priority task to achieve a well-functioning Internal Energy Market, a necessary step to attain the European Union energy policy goals: security of supply, sustainability and competitiveness.

These are the general frame of this master thesis and the motives to focus on cross border balancing energy exchange, a quite hot issue in many international fora.

The work revolves around the proposed ACER and ENTSO-E target model in the long term. Taking it as the starting point, the objective is to design a regional market for manually-activated balancing energy procurement based on optimization techniques for its clearing, providing all the assumptions and rules, and implement it on a platform which allows simulating its behavior and analyzing its performance with respect to the available transmission capacity[2] among systems and bidding rule.

The region studied comprises Portugal, Spain, France and Great Britain. Neither the data about offers, requirements, margins, reference price and available transmission capacity

[1] To be integrated means physically sufficiently interconnected and under a harmonized regulatory framework.
[2] Another present topic very frequently discussed in the newspapers nowadays.

nor the obtained results are real, they are only simulations. Nevertheless, they reflect their usual order of magnitude.

After this introduction, chapter 2 briefly describes the balancing energy markets in the Spanish system to know a little bit better one of these national mechanisms to be integrated; chapter 3 introduces the European framework, mainly, the legal ground, institutional positions and current similarities and differences all over Europe regarding balancing services and interconnection capacity; chapter 4 outlines the existing mechanism in place for cross border balancing energy exchange between Portugal, Spain and France —i.e. southwest Europe region or SWE—; chapter 5, the heart of the document, fully develops the core of the work, detailing the market design, its mathematical formulation and its performance; and chapter 6 gathers the conclusions and suggests some topics to continue this research.

The references and appendices —they include a glossary of terms[3]— are at the end of the document.

As in life itself, an important part of the learning process when developing a work like this is to make mistakes, realized about that, understand the reason why and find a solution, being careful not to fail again. With the aim of showing, not only the final result, but also these valuable underlying confusions, the document incorporates some grey boxes to separately explain them.

Finally, it should be borne in mind that this is a little piece of work in the immensity of the electric power industry about a very particular issue. When putting it down, the purpose was to be simple and clear and get straight to the point; therefore, the document neither explains all the necessary basic concepts, assuming they are known, nor considers all the opinions, models or theories about the topic.

[3] It is advisable to quickly go through this glossary of terms before continuing reading to be familiar with the more important meanings.

CHAPTER 2
BALANCING ENERGY MARKETS IN THE SPANISH SYSTEM

The 1st of January of 1998 came into force a new regulatory framework for the generation business, liberalizing this activity by means of a wholesale market open to competition [MIE_97].

This market for power encompasses: forward market, day-ahead market, bilateral contracts —over the counter—, intraday market and system adjustment services, which in turn includes, the resolution of the supply guarantee and technical constraints, and the ancillary services.

The ancillary services, needed to ensure power supply with the required conditions of safety, quality and reliability, are:

- Additional upward power reserve.
- Regulation and balancing services: primary reserve, secondary reserve and tertiary balancing energy.
- Deviation management: slow balancing energy.
- Voltage control.
- Black start service.

Economically, system adjustment services markets have little influence on the final consumer electricity price; however, they are indispensable to guarantee both security and quality of power supply.

Since this work deals with balancing energy purchased through market-based mechanisms, it focuses, from the Spanish system point of view, on tertiary regulation and deviation management.

2.1 TERTIARY REGULATION (ENERGY MARKET)

Tertiary reserve is the maximum variation of power that a generation or pump storage unit is able to carry out within a maximum of 15 minutes dynamic time response and to maintain for, at least, 2 consecutive hours.

This chapter is mainly based on [REE_12]

Its objective is the recovery of the secondary regulation reserve that has been used and the solution to the short term imbalances between generation and demand within up to 1 hour time frames.

It is an optional and remunerated ancillary service. It is mandatory to bid all the upward and downward tertiary capability for those units licensed to provide this service. The market is called for every hour by the system operator and the allocation mechanism uses a minimum cost criterion. Its settlement is based on marginal pricing.

Tertiary regulation reserve is manually-activated, respecting all the limitations established for system security reasons and the unavailability of generation plants and pump storage units communicated to the system operator by the responsible market players. The associated energy re-dispatches do not necessarily cover the whole hourly scheduling period, i.e. it can be allocated and unallocated.

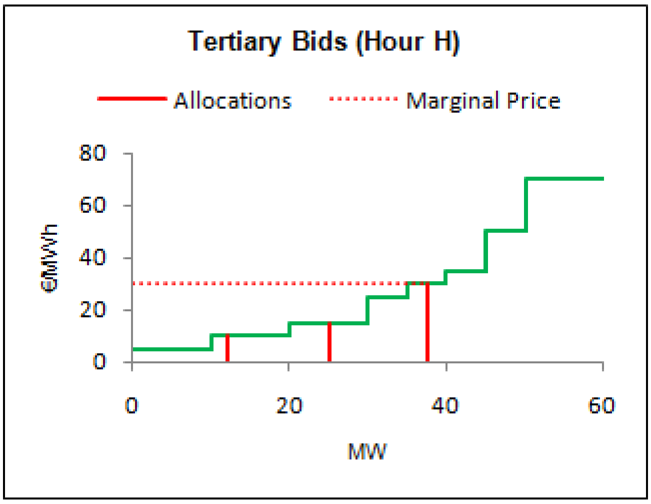

Figure 2.1 – Tertiary allocation

All the details about this tertiary regulation energy market can be found in [MIET14].

2.2 DEVIATION MANAGEMENT (ENERGY MARKET)

Its objective is 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 time frame. The deviation management mechanism is a link between intraday markets and tertiary regulation, providing the system operator with a service managed through a competitive market-based mechanism and with more flexibility to solve imbalances that could be identified after the last intraday market gate closure.

Thus, deviations are communicated and/or predicted for the time frame until the next intraday market session and, in case of identifying deviations above 300 MWh —positive or negative— with a duration of several hours, the system operator calls a deviation management market session. This service is slower than tertiary regulation, its dynamic time response ranges from 15 to 30 minutes. The associated energy re-dispatches do cover the whole hourly scheduling period, therefore, it is less flexible than tertiary regulation.

The allocation is based on the upward and downward bids of licensed —for this specific market— generation plants and pump storage units presented in the corresponding session. Settlement is done according to the marginal pricing criterion.

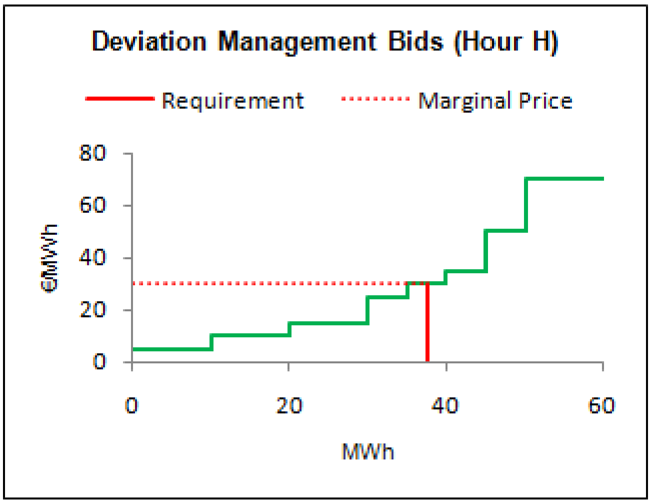

Figure 2.2 – Deviation management allocation

All the details about this deviation management energy market can be found in [MITC09].

2.3 EQUIVALENCE TO ACER AND ENTSO-E NAMES

Hereafter, to easily associate the foregoing balancing products names with those used in ACER Framework Guidelines and ENTSO-E Network Codes —in their attempt to unify the nomenclature too—, the next table indicates the equivalence.

SPANISH SYSTEM	ACER | ENTSO-E
Primary reserve	Frequency containment reserve —FCR—
Secondary reserve	Frequency restoration reserve —automatic, FRRa—
Tertiary balancing energy	Frequency restoration reserve —manual, FRRm—
Tertiary balancing energy Deviation management	Replacement reserve —RR—

Table 2.1 – Spanish system names equivalence to ACER | ENTSO-E nomenclature

CHAPTER 3
THE EUROPEAN UNION FRAMEWORK

The third legislative energy package of the European Commission champions the integration of national electricity markets and the regional cooperation of incumbent institutions as a way to attain a well-functioning European Internal Energy Market, a necessary step to achieve the European Union energy policy objectives: security of supply, sustainability and competitiveness [EPCO09] [EPCO09_1].

Furthermore, the lack of integration of balancing markets was identified as a key impediment to the development of a single European electricity market. In January 2007, the European Commission published its energy sector inquiry[1], which stressed the fact that balancing energy and reserve markets are highly concentrated, concluding among other things that: "*Concentration in balancing markets could be reduced if the geographical size of control areas was enlarged. Harmonization of balancing markets regime would be an important step to increase the size of control areas, improve market integration and simplify trade"* [ERGE09].

This integration will promote efficient and competitive price formation and market liquidity besides the following benefits:

- Provide TSOs with access both to a more diversified generation technology mix and further opportunities to offset net deficit and surplus generation positions, thereby helping them to lower the total amount of necessary reserves and achieving more efficient utilization of balancing resources.

- Increase competitiveness so that the exercise of market power is reduced. In this regard, the aforementioned energy sector inquiry emphasized the fact that "*balancing markets are generally national in scope (or smaller)*" and "*are highly concentrated, which gives generators scope for exercising market power*".

- Contribute to the sharing of reserves and the reduction of the risk of supply outages since each TSO will be able to purchase balancing energy from neighboring TSOs in a market-based way.

3.1 INSTITUTIONAL POSITION

Pursuant to article 6(2) of Regulation (EC) No. 714/2009, ACER developed and finally adopted in September 2012 the Framework Guidelines on Electricity Balancing, which aims at setting out clear and objective principles for the development of network codes [ACER12].

[1] COM(2006)851 final, 10 January 2007.

These Framework Guidelines will strive for integration, coordination and harmonization of the balancing regimes in order to facilitate electricity purchase within the European Union in compliance with the third energy package. They specifically address the roles and responsibilities of stakeholders involved in electricity balancing, the procurement of frequency restoration reserves and replacement reserves, the activation of balancing energy from frequency restoration reserves and replacement reserves, and the imbalance settlement.

The core element of the Framework Guidelines are the models for cross border exchanges of balancing energy that should first emerge in different geographical areas and gradually be integrated into one European platform where all TSOs would have access to different types of balancing energy while taking into account the transmission capacities available between different areas.

In this regard, and focusing on cross border exchanges of balancing energy from replacement reserves and manually-activated frequency restoration reserves, ACER proposes a multilateral TSO-TSO model with common merit order list, making use of the available transmission capacity after the intraday cross border gate closure time. In this model, TSOs share their balancing resources and optimize their activation in order to minimize the cost of balancing by gathering upwards and downwards balancing offers, that have submitted by balancing services providers —BSPs— in their control areas, into a common list and activate them according to the common merit order list, taking into account technical constraints and operational security limits, including the availability of transmission capacity. Access of balancing offers to the common list and their activation shall be non-discriminatory, fair, objective and transparent.

With respect to balance responsibility and imbalance settlement, balance responsible parties —BRPs— shall have the right incentives to manage their own balance close to real time. Therefore, imbalances shall be settled at a price that provides incentives to BRPs to support the system’s balance in an efficient way and/or to balance their portfolio before real time actions are necessary from the TSOs, and reflects the costs of balancing the system in real time. Imbalance pricing shall at least include the costs of activated balancing energy —from FRR and RR— in the imbalance settlement period.

The Network Code on Electricity Balancing[2] shall set the minimum standards and requirements needed for a competitive, harmonized and effective European Union wide balancing market, concerning cross border and market integration issues. In particular, it shall define the necessary level of harmonization of the varying national balancing regime design elements, in order to foster European balancing market integration [ENTS14].

[2] Currently it is pending ACER's recommendation to the European Commission for adoption of the code. It will then progress through the Comitology process, through which it should become European law.

3.2 ANCILLARY SERVICES PROCUREMENT AND BALANCING MARKETS DESING

The following figures graphically illustrate an overview of the different market arrangements in place throughout Europe related to ancillary services procurement and balancing markets design. The maps show how various approaches have been taken to implement national mechanisms.

While most of these arrangements can be harmonised to a certain degree, some differences appear to be inherent to dissimilarities in the balancing resources available in each Member State [ENTS14_1].

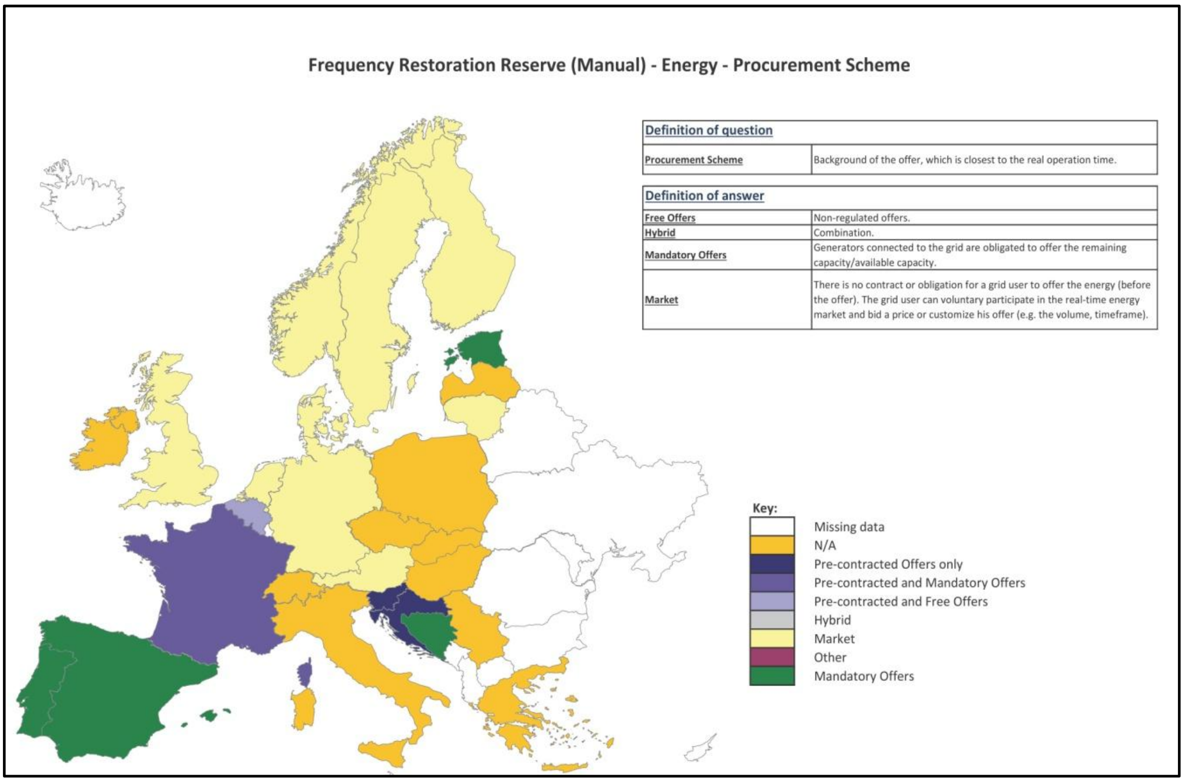

Figure 3.1 – FRRm – Energy – Procurement scheme

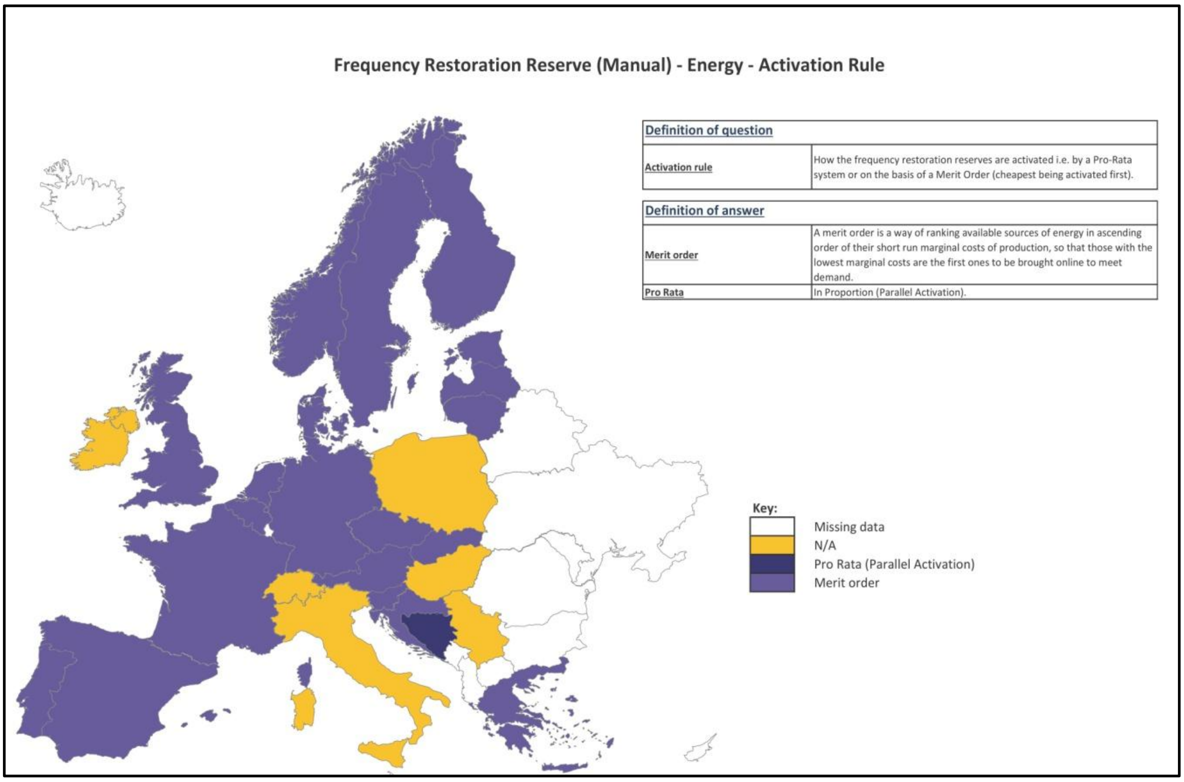

Figure 3.2 – FRRm – Energy – Activation rule

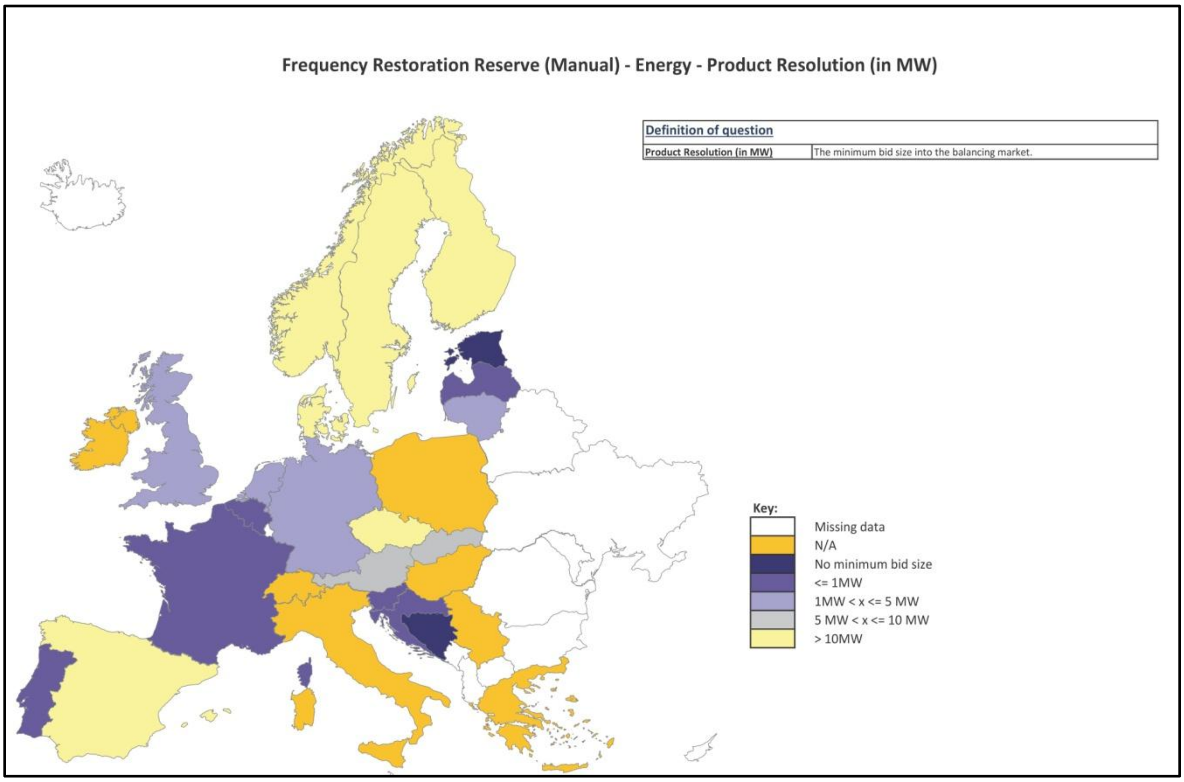

Figure 3.3 – FRRm – Energy – Product resolution in MW

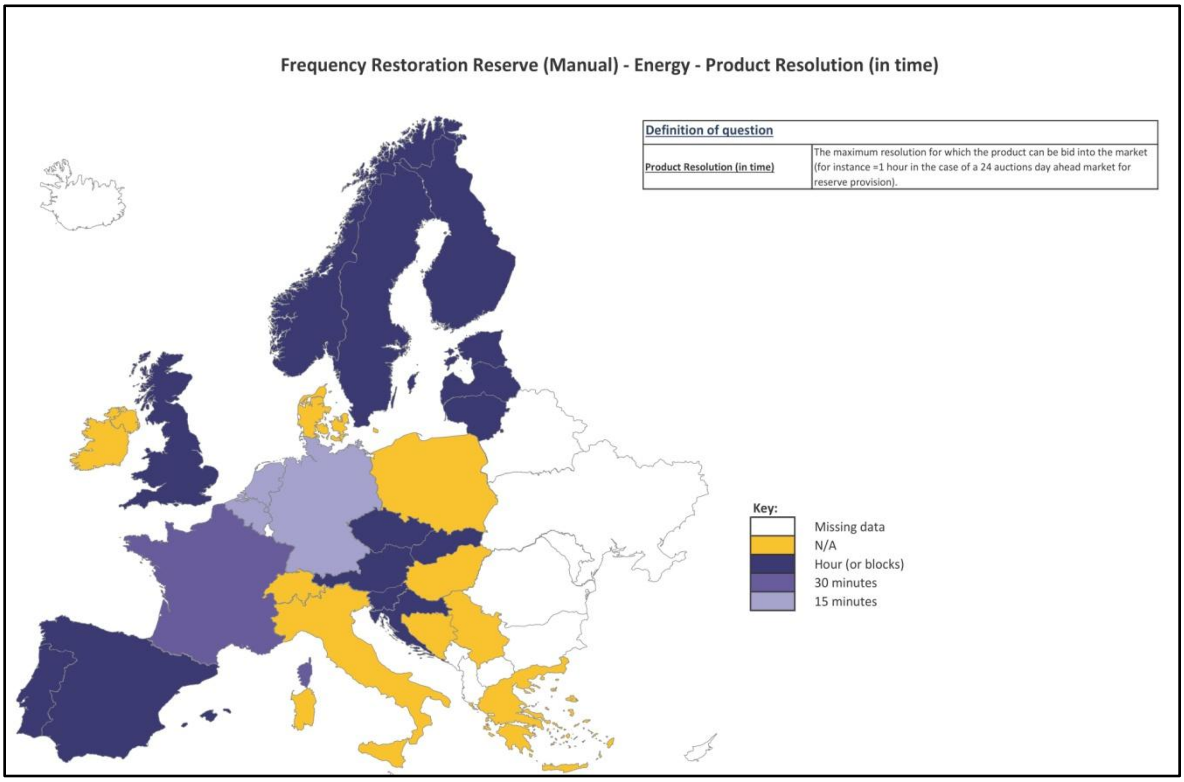

Figure 3.4 – FRRm – Energy – Product resolution in time

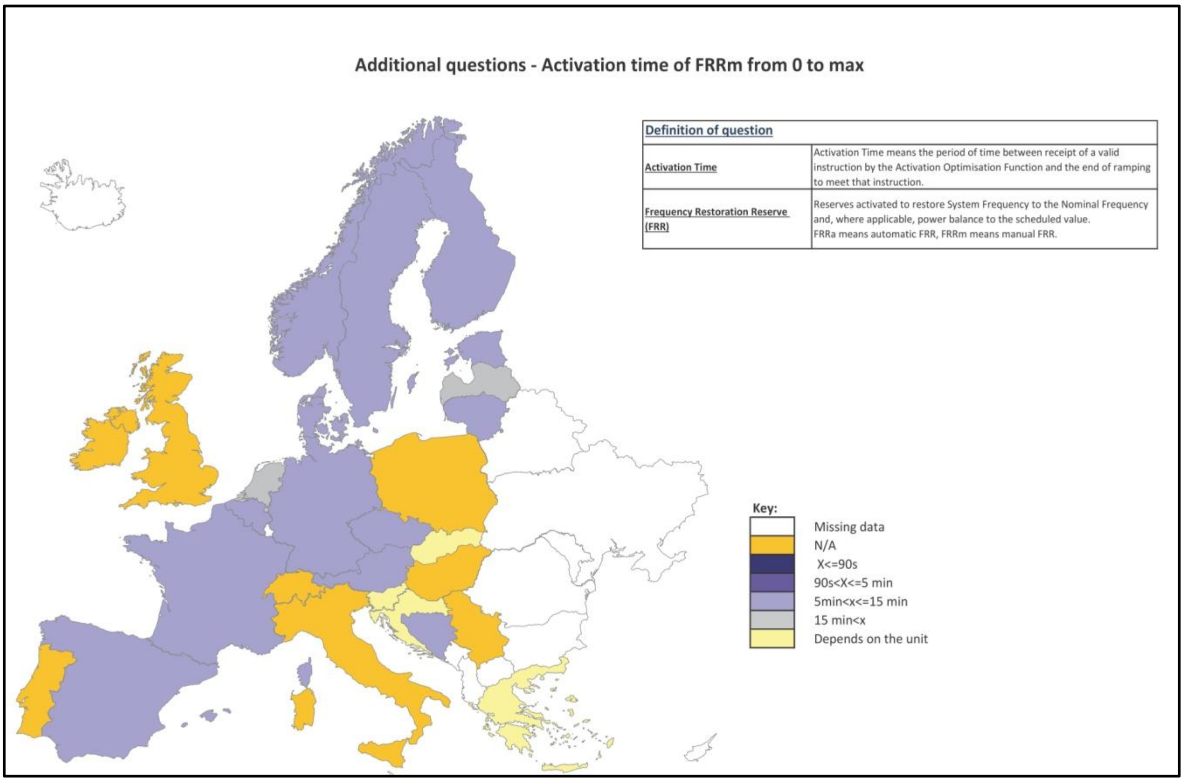

Figure 3.5 – Activation time of FRRm from 0 to max

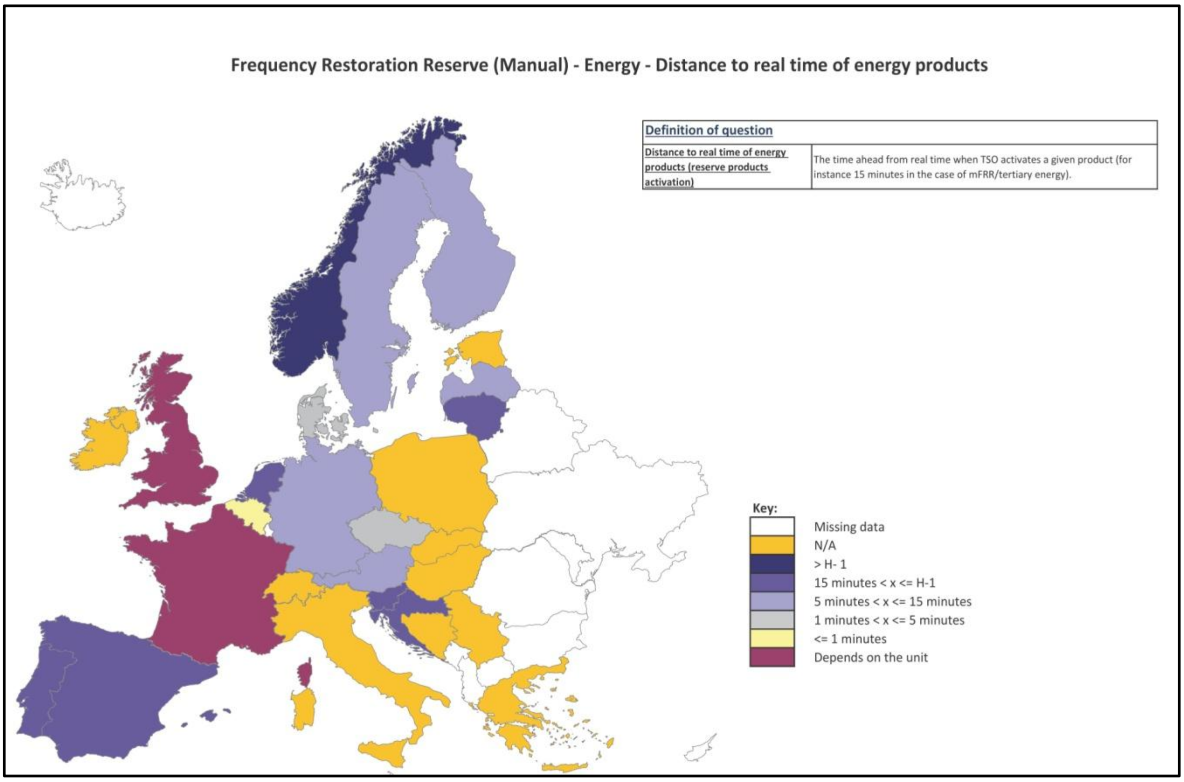

Figure 3.6 – FRRm – Energy – Distance to real time of energy products

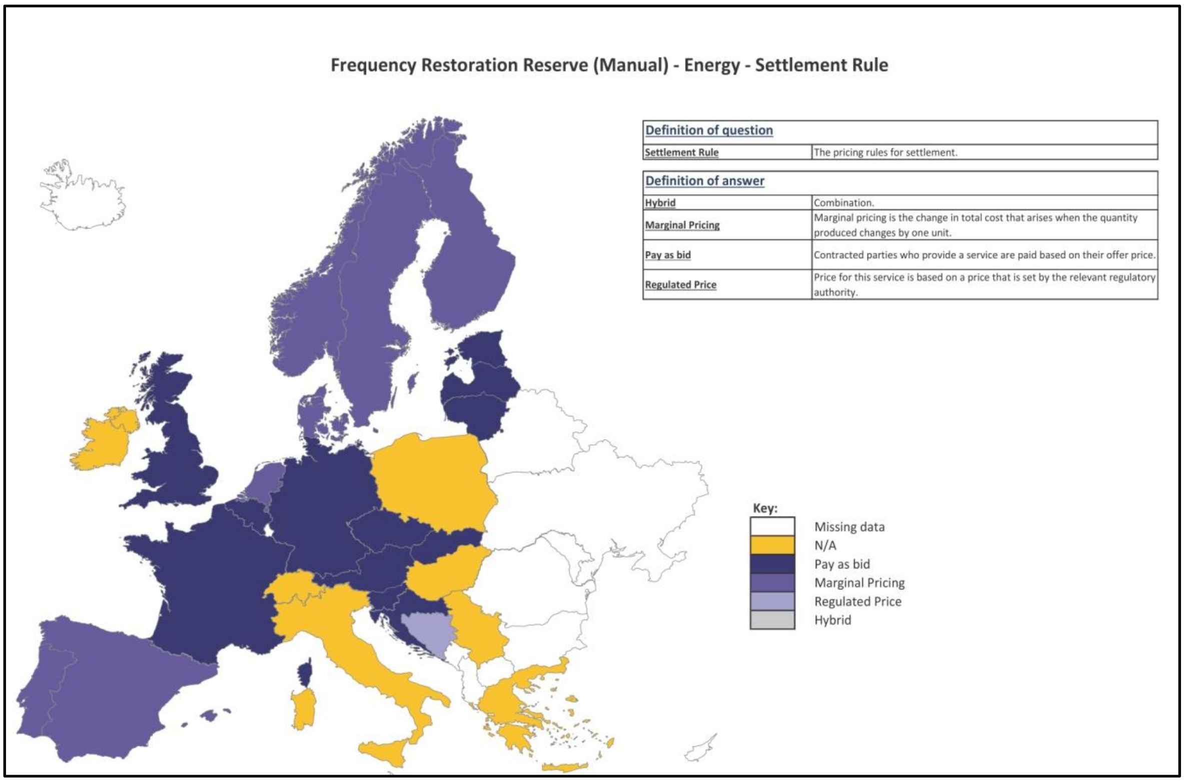

Figure 3.7 – FRRm – Energy – Settlement rule

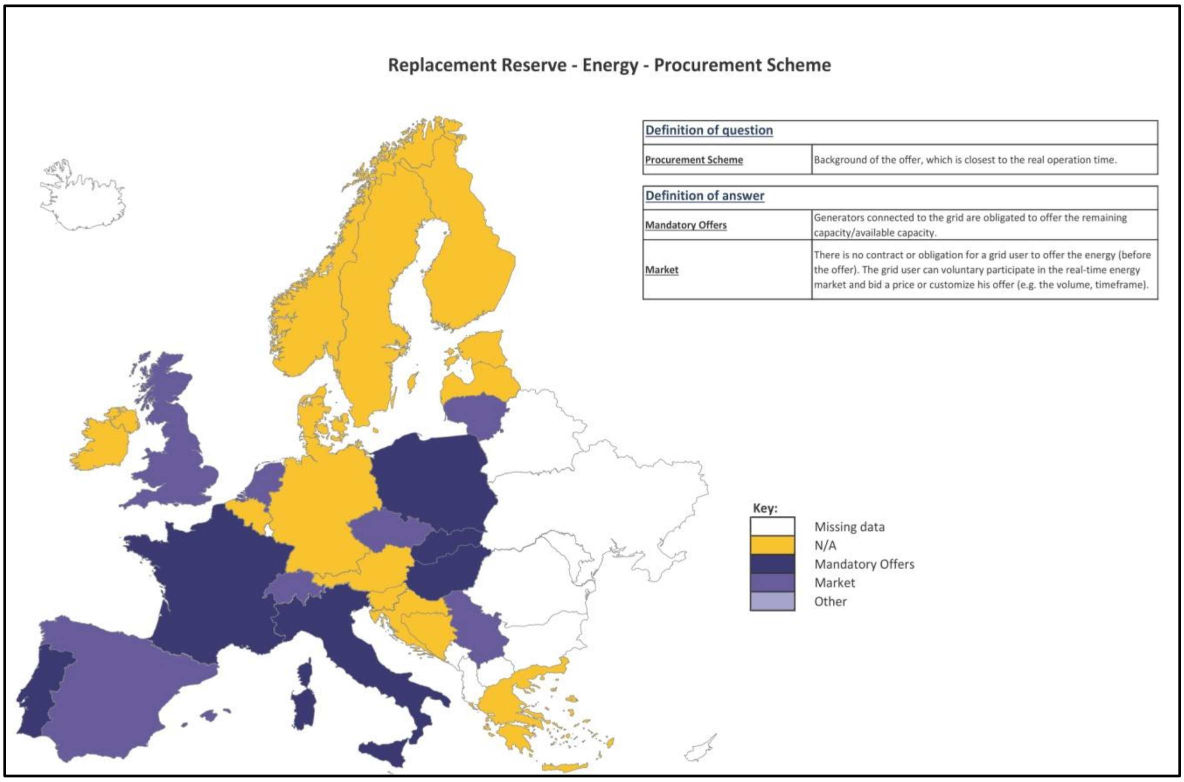

Figure 3.8 – RR – Energy – Procurement scheme

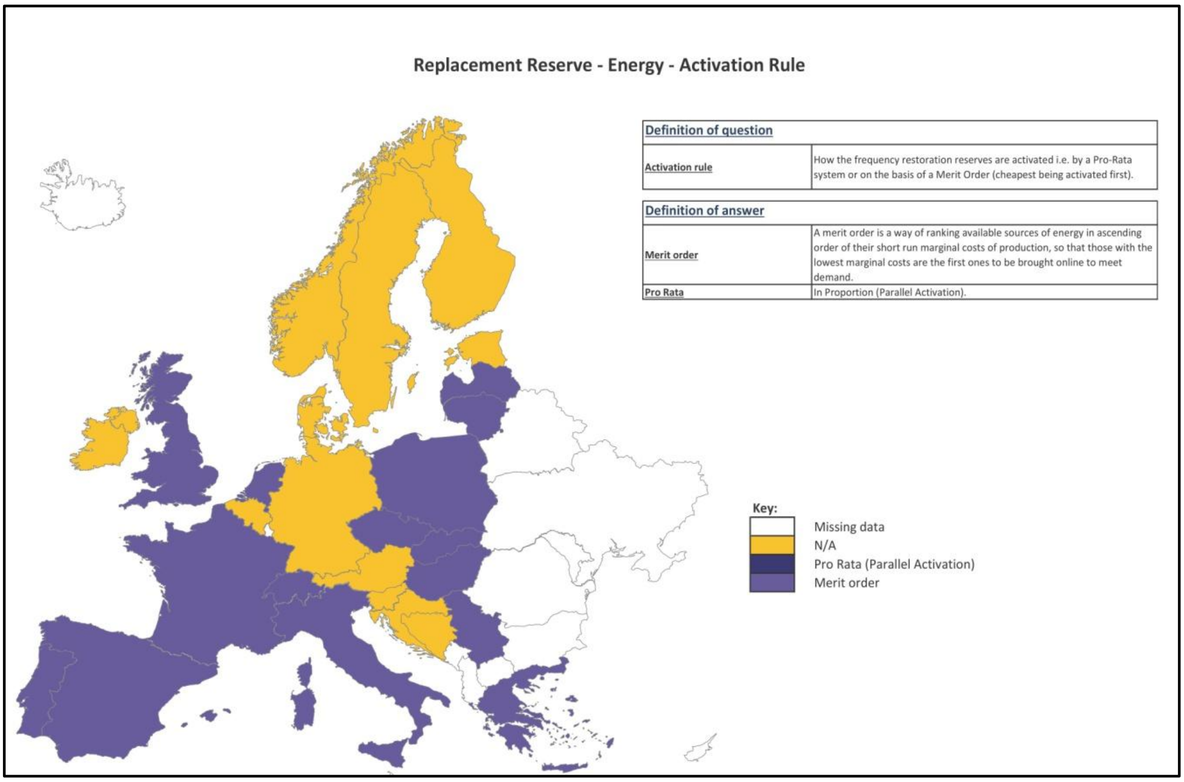

Figure 3.9 – RR – Energy – Activation rule

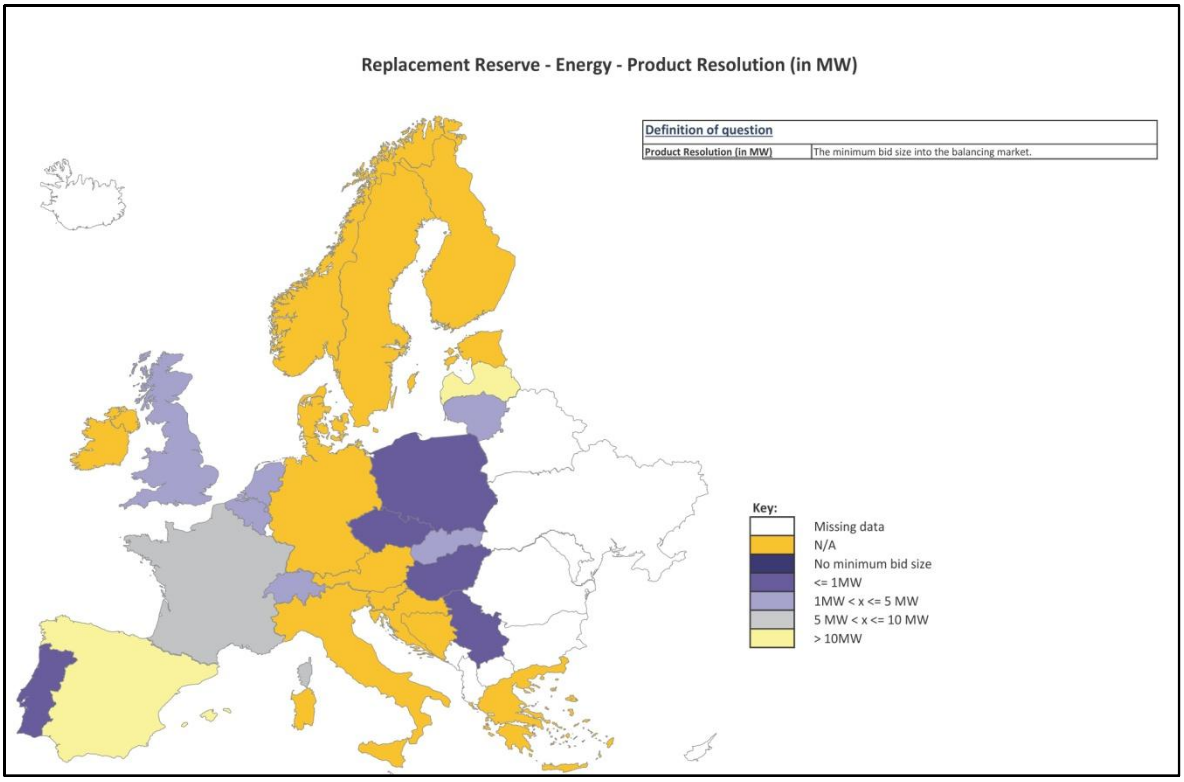

Figure 3.10 – RR – Energy – Product resolution in MW

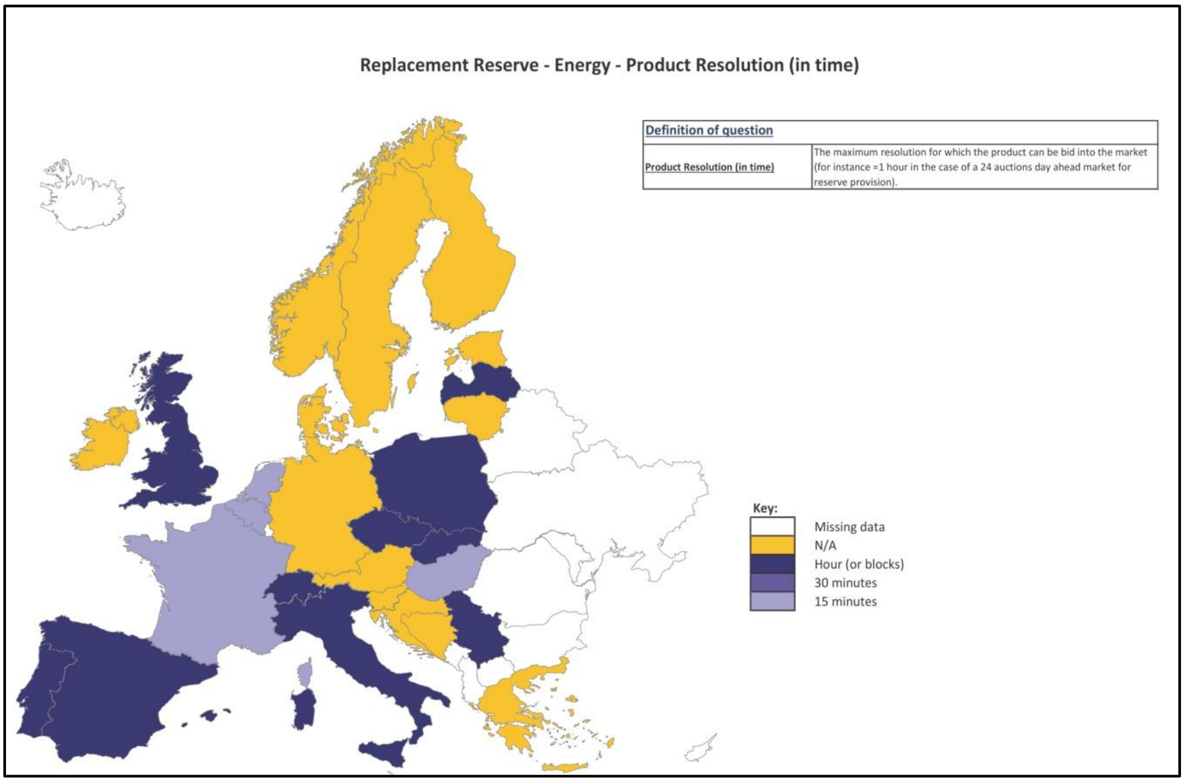

Figure 3.11 – RR – Energy – Product resolution in time

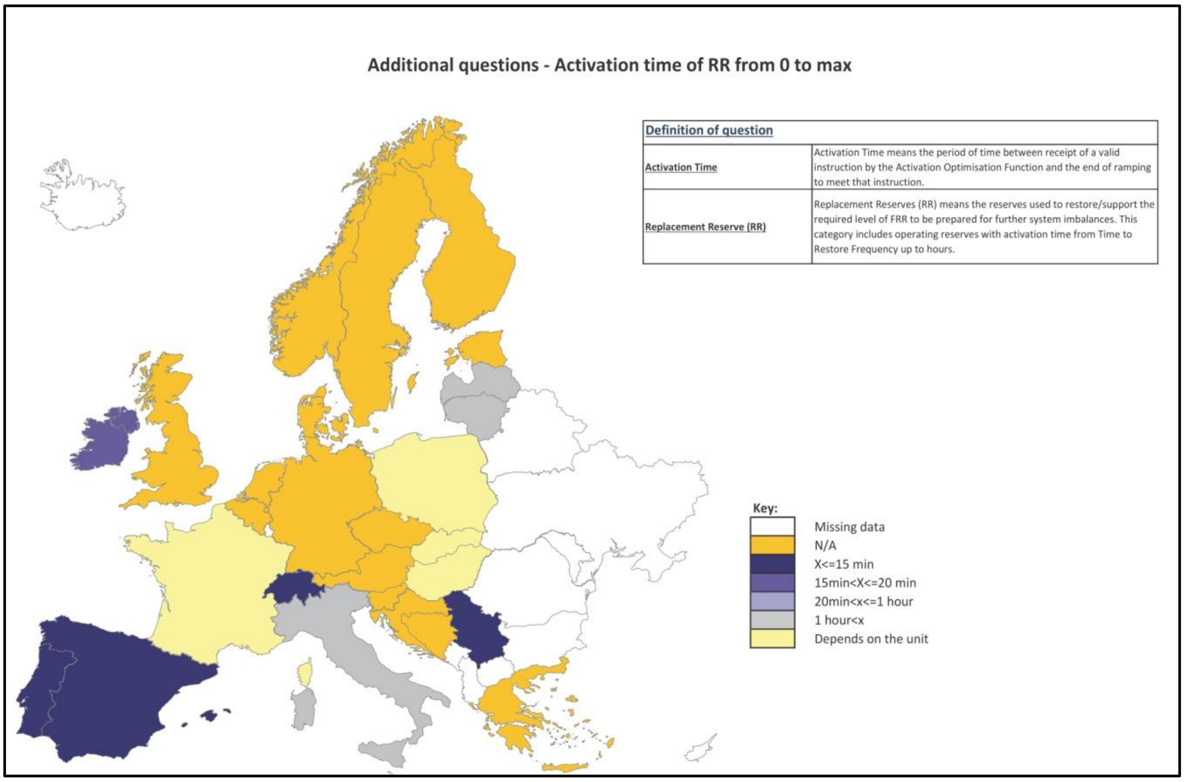

Figure 3.12 – Activation time of RR from 0 to max

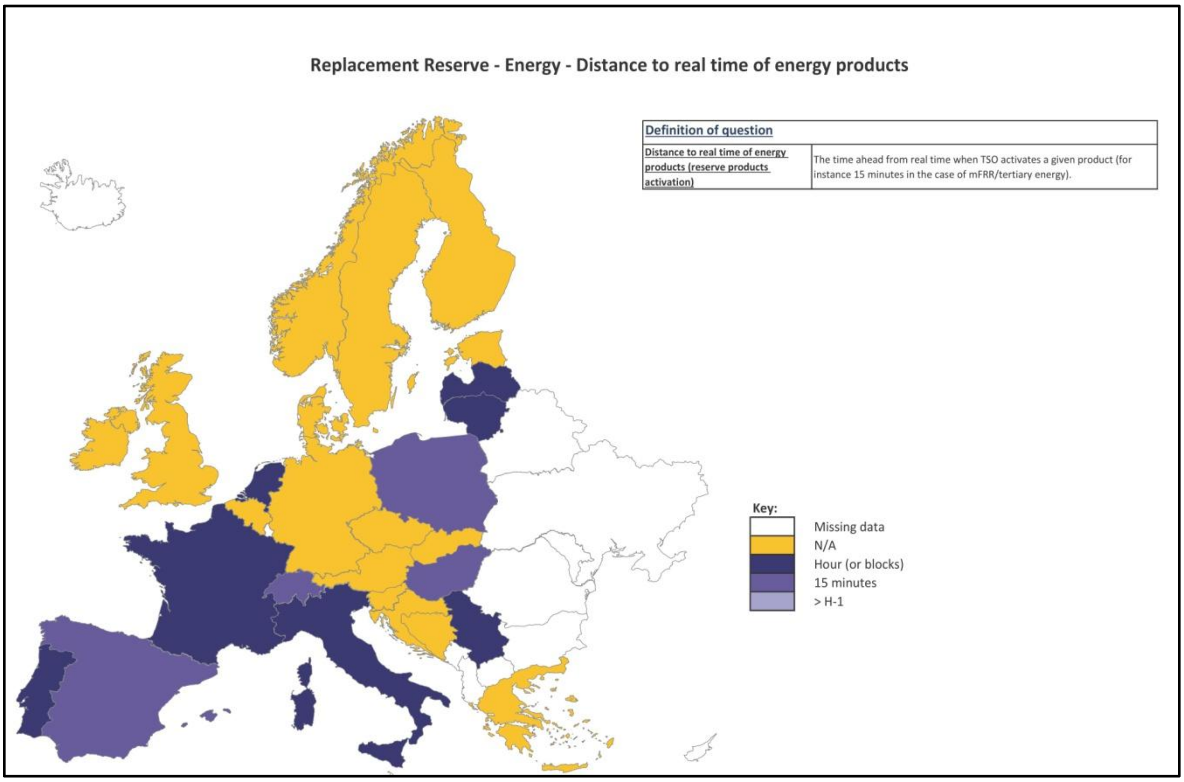

Figure 3.13 – RR – Energy – Distance to real time of energy products

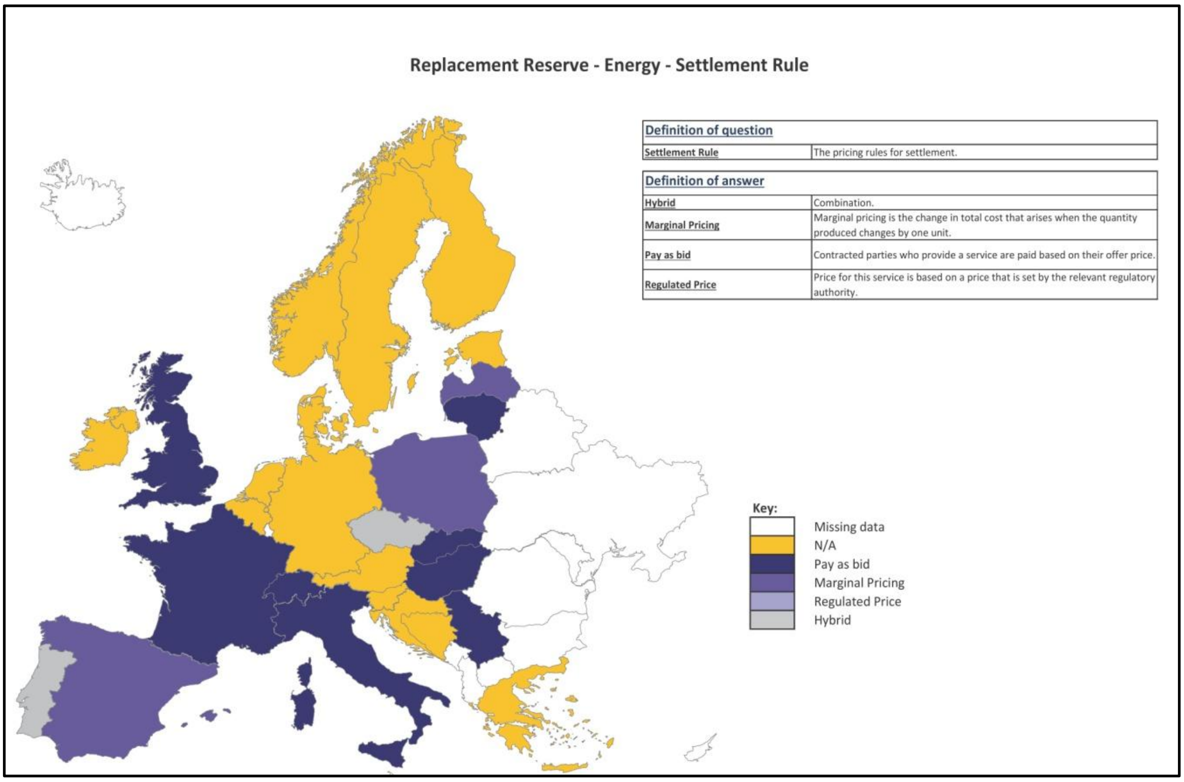

Figure 3.14 – RR – Energy – Settlement rule

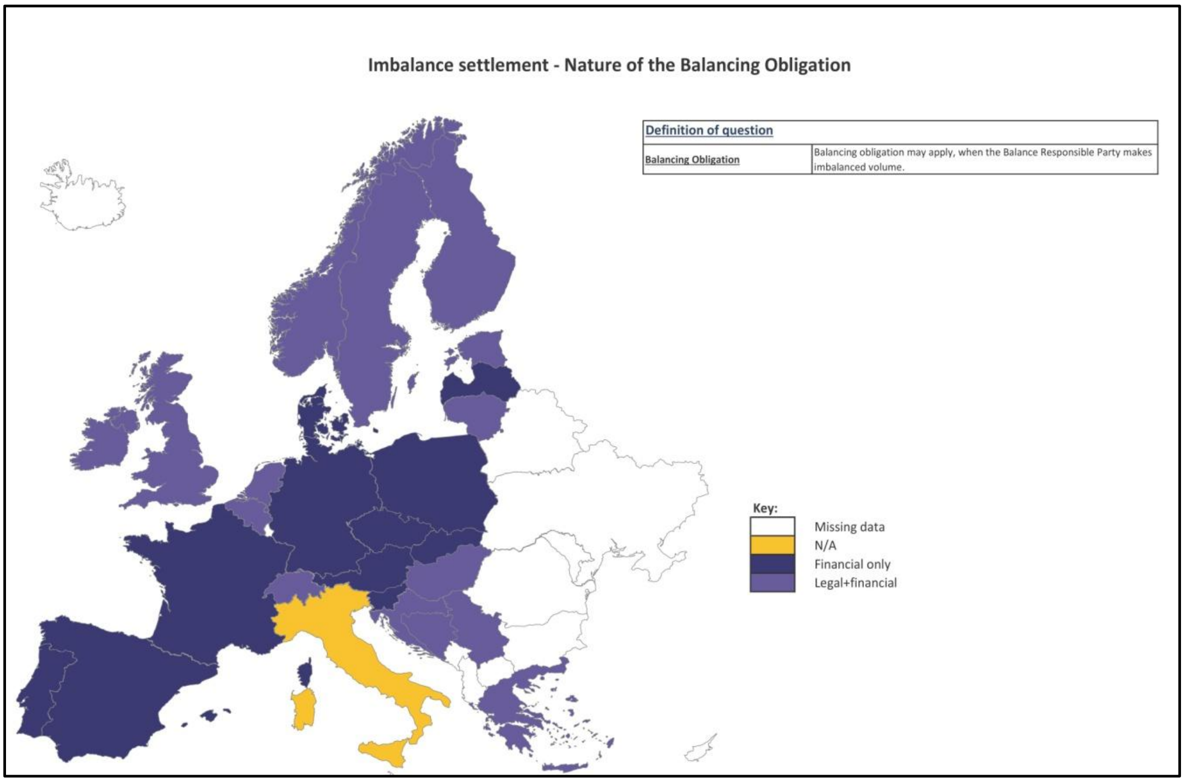

Figure 3.15 – Imbalance settlement – Nature of the balancing obligation

3.3 INTERCONNECTIONS

Due to its relevance in this process of balancing markets integration, it is convenient to give an idea of the current state of the interconnections between systems throughout Europe having a quick look to the next picture [ENTS14_2].

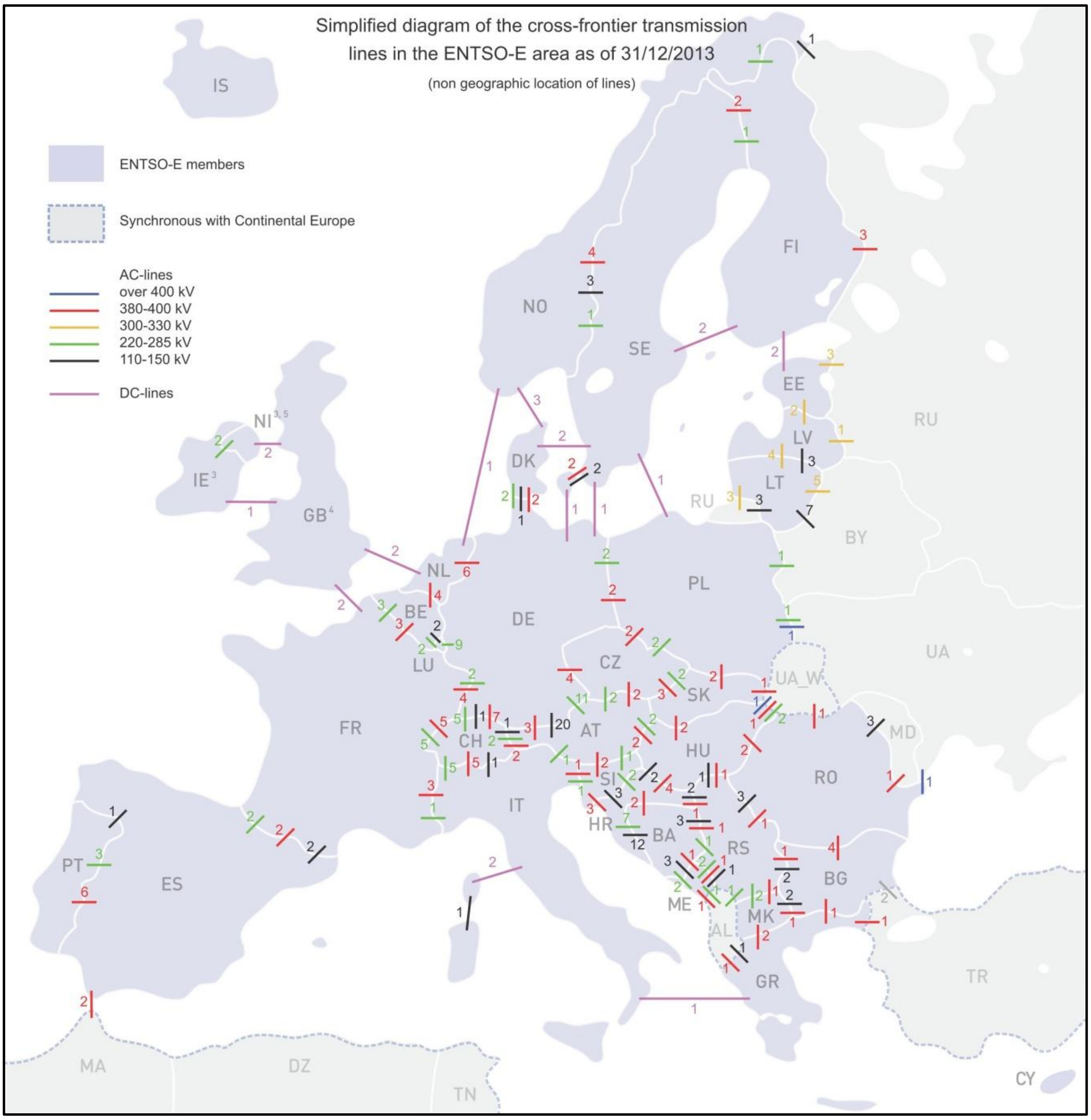

Figure 3.16 – Simplified diagram of tie lines

3.4 ONGOING PROJECTS ON CROSS BORDER ELECTRICITY BALANCING

Currently, there are eight pilot projects on cross border electricity balancing under development all over Europe [ENTS14_3][3]:

1. Common merit order for FRRm and FRRa with real time flow-based congestion management.
2. Cross border market for FCR based on a TSO-TSO model.
3. E-GCC
4. Trans-European Replacement Reserves Exchange —TERRE.
5. Development of the Nordic RPM.
7. Design and evaluation of a harmonized reactive balancing market with cross border optimization of frequency restoration while keeping control areas, bid zones, and regulatory oversight.
8. BritNed / TenneT / National Grid balancing services —project on hold.
9. IGCC imbalance netting, FRRa-assistance and flow-based congestion management.

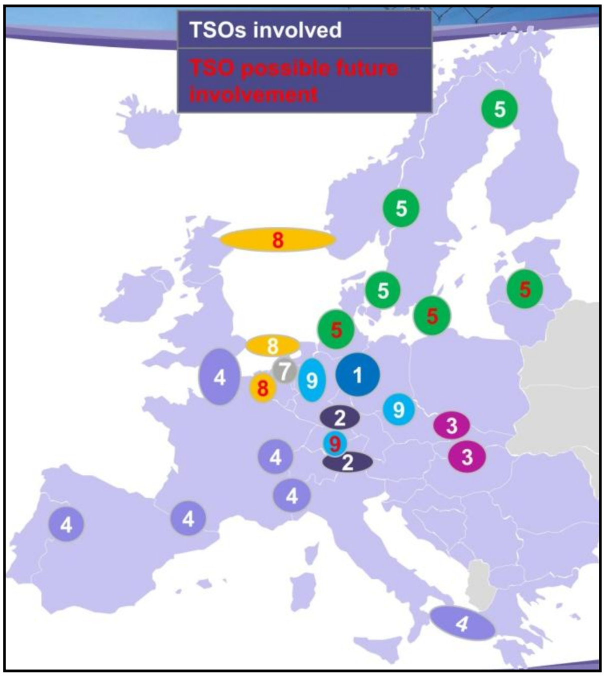

Figure 3.17 – Pilot projects on cross border electricity balancing

[3] Number 6 is missed because that project has disappeared.

CHAPTER 4
CURRENT CROSS BORDER BALANCING MECHANISM INTER SWE TSOs

Under the Electricity Regional Initiative South West Europe[1], Réseau de Transport d'Électricité —RTE—, Redes Energéticas Nacionais —REN—, and Red Eléctrica de España —REE—, TSOs of the French, Portuguese and Spanish electric systems, have developed a common project for the exchange of cross border balancing energy in the SWE region. This mechanism widens the scope of national balancing markets, enhancing competition and fostering an efficient use of the balancing resources.

4.1 PRINCIPLES OF THE CURRENT CROSS BORDER BALANCING MECHANISM

On the grounds of a TSO-TSO model, the main features of this cross border balancing market are:

- Bilateral exchanges —REN-REE and REE-RTE— ensuring reciprocity, transparency and non-discrimination.
- Use of the available transmission capacity after the adjustments of the commercial schedules in the corresponding intraday market session, therefore, making the most of the interconnections.
- The services are managed in a coordinated way by TSOs. Market players take part in the corresponding national balancing markets.
- Clear by means of a first-come-first-served allocation process.
- The settlement of the cross border balancing energy exchanged is based on a pay-as-bid scheme and complements the internal settlement of national balancing energy —balancing energy price and imbalance settlement.

All the foregoing provided that each electric system fulfills the established security criteria.

Thus, this cross border balancing service allows the participating systems to:

This chapter is mainly based on [CNMC14], [CNMC14_1] and [REE_14]

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[1] www.acer.europa.eu/Electricity/Regional_initiatives/Pages/default.aspx
www.ceer.eu/portal/page/portal/EER_HOME/EER_ACTIVITIES/EER_INITIATIVES/ERI
www.ceer.eu/portal/page/portal/EER_HOME/EER_ACTIVITIES/EER_INITIATIVES/ERI/South-West/Overview

- Offer their surplus of balancing energy.
- Have access to balancing resources from other interconnected electric systems making it possible to replace the allocation of internal offers with more competitive cross border balancing energy.

4.2 THE CROSS BORDER BALANCING PRODUCT

The standard cross border balancing product has the following characteristics:

- 50 MWh non-divisible energy blocks.
- Each block priced in €/MWh.
- Direction —upwards or downwards.
- 30 minutes activation time.
- Firm TSO-TSO re-schedule during one hour.

The pricing methodology, common to the three systems, sets the price of each 50 MWh energy block at the price of the last internal offer used to build the block.

4.3 SCHEDULE

The scheduling process of the cross border balancing energy spans the first 30 minutes of the hour previous to the delivery period. In the next figure, request and acceptance time frames mean requests of activation of a balancing energy offers and acceptance of those requests.

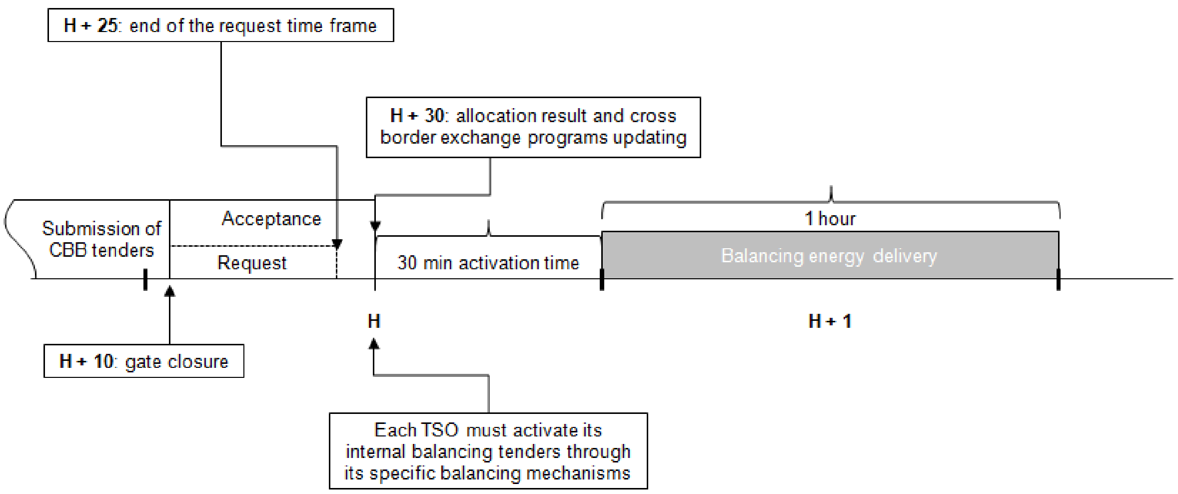

Figure 4.1 - Schedule

CHAPTER 5
CROSS BORDER BALANCING THROUGH OPTIMIZATION

This chapter, the core of the document, explains the platform developed to analyze the implementation of the European target model for the exchange of balancing energy in the long-term, i.e. a TSO-TSO model with a common merit order list, giving all the details to fully understand the design, including its mathematical formulation. The analysis of the market performance reviews the effect of the available transmission capacity —section 5.3— and the bidding rule —section 5.4— and it considers the impact of this regional platform in the internal balancing markets of the participating TSOs.

As support, figures and tables extracted from the platform real simulations —marked with †— illustrate the text.

Its main characteristics and the more outstanding differences with respect to the mechanism described in the previous chapter are the following:

	CURRENT MECHANISM	CBB THROUGH OPTIMIZATION
Scope	Bilateral	Regional
Tenders	Offers (surpluses)	Requirements and offers (all)
Clearing	First-come-first-served	Binary integer optimization
Settlement of the CB balancing energy	Pay as bid	Marginal price

Table 5.1 – Cross border balancing platform main characteristics

The balancing product is exactly the same as before —section 4.2.

5.1 THE CROSS BORDER BALANCING PLATFORM

Under this model, TSOs share all their balancing energy resources —common merit order list—, without keeping anything for their internal use. Therefore, once received the internal balancing energy offers, both upwards and downwards, they are all divided into 50 MWh non-divisible energy blocks, assigning a price to each block based on the offers submitted by the BSPs of each system[1]. Besides this, each TSO sets its requirement, only in one direction —upwards or downwards—, and margin, in both directions —upwards and downwards— (see figure 5.1).

[1] According, for instance, to the same pricing rule already mentioned in chapter 4.

The concept of margin does not really apply to this target model, since all the resources are sent to the platform. Nevertheless, it will be mentioned in section 5.4, finding it convenient to introduce it from the beginning.

For the sake of simplicity, the design considers a maximum of ten blocks, both upwards and downwards. Regarding the price of the cross border balancing energy offers, the following rules are established:

- All offers must be strictly positive, with only one exception —see the third bullet point.
- Upwards offers must be increasing and downwards ones decreasing —not necessarily strictly.
- At least the last block, both upwards and downwards —#10—, must be reserved to simulate the lack of reserve, allowing the use of more blocks if necessary. In this regard, the price considered in this model —price of the non-served energy— for the upwards block is 10000 €/MWh and for the downwards one -10000 €/MWh.
- The last upwards block, just before the lack of reserve, must be lower than 1000 €/MWh, and the last downwards block, just before the lack of reserve, must be higher than 0.1 €/MWh. These cap and floor are related to how requirements are priced, as it is immediately explained.
- Upwards offers must be higher than a reference price and downwards ones must be lower than this reference price. The reason for using a reference price (figure 5.1) is detailed afterwards in subsection 5.1.7, devoted to the effect and consequences of offer-offer allocation.

Figure 5.1 – Internal offers (green), requirements (red), margins (blue) and reference price (orange) †

In this design, besides offers, TSOs must send to the platform also their requirements. To do so, the following instrumental prices are fixed:

- Upwards requirements at 1000 €/MWh.
- Downwards requirements at 0.1 €/MWh.

These values are aimed at reflecting the TSOs willingness to buy/sell their lack/excess[2] of energy, and therefore must be high/low enough in order to, insofar as possible, ensure that the requirements are activated —TSOs are price takers—.

Thus, the structure of the offers and requirements submitted by the TSOs, hereafter known as cross border balancing tenders, is as illustrated in figure 5.2.

[2] Lack (less generation or more consumption): upwards requirement | Excess (more generation or less consumption): downwards requirement.

Figure 5.2 – Offers (green) and requirements (red) sent to the cross border balancing platform, and reference price (orange) †

The model, in its algorithm, includes a piece of code to validate that the tenders meet the aforementioned standards, rejecting them in case of failing and halting the execution.

5.1.1 Clearing process

Once in the platform, all these tenders are arranged to build the supply and demand curves of the region as follows:

- Supply: cross border balancing downwards requirements and upwards offers.
- Demand: cross border balancing upwards requirements and downwards offers.

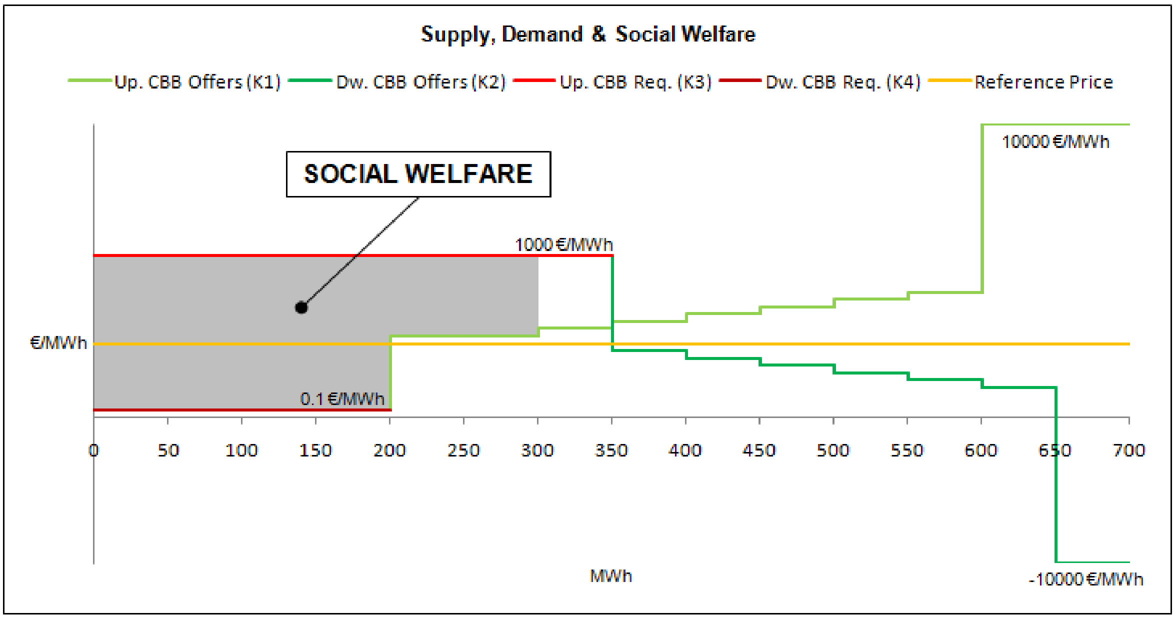

Figure 5.3 – Supply, demand and social welfare[3]

The goal is to clear the market so that the regional social welfare, i.e. the area between the supply and demand curves, is maximized, allocating balancing energy and transmission capacity at the same time, subject to the capacity limits in the tie lines — available transmission capacity constraint, see table 5.2— and to the energy balance — supply must equal demand.

Interconnection	ATC [MW]
ES - FR	150
FR - ES	50
PT - ES	1000
ES - PT	1000
GB - FR	200
FR - GB	200

Table 5.2 – Available transmission capacity †

For these cross border exchanges, TSOs make use of the available capacity in the interconnections after the closure of the last binding commercial[4] transaction in the intraday timeframe. Transmission capacity reservation for balancing energy trading is not allowed in this case.

This is about a binary integer optimization problem, solved by binary integer programming, in which it is necessary to determine what balancing energy blocks have to

[3] Ki are the references used in the code.
[4] Trade of energy, not services.

be activated (1) or not activated (0) in order to maximize the area between the supply and demand curves, while meeting the constraints.

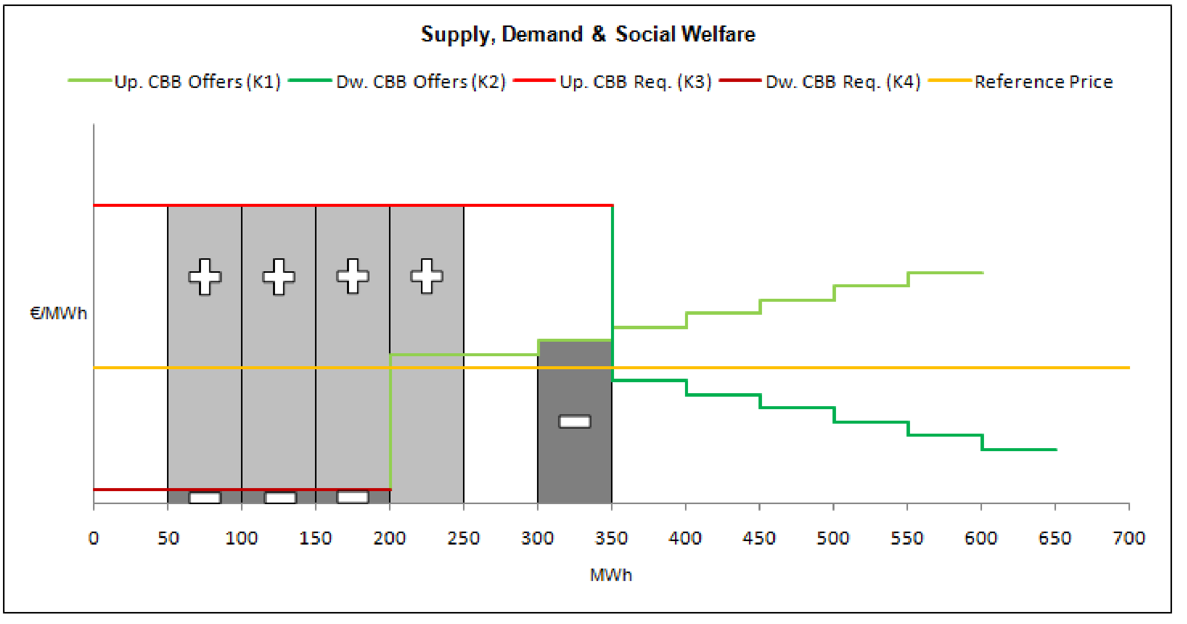

Figure 5.4 – Activated (solid) and not activated (hollow) balancing energy blocks during the clearing process

Activated demand blocks —light grey blocks in figure 5.4— contribute to the social welfare adding positive area —symbol + inside the blocks—, while activated supply blocks —dark grey blocks in figure 5.4— subtracting it —symbol – inside the blocks. Any deviation from a continuous activation of supply and demand blocks in the common merit order list is due to the ATC constraint, as shown in figure 5.4 with the last activated supply block.

Box 5.1

It could be thought that this kind of optimization problem could be solved by linear programming, although being binary integer, because, due to its nature, the variables tend to be set at 1 or 0 by themselves, without being forced to that. After some simulations, it has been proven that this is not true at all, having obtained results of, for instance, 0.3 or 0.7. This could be interpreted as a partial activation of the tender, something that is not allowed —50 MWh non-divisible blocks.

After finishing the clearing, the platform yields the results of the process, namely: requests and offers activated and not activated per TSO and their corresponding cross border balancing energy exchanges, indicating whether there is some tie line at full capacity or not (figures 5.5 and 5.7).

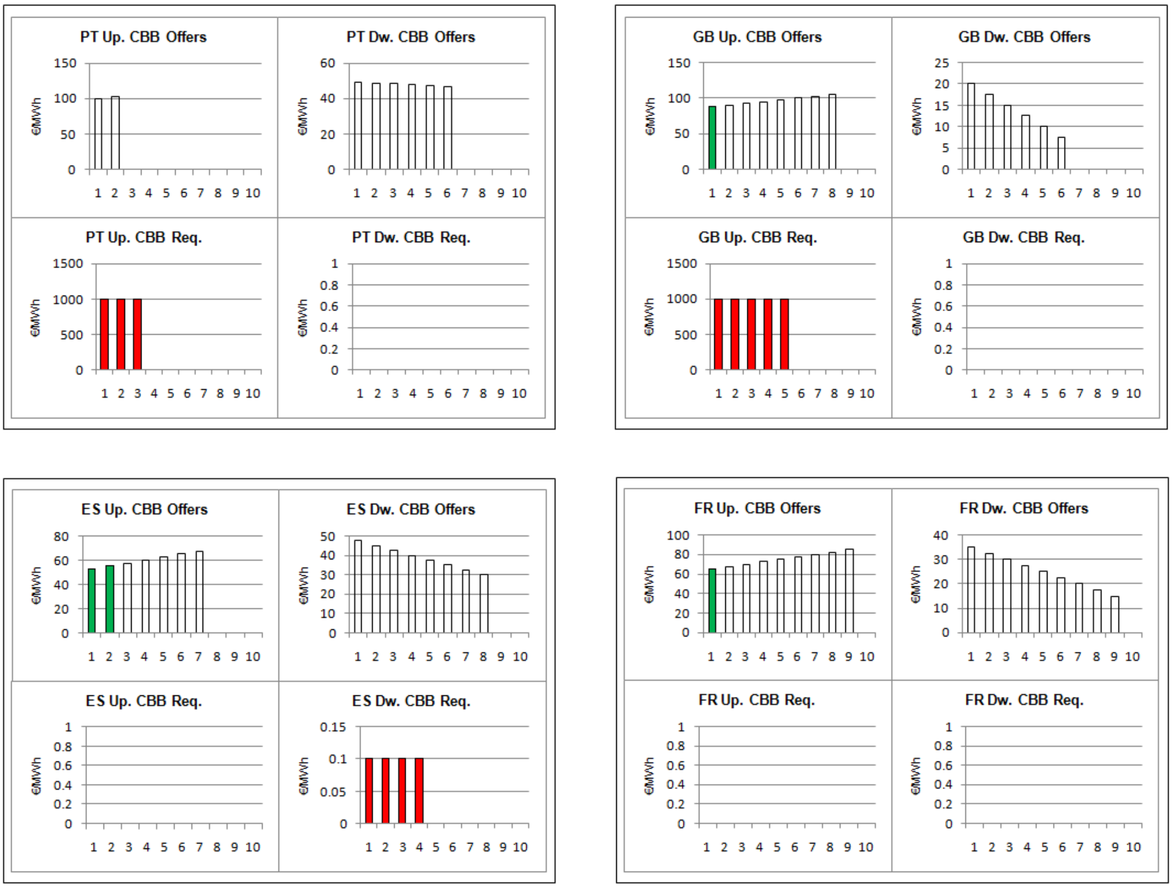

Figure 5.5 – Activated (solid) and not activated (hollow) tenders †

As a summary, the platform also computes the requests and offers submitted per TSO and how many of them have been activated, including the result of the region too.

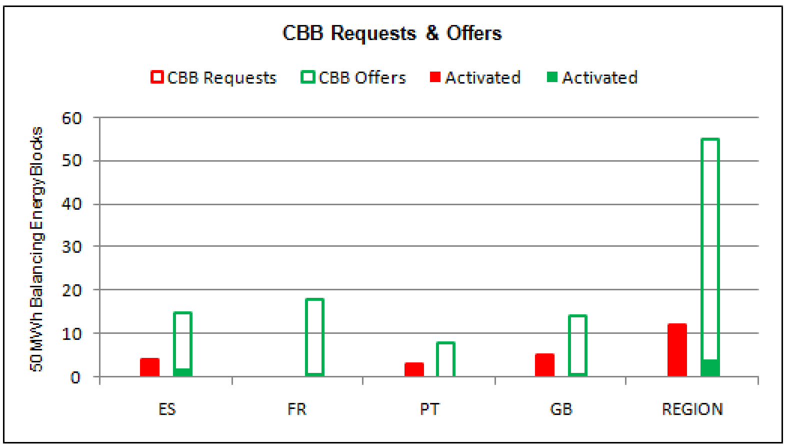

Figure 5.6 – Summary of the tenders’ activation outcome †

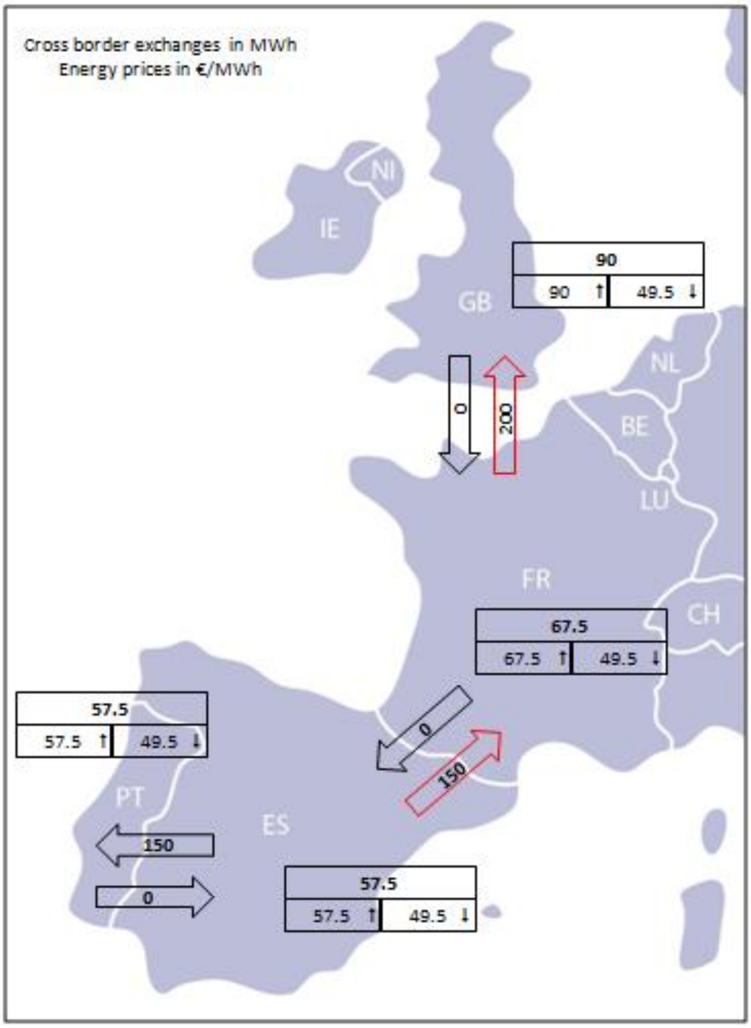

Figure 5.7 – Cross border exchanges (interconnections at full capacity in red arrows) and balancing energy prices (↿ upwards, ⇂ downwards) †

Regarding prices, each table in figure 5.7 contains three values. The price to apply in the cross border balancing platform to each system is the one in the upper row, highlighted in bold type, and it is selected from the other two according to the criterion stated below in subsection 5.1.2.

5.1.2 Pricing methodology

First of all, let us make a brief mathematical reflection. This is a non differentiable problem —binary integer variables—, therefore, it is not mathematically possible to compute marginal sensitivities. Despite that, it has been decided to conceptually use them as a measure of the cost of the balancing resources. The platform computes marginal prices, both upwards and downwards, for each TSO, according to the following rule from the clearing outcome:

- Upwards: the TSO acts as demand, so, what is the cost of activating an additional block of upwards balancing energy?

- Downwards: the TSO acts as supply, so, what is the income of activating an additional block of downwards balancing energy?

The criterion to fix the price in each zone is as follows:

- If upwards/downwards balancing offers have been activated in the zone, it is selected the upwards/downwards price.

- If no BSP results cleared in that zone, then it depends on the zone net balancing requirement. If there is lack/excess of energy, i.e. upwards/downwards requirements, it is selected the upwards/downwards price.

For instance, according to figure 5.7, Portugal and Spain form a zone. Since there are activated upwards balancing offers within the zone (see figure 5.5), the price to apply is the upwards one.

Similarly, Great Britain constitutes another zone, and again, since there is one activated upwards balancing offer within the zone (see figure 5.5), the price to apply is the upwards one.

This very example is useful to deeply explain the reasoning behind the pricing rule. If the price was chosen according to the net requirement, the outcome in Great Britain would be the same. On the other hand, Portugal and Spain have net downwards requirements, therefore, if the price was chosen according to the net requirements the result is just the other way round. This zone, despite it has excess of energy, ends up activating upwards balancing resources and exporting all that energy, both the net downwards requirement and the upwards offers. And it does not make sense to sell upwards balancing energy coming from the BSPs at the downwards price.

Thus, each TSO has only one price, at which it purchases cross border balancing energy, and they fulfill with the following basic rules:

- They are cost-reflective, in order to due settle the balancing services.

- They mean an incentive for the BRPs to be balanced.

- They are equal within systems in the same zone.

- Balancing services flows according to the economic signals provided by them and the common merit order list.

Box 5.2

Despite it could seem simple or obvious, the pricing rule has been one of the more difficult tasks of this work, giving rise to interesting and long discussions. The first try was to choose the marginal price at each system according to the net regional balancing requirement. It has been proven how this completely distorts the economic signal in those zones in which, for instance, the net balancing requirement or the activated BSPs offers were in the opposite direction.

5.1.3 Economic surplus after the clearing

Each TSO must pay/charge at its own marginal price the cross border balancing energy bought/sold, being the platform the central counterpart.

In the most general case, there are different zones, separated by interconnections at full capacity, with different prices. Due to this difference in prices, there is an economic surplus in the platform, namely, the difference between what TSOs pay and charge. This surplus is directly related to the capacity limit in the interconnections[5] and, in this design, the surplus is given back to the incumbent adjacent TSOs —half each— as part of the settlement process, since the platform must be financially neutral. According to the marginalist theory, this economic surplus should be invested by TSOs to increase the cross border transmission capacity.

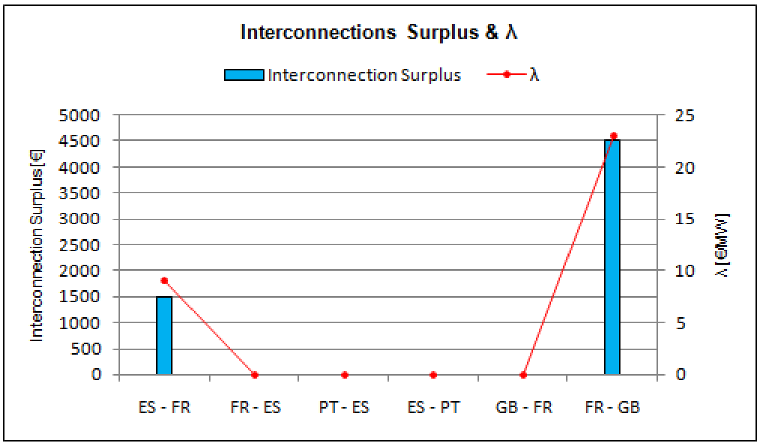

Figure 5.8 – Interconnections economic surplus and Lagrange multipliers †

5.1.4 Cross border settlement

The platform settlement encompasses two terms per TSO: one corresponding to the cross border balancing energy bought/sold and the aforementioned one related to the economic surplus in the tie lines at full capacity.

[5] This is more clearly shown in section 5.2.

The regional settlement, i.e. the sum of the settlements of all the TSOs, equals cero, being the platform, as already said, financially neutral.

It is important to emphasize that the outcome of the clearing process —tenders activated and their corresponding cross border balancing energy exchanges, interconnections at full capacity, and therefore, the resulting zones— is fully independent of the pricing methodology and settlement rule.

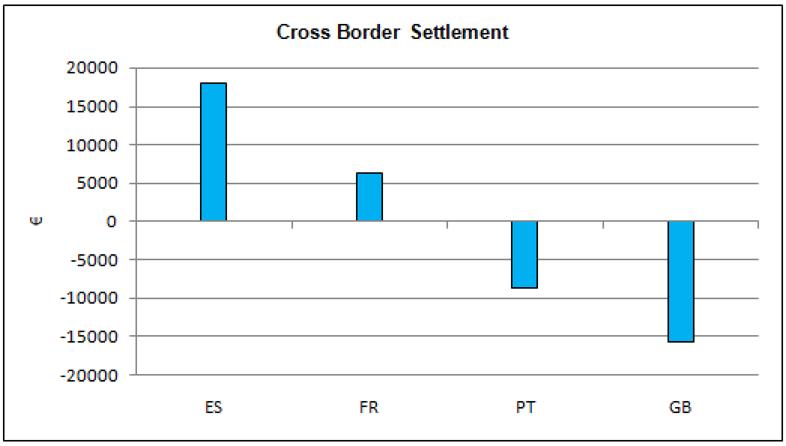

Figure 5.9 – Cross border settlement. Platform financially neutral †

5.1.5 Lagrange multipliers (λ)

Solving the optimization problem using linear programming, allowing the variables to be in the range [0,1] instead of being strictly integer, it is possible to obtain the sensitivity of the social welfare to the transmission capacity constraints and relate it to the economic surplus (figure 5.8).

This is a very interesting and useful result when dealing with investment decisions related to interconnections, since it gives an idea of the priority corridors to be upgraded[6].

Among all the results provided by the linear programming optimization, the model only saves the value of λ, disregarding the rest[7].

5.1.6 Merit order list

The model also yields the merit order list, showing the tenders sent, which of them have been activated, the effect of the transmission capacity constraints and the regional social welfare.

[6] Of course, from a European balancing services market perspective. A comprehensive decision should also include energy markets.

[7] Reminder: the results, except λ, are obtained by binary integer programming optimization.

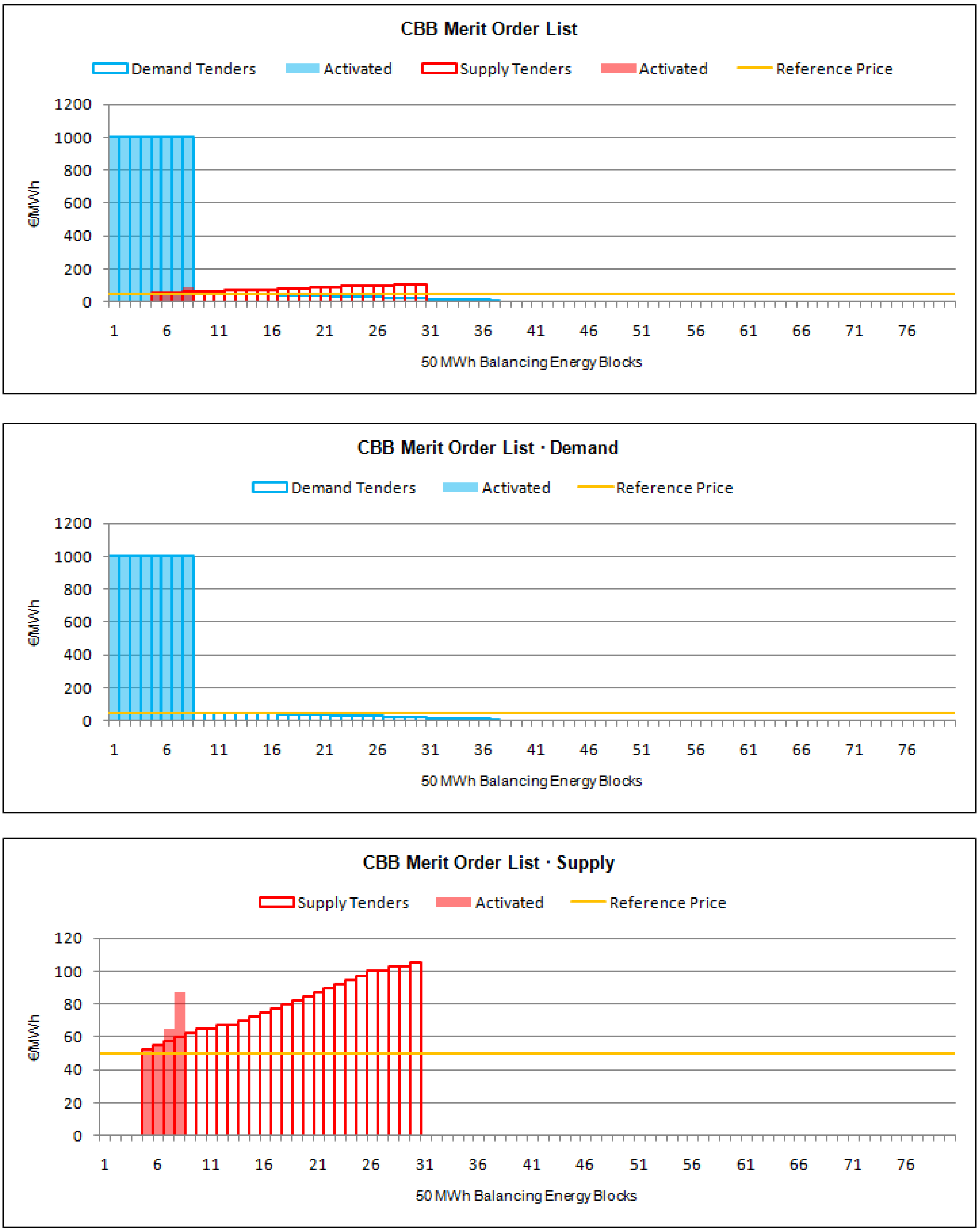

Figure 5.10 – Merit order list †

This information must be carefully interpreted[8], not meaning at all that each activated demand block has been cleared with the corresponding supply block graphically on top of it.

[8] See box 5.3.

5.1.7 Offer-Offer allocation effect

It must be borne in mind that the objective of the platform is to solve the balancing energy needs of the participating TSOs, as the balancing market that it is. This can be done through offsetting opposite requirements taking advantage of its regional scope or making use of the balancing offers. And this is the key, the use of those balancing offers must be restricted to relieve TSOs requirements, trading system services. Therefore, balancing offers transactions without requirements being involved are not allowed.

To avoid this offer-offer allocation, not only between offers of different systems, but also between offers within the same system[9], the model uses a reference price[10]. Since, as already explained, all upwards offers are higher than this value and all the downwards offers are lower, it is guaranteed that this energy exchange will not happen, just because the activation of this tenders turns out in adding negative area, thus decreasing the social welfare.

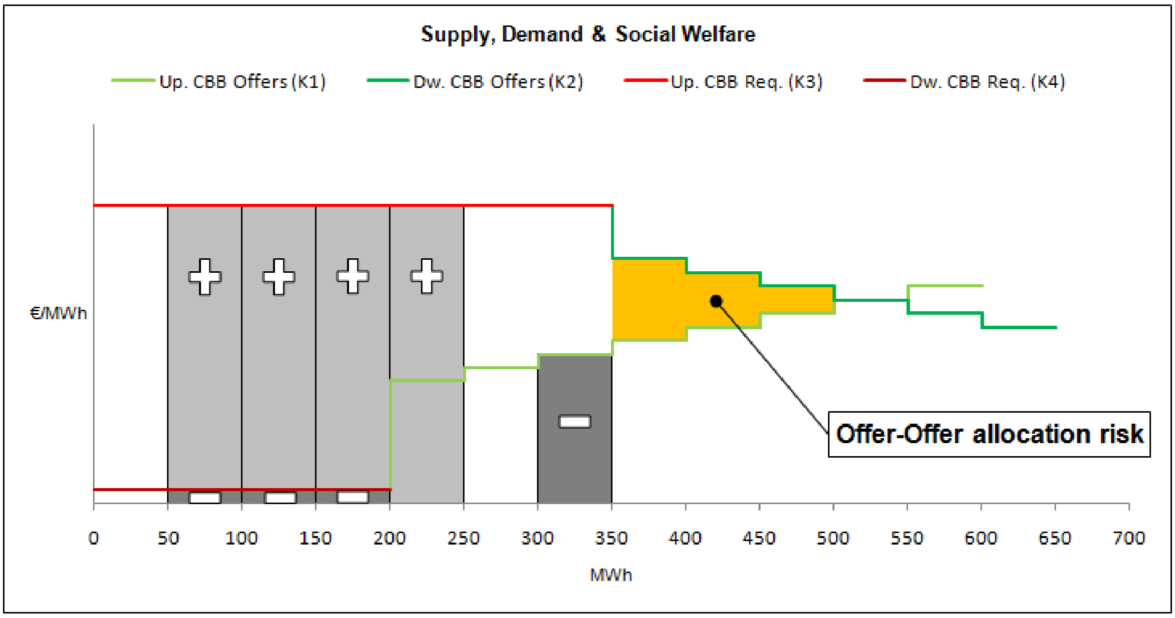

Figure 5.11 – Offer-Offer allocation without reference price

Next, offers and platform results without taking into account the reference price are included to illustrate this effect.

[9] Non-desirable at all.
[10] For instance, the average spot price in the region.

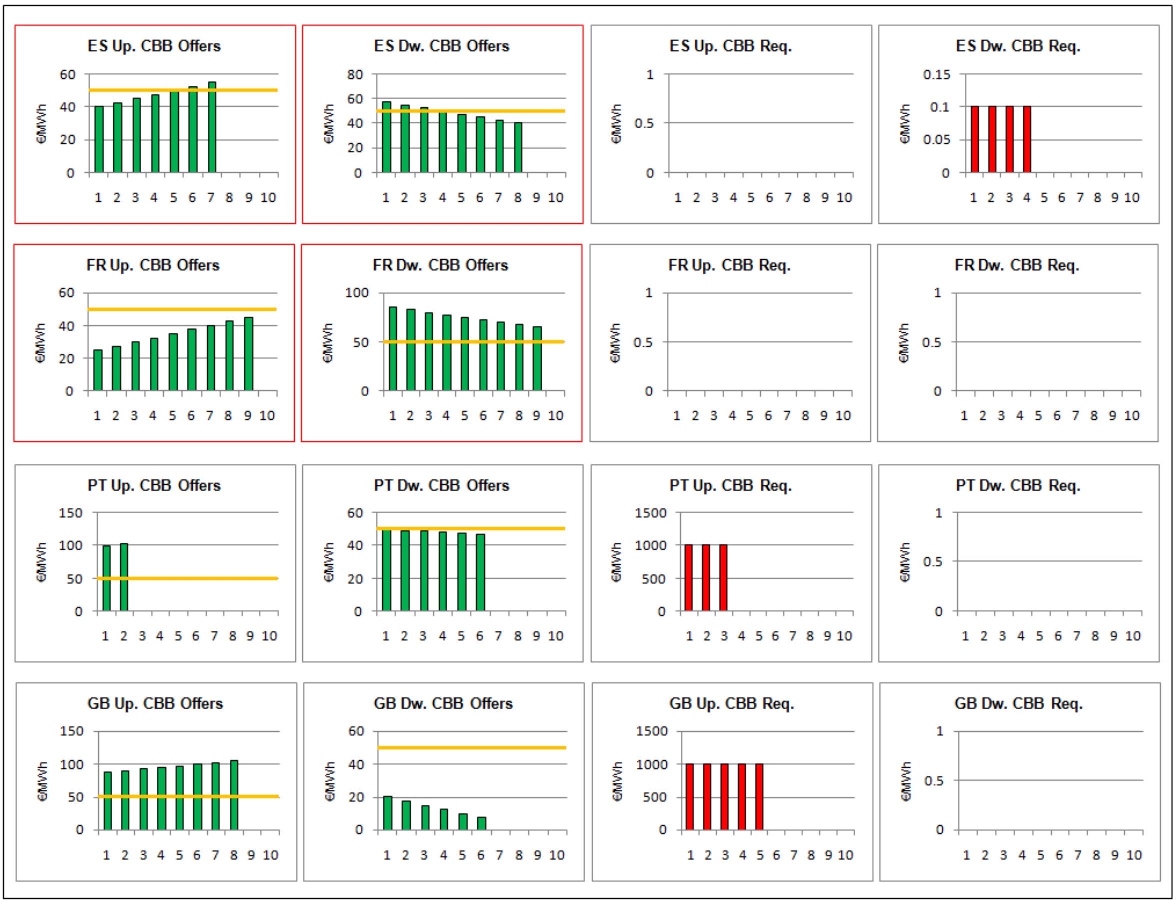

Figure 5.12 – Offers (green) not considering the reference price (orange) rule in Spain and France (red frames) †

Box 5.3

Coming back to the warning at the end of subsection 5.1.6, in some cases it is possible to find in the merit order list activated upward offers on top of activated downwards offers —i.e. graphically superimposed. This does not necessarily mean an offer-offer allocation. It is required a deep analysis, considering which systems these offers belong to and whether they were activated once all the requirements were met or not.

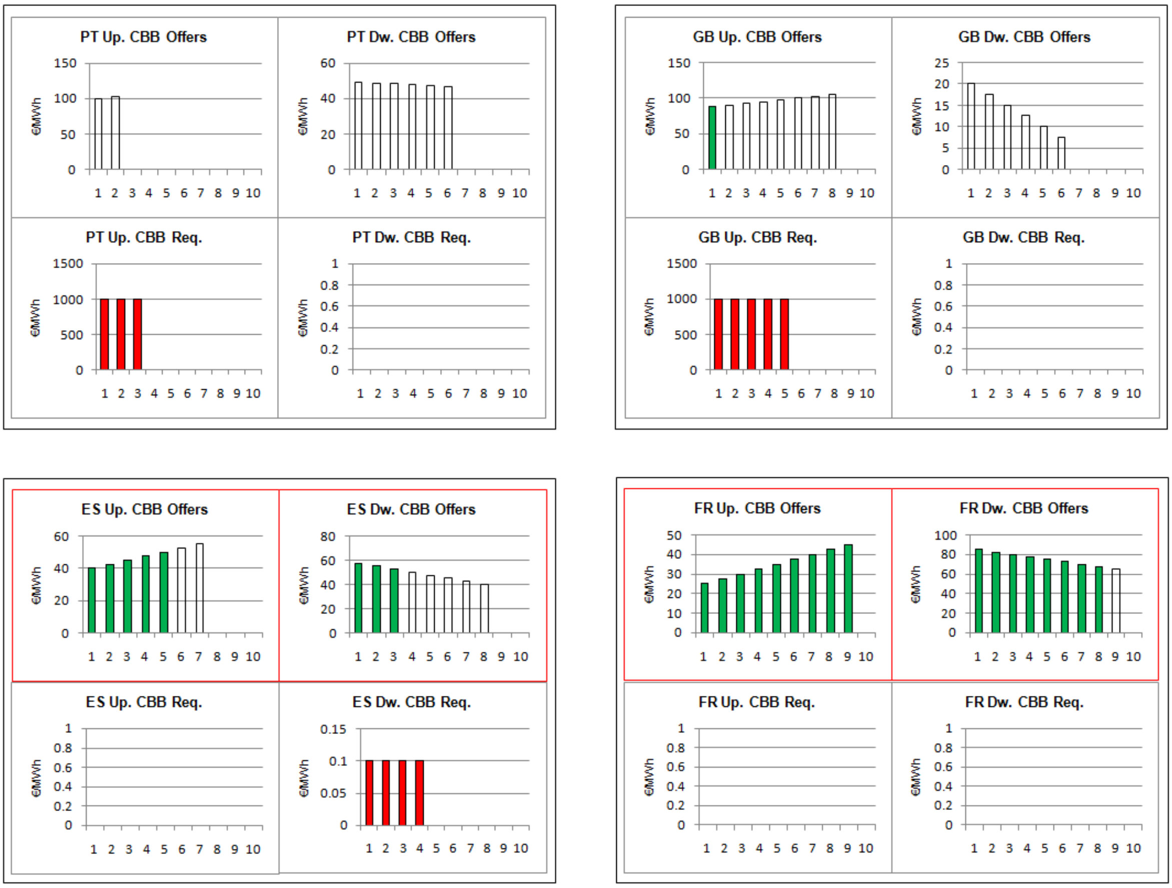

Figure 5.13 – Offer-Offer allocation in Spain and France (red frames), as consequence of figure 5.12 †

5.1.8 Impact of the mechanism in the internal balancing energy markets

This subsection is of great relevance. The platform is built on a TSO-TSO model, being each of them responsible after the cross border platform results publication for the following tasks:

- Update of the cross border exchange programs.
- BSPs activation.
- Balancing services —BSPs— settlement.
- Imbalances or deviations —BRPs— settlement.

The model gathers all the information about energy volumes and prices and summarizes the various settlement[11] results, both for the cross border mechanism —TSO perspective— and for the internal markets —BSP and BRP perspective.

[11] Positive settlement: cash inflow; negative settlement: cash outflow.

	CROSS BORDER BALANCING PLAFORM					
	TSO perspective					
	Req. Activated [MWh]	Req. Pending [MWh]	Marginal Price [€/MWh]	Energy Settlement [€]	Interconn. Surplus [€]	Settlement [€]
ES	200	0	57.5	17250	750	18000
FR	0	0	67.5	3375	3000	6375
PT	150	0	57.5	-8625	0	-8625
GB	250	0	90	-18000	2250	-15750

	INTERNAL BALANCING ENERGY MARKETS			
	BSP perspective			BRP perspective
	BSPs Energy [MWh]	Energy Price [€/MWh]	BSPs Settlement [€]	BRPs Settlement [€]
ES	100	57.5	5750	11500
FR	50	Pay as bid	3250	125
PT	0	0	0	-8625
GB	50	Pay as bid	4375	-22375

Reference Price [€/MWh]
50

Table 5.3 – Summary of the mechanism impact in the internal balancing markets †

Using this data —the whole picture— conclusions can be drawn about who benefits of taking part in the cross border mechanism: TSOs, BSPs, BRPs? Despite this question must be answered on a case by case basis, there are general features worth to be mentioned.

Prices applied in the cross border model are coherent with those later used in the internal markets to settle the services.

Regarding the BRPs settlement, it is computed as cross border balancing energy settlement plus BSPs settlement[12]. How this amount is allocated between BRPs depends on each particular system imbalance settlement rules. In this regard, there are two options:

- Single pricing: both upwards and downwards deviations are settled at the same price. It is possible to charge/pay more/less than the reference price if the BRP imbalance is in favor of the system needs, penalizing only those BRPs against.

- Dual pricing: in order to penalize deviations both in favor of and against the system needs, setting a stronger incentive to keep balanced, the settlement includes a cap/floor for the price to be charged/paid fixed at the reference price. This rule usually gives rise to different prices for upwards and downwards imbalances.

It is important to remark that, regarding imbalance settlement, each TSO only considers deviations within its control area, being the requirements equal to the control area net imbalance.

As an example, these are the results for Spain in both situations:

[12] Reminder: the interconnections economic surplus is not considered here since it is earmarked for network investments.

SINGLE PRICING [€/MWh]		
Upwards imbalances	11500 / 200 = 57.5	Charge
Downwards imbalances	11500 / 200 = 57.5	Pay
DUAL PRICING [€/MWh]		
Upwards imbalances	11500 / 200 = 57.5 → Cap = 50	Charge
Downwards imbalances	11500 / 200 = 57.5	Pay

Table 5.4 – BRPs settlement example

5.1.9 Schedule

As in any other organized market, there must be a schedule to coordinate all the actions and processes. The next self-explanatory figure reflects this model proposal, fixing the parameters at: ε = 10 min, β = 20 min, δ = 30 min.

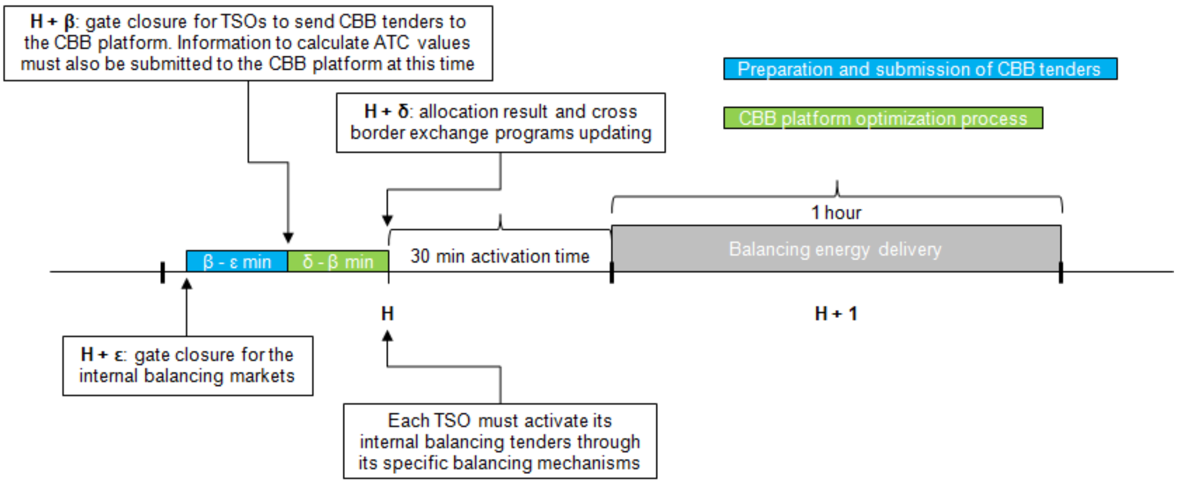

Figure 5.14 - Schedule

5.1.10 Base case

All the results shown up to now constitute the base case with respect all the comparisons are made to.

5.2 MATHEMATICAL FORMULATION

All the foregoing ideas must be translated into a mathematical model that allows the use of specific software to solve the optimization problem and compute all the desired results.

DATA		
energyblock = 50	Fix size of the non-divisible balancing energy block	MWh
K1i	Upwards CBB offers of the TSO i	€/MWh
K2i	Downwards CBB offers of the TSO i	€/MWh
K3i	Upwards CBB requests of the TSO i	€/MWh
K4i	Downwards CBB requests of the TSO i	€/MWh
ATCij	Available transmission capacity from TSO i to TSO j	MW

VARIABLE	
x	Vector with the activation status (0 or 1) of each cross border balancing tender

OBJECTIVE FUNCTION		
f = [K2i K3i K2j K3j … K2k K3k | -K1i -K4i -K1j -K4j … -K1k -K4k] · energyblock		€
f · x	Regional social welfare	€

INEQUALITY CONSTRAINT		
cbbexchangeij(x)	CBB energy exchange between TSO i and TSO j	MWh

EQUALITY CONSTRAINT		
supply(x) – demand(x)	Energy balance must equal 0	MWh

OPTIMIZATION PROBLEM		
	max f · x	
subjected to:	cbbexchangeij(x) ≤ ATCij	(λ)
	supply(x) – demand(x) = 0	

RESULTS		
x*	Optimum solution	
f · x*	Maximum regional social welfare	€
cbbexchangeij(x*)	CBB energy exchange between TSO i and TSO j	MWh
λ	Inequality constraint Lagrange multipliers	€/MW
UPMPi	Upwards marginal price for the TSO i	€/MWh
DWMPi	Downwards marginal price for the TSO i	€/MWh
MPi	Marginal price for the TSO i	€/MWh
SURij	Surplus in the interconnection between TSO i and j	€
SETTLEi	TSO i cross border settlement	€
SWi	TSO i social welfare	€

Table 5.5 – Mathematical formulation

The optimization problem is solved twice: firstly, by linear programming only to obtain the values of λ; and secondly, by binary integer programming to compute x*.

For this, the model uses the functions already included in the commercial software utilized to develop the algorithm[13].

5.2.1 Economic surplus and cross border settlement

The economic surplus in the platform, as the central counterpart, i.e. the difference between what TSOs pay and charge for the cross border balancing energy is:

(cbbexchangefres + cbbexchangeptes) · MPes + (cbbexchangeesfr + cbbexchangegbfr) · MPfr + cbbexchangeespt · MPpt + cbbexchangefrgb · MPgb – (cbbexchangeesfr + cbbexchangeespt) · MPes – (cbbexchangefres + cbbexchangefrgb) · MPfr – cbbexchangeptes · MPpt – cbbexchangegbfr · MPgb =

$$\underbrace{\text{cbbexchangeesfr} \cdot (\text{MPfr} - \text{MPes}) + \text{cbbexchangefres} \cdot (\text{MPes} - \text{MPfr}) +}_{\text{Economic surplus due to ES – FR interconnection}}$$

$$\underbrace{\text{cbbexchangeptes} \cdot (\text{MPes} - \text{MPpt}) + \text{cbbexchangeespt} \cdot (\text{MPpt} - \text{MPes}) +}_{\text{Economic surplus due to ES – PT interconnection}}$$

$$\underbrace{\text{cbbexchangegbfr} \cdot (\text{MPfr} - \text{MPgb}) + \text{cbbexchangefrgb} \cdot (\text{MPgb} - \text{MPfr})}_{\text{Economic surplus due to GB – FR interconnection}}$$

It is clear how this surplus is related to the difference in prices which in turn is connected with interconnections operating at full capacity.

The cross border settlement of each TSO taking into account both the energy and the economic surplus given back is:

SETTLEes = (cbbexchangeesfr + cbbexchangeespt – cbbexchangefres – cbbexchangeptes) · MPes + (SURestr + SURfres)/2 + (SURespt + SURptes)/2

SETTLEfr = (cbbexchangefres + cbbexchangefrgb – cbbexchangeesfr – cbbexchangegbfr) · MPfr + (SURfres + SURestr)/2 + (SURfrgb + SURgbfr)/2

SETTLEpt = (cbbexchangeptes – cbbexchangeespt) · MPpt + (SURptes + SURespt)/2

[13] These functions actually minimize instead of maximizing. That is why in the code the objective function coefficients are: f = [-K2i -K3i -K2j -K3j … -K2k -K3k | K1i K4i K1j K4j … K1k K4k] · energyblock.

SETTLEgb = (cbbexchangegbfr – cbbexchangefrgb) · MPgb + (SURgbfr + SURfrgb)/2

Thus, SETTLEes + SETTLEfr + SETTLEpt + SETTLEgb = 0, being the platform financially neutral.

5.2.2 Social welfare

Each TSO social welfare is computed as:

SWes = (K2esSet + K3esSet – K1esSet – K4esSet) · energyblock + SETTLEes

SWfr = (K2frSet + K3frSet – K1frSet – K4frSet) · energyblock + SETTLEfr

SWpt = (K2ptSet + K3ptSet – K1ptSet – K4ptSet) · energyblock + SETTLEpt

SWgb = (K2gbSet + K3gbSet – K1gbSet – K4gbSet) · energyblock + SETTLEgb

Where the code only considers the activated tenders —that is the meaning of the suffix Set— and (K2iSet + K3iSet) · energyblock ≡ area under the demand curve, i.e. UTILITY, and (K1iSet + K4iSet) · energyblock ≡ area under the supply curve, i.e. COST.

Thus, the regional social welfare is:

SWre = SWes + SWfr + SWpt + SWgb = (K2esSet + K3esSet – K1esSet – K4esSet) · energyblock + ~~SETTLEes~~ + (K2frSet + K3frSet – K1frSet – K4frSet) · energyblock + ~~SETTLEfr~~ + (K2ptSet + K3ptSet – K1ptSet – K4ptSet) · energyblock + ~~SETTLEpt~~ + (K2gbSet + K3gbSet – K1gbSet – K4gbSet) · energyblock + ~~SETTLEgb~~ =

(K2esSet + K3esSet – K1esSet – K4esSet) · energyblock + (K2frSet + K3frSet – K1frSet – K4frSet) · energyblock + (K2ptSet + K3ptSet – K1ptSet – K4ptSet) · energyblock + (K2gbSet + K3gbSet – K1gbSet – K4gbSet) · energyblock =

(K2esSet + K3esSet + K2frSet + K3frSet + K2ptSet + K3ptSet + K2gbSet + K3gbSet – K1esSet – K4esSet – K1frSet – K4frSet – K1ptSet – K4ptSet – K1gbSet – K4gbSet) · energyblock

Naturally, the area between the demand and supply curves or the objective function the model maximizes.

5.3 THE IMPORTANCE OF THE INTERCONNECTIONS

Interconnections between electric systems are at the very heart of the harmonization and integration of national electricity markets, both energy and services, for the achievement of a well-functioning European Internal Energy Market. They have a huge effect in the energy exchanges and their prices, and this cross border mechanism is not different.

This section is aimed at showing this key issue by comparing the target model simulation results —base case, which has limited ATC according to table 5.2— to two extreme cases: without ATC —ATC = 0— and without ATC limits —ATC = ∞—; remaining all the rest equal.

Moreover, it also includes a comparison with a bilateral model, in which transactions are restricted to adjacent[14] TSOs. This is not a constraint related to the transmission capacity, but at the end of the day, it puts limits to the energy flow. That is why is considered in this section. The only difference with respect to the base case is the bilateral trading additional constraint, being all the rest equal, included the ATC.

5.3.1 Results without ATC (ATC = 0)

Under this scenario, cross border transactions are not possible. Therefore, and since TSOs share all their balancing resources in the platform and send all their requirements, the result is the clearing of the internal balancing energy markets, reflecting the platform prices the cost of the balancing resources in each isolated system.

[14] Adjacent from an electrical point of view, not geographical; although in this platform both perspectives coincide.

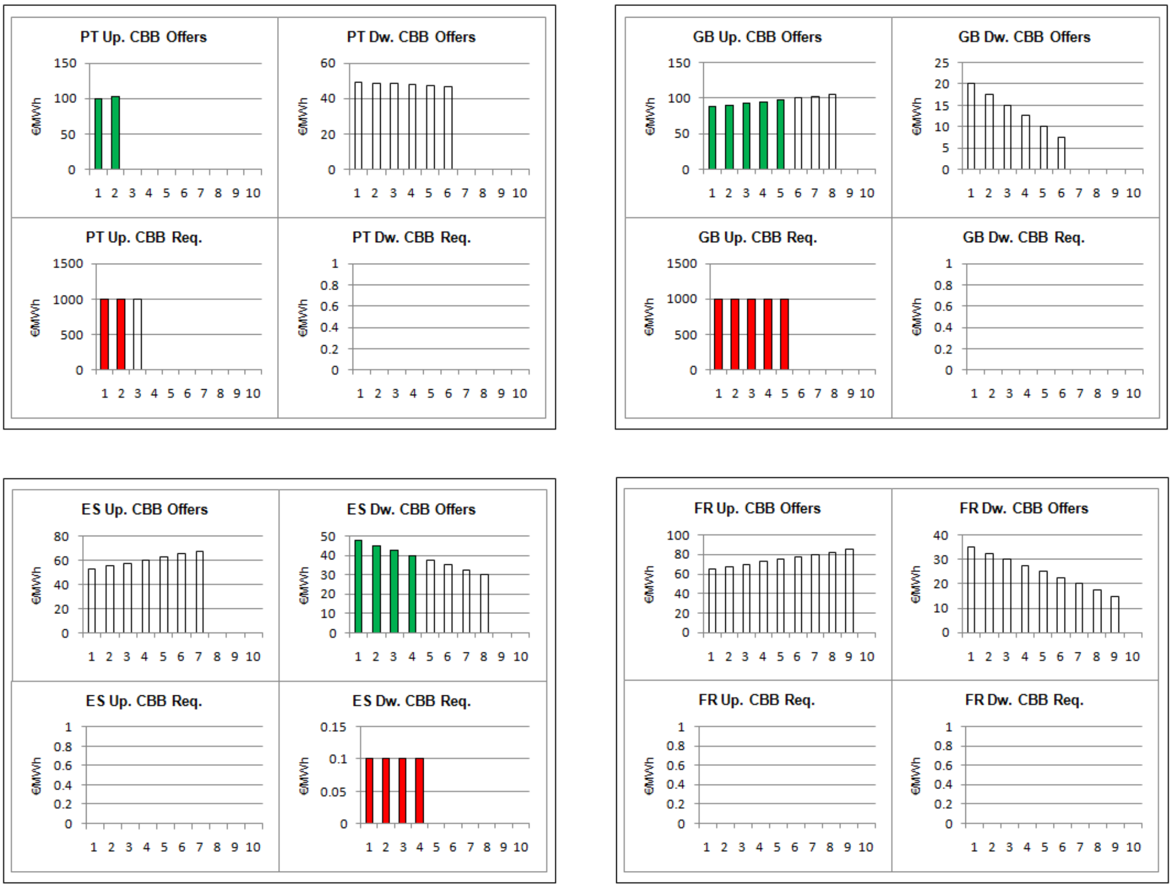

Figure 5.15 – Activated (solid) and not activated (hollow) tenders (ATC = 0) †

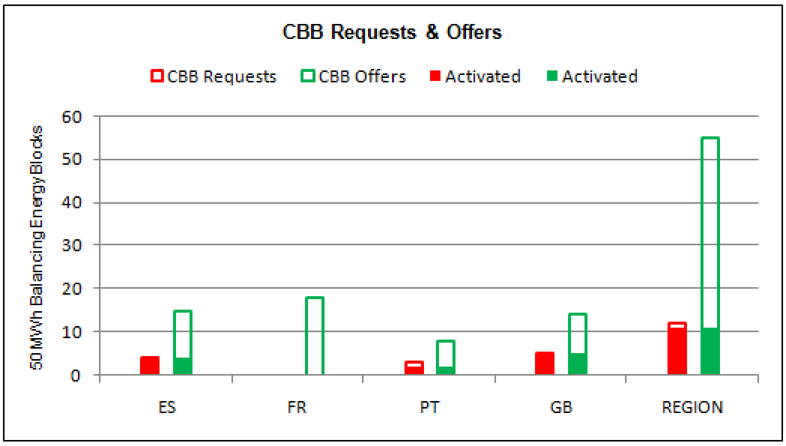

Figure 5.16 – Summary of the tenders' activation outcome (ATC = 0) †

Especially relevant it is the situation of Portugal in this example, which does not have enough internal resources to meet its balancing needs —that is why the price of the non-served energy, 10000 €/MWh, appears. The benefit of its participation in the regional market is clear under this circumstance.

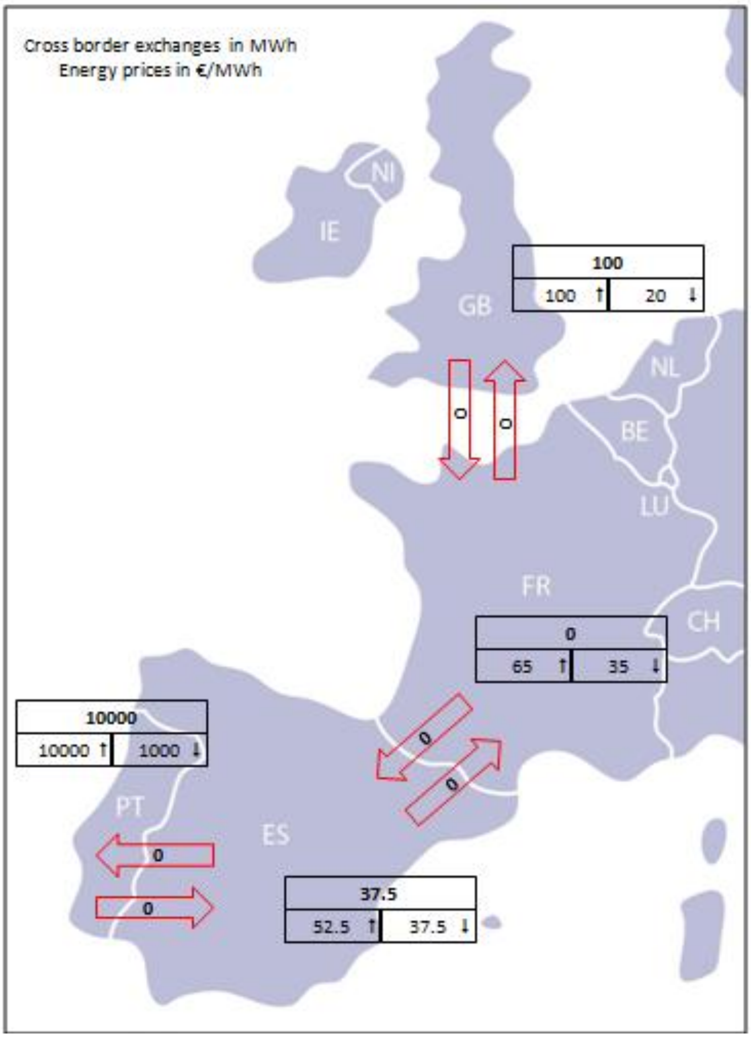

Figure 5.17 – Cross border exchanges (ATC = 0, red arrows) and balancing energy prices (↿ upwards, ⇂ downwards) †

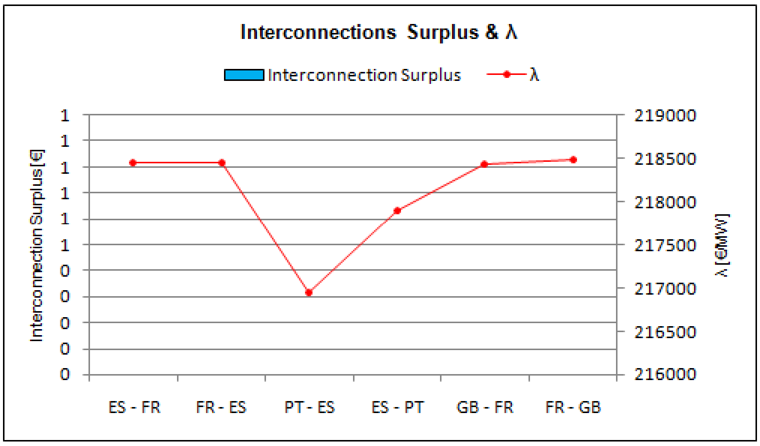

Figure 5.18 – Interconnections economic surplus and Lagrange multipliers (ATC = 0) †

Obviously, there are not economic surplus in the interconnections, since there are not cross border balancing energy exchanges. So, in this case, the mechanism does not yield economic resources earmarked to network investments, funds must be raised differently. But the platform does provide relevant information for the allocation of those funds from a regional social welfare point of view within this balancing energy framework, namely, the values of λ.

Figure 5.19 – Merit order list (ATC = 0) †

The merit order list gives an idea of the regional social welfare lost through the decrease of the area between the demand and supply curves and how the activation of tenders deviates due to the lack of cross border transmission capacity.

	CROSS BORDER BALANCING PLAFORM					
	TSO perspective					
	Req. Activated [MWh]	Req. Pending [MWh]	Marginal Price [€/MWh]	Energy Settlement [€]	Interconn. Surplus [€]	Settlement [€]
ES	200	0	37.5	0	0	0
FR	0	0	0	0	0	0
PT	100	50	10000	0	0	0
GB	250	0	100	0	0	0

	INTERNAL BALANCING ENERGY MARKETS			
	BSP perspective			BRP perspective
	BSPs Energy [MWh]	Energy Price [€/MWh]	BSPs Settlement [€]	BRPs Settlement [€]
ES	200	37.5	-7500	7500
FR	0	Pay as bid	0	0
PT	100	10000	1000000	-1000000
GB	250	Pay as bid	23125	-23125

Reference Price [€/MWh]
50

Table 5.6 – Summary of the mechanism impact in the internal balancing markets (ATC = 0) †

5.3.2 Results without ATC limits (ATC = ∞)

Now, the four systems fully physically integrated make up a single zone, without energy flow constraints, i.e. the ideal situation to the regional social welfare.

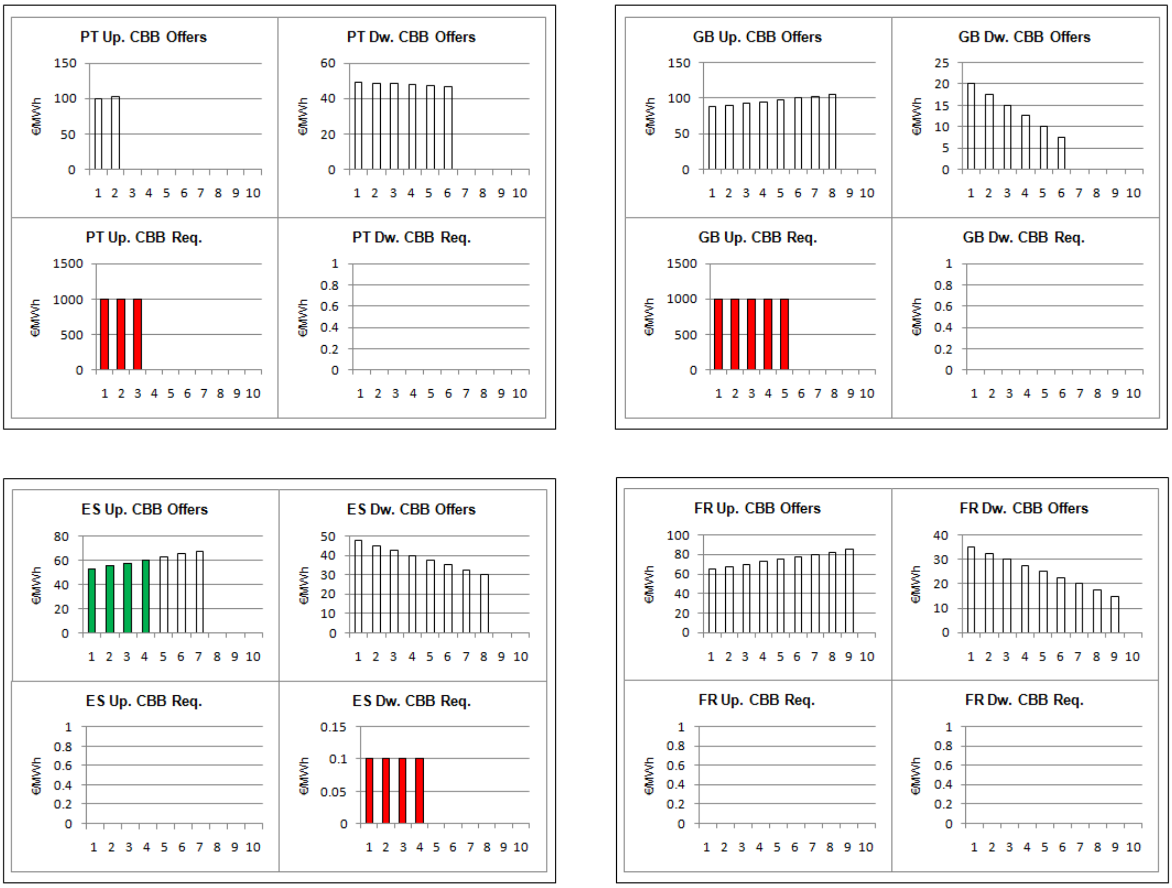

Figure 5.20 – Activated (solid) and not activated (hollow) tenders (ATC = ∞) †

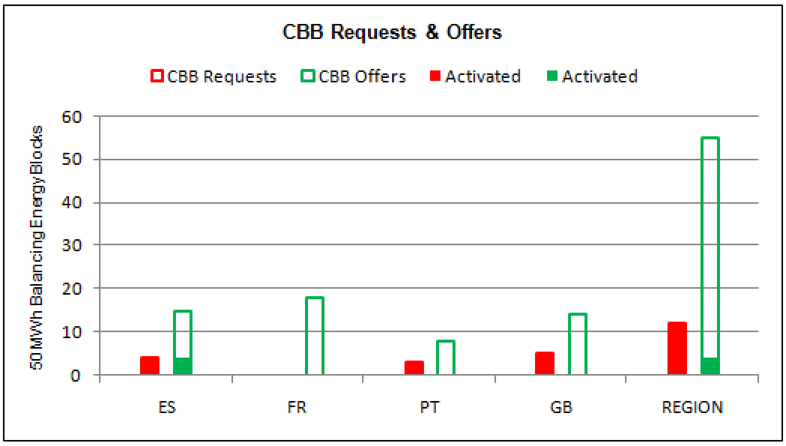

Figure 5.21 – Summary of the tenders' activation outcome (ATC = ∞) †

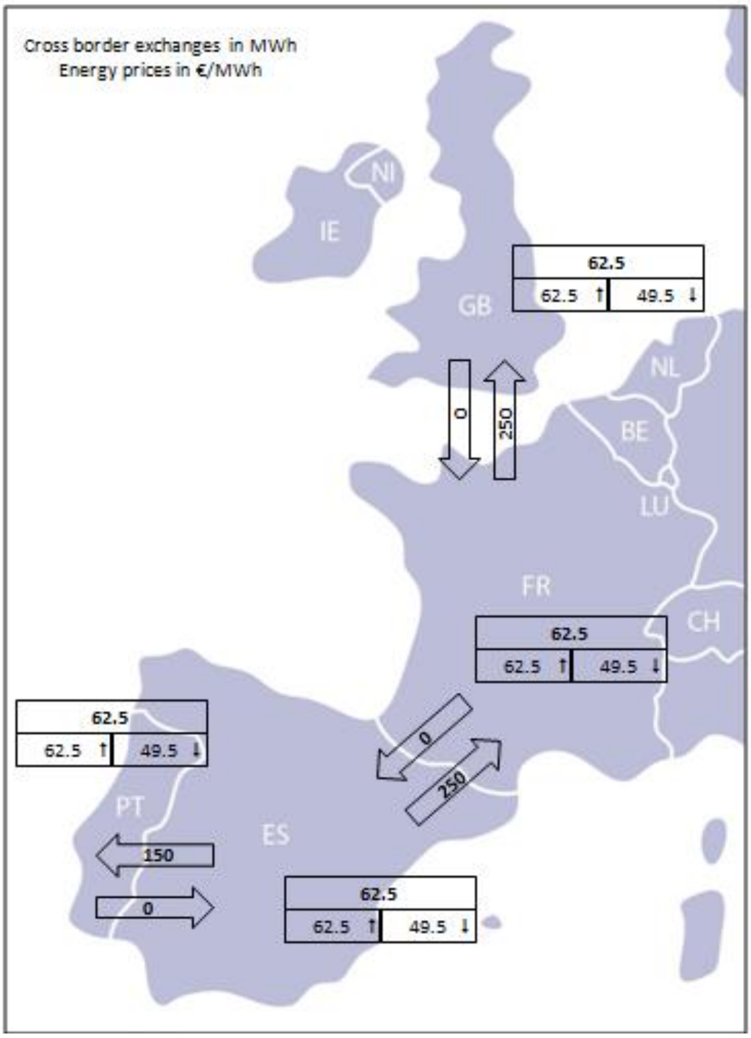

Figure 5.22 – Cross border exchanges (ATC = ∞)
and balancing energy prices (↿ upwards, ⇂ downwards) †

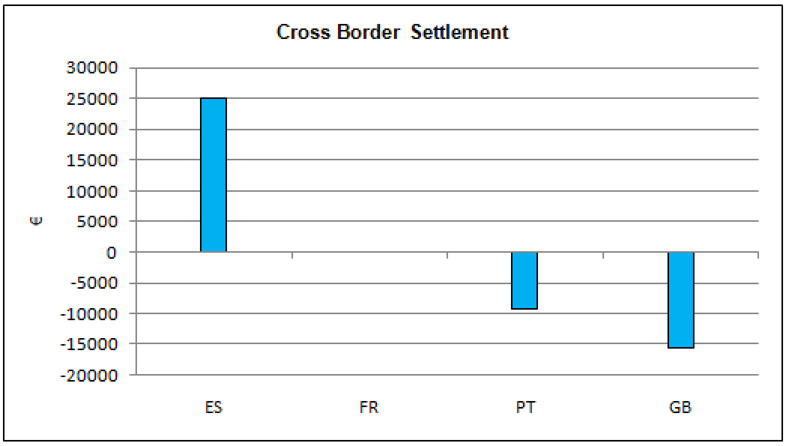

Figure 5.23 – Cross border settlement. Platform financially neutral (ATC = ∞) †

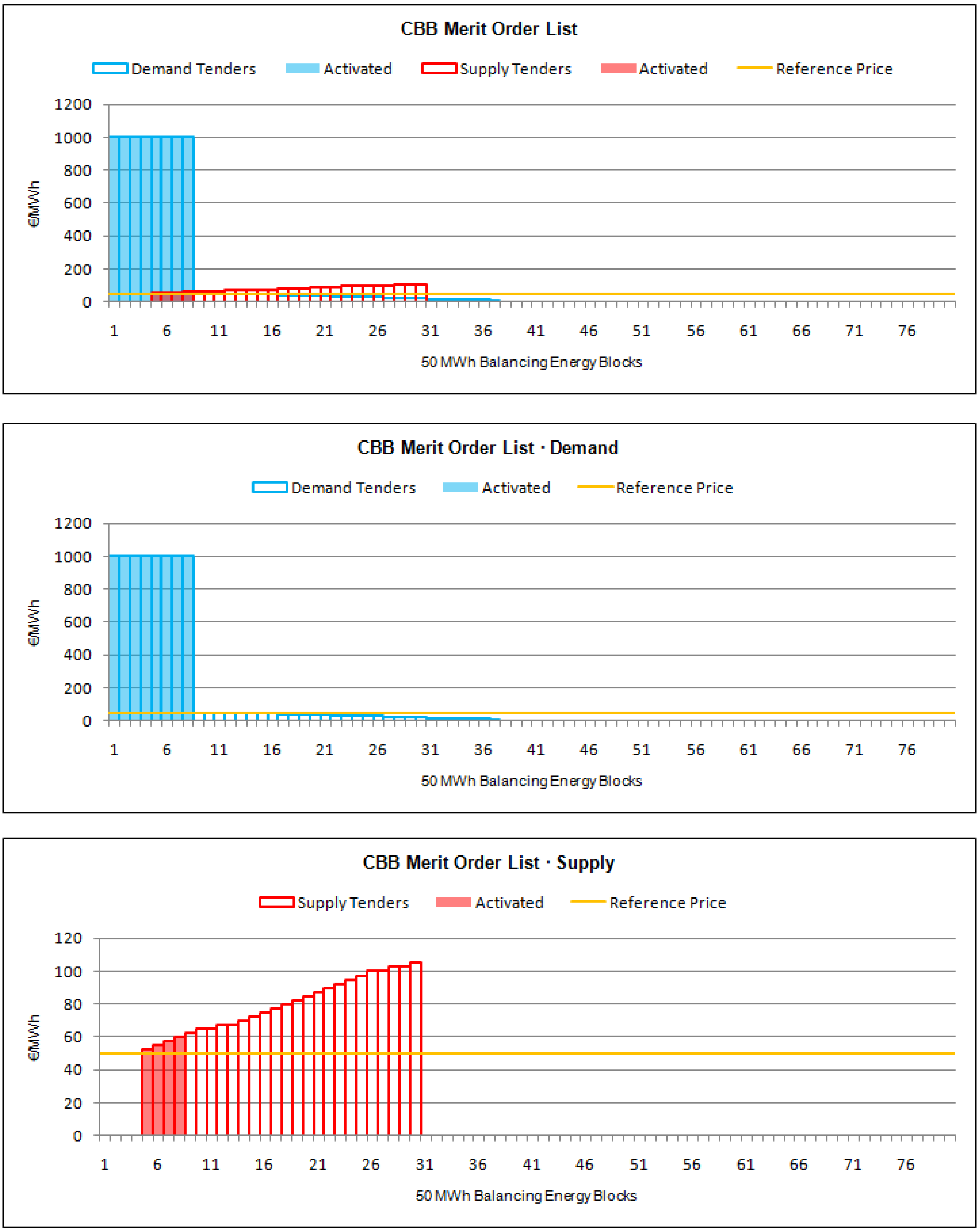

Figure 5.24 – Merit order list (ATC = ∞) †

As expected, there are not any deviations in the merit order list, giving rise to the maximum regional social welfare of the analyzed scenarios.

	CROSS BORDER BALANCING PLAFORM					
	TSO perspective					
	Req. Activated [MWh]	Req. Pending [MWh]	Marginal Price [€/MWh]	Energy Settlement [€]	Interconn. Surplus [€]	Settlement [€]
ES	200	0	62.5	25000	0	25000
FR	0	0	62.5	0	0	0
PT	150	0	62.5	-9375	0	-9375
GB	250	0	62.5	-15625	0	-15625

	INTERNAL BALANCING ENERGY MARKETS			
	BSP perspective			BRP perspective
	BSPs Energy [MWh]	Energy Price [€/MWh]	BSPs Settlement [€]	BRPs Settlement [€]
ES	200	62.5	12500	12500
FR	0	Pay as bid	0	0
PT	0	0	0	-9375
GB	0	Pay as bid	0	-15625

Reference Price [€/MWh]
50

Table 5.7 – Summary of the mechanism impact in the internal balancing markets (ATC = ∞) †

5.3.3 Bilateral trading

The regional model is modified adding one more constraint to the optimization problem on top of the other two. This new feature makes things more difficult than it seems at first sight. Now, the zones are not defined only according to the interconnections, since there is another restriction limiting the energy flow. There are two systems, Portugal and Great Britain, which can only trade with another one, respectively Spain and France. In turn, Spain and France are able to trade with two TSOs each one, respectively Portugal and France, and Great Britain and Spain.

Assuming that there is available transmission capacity, France, for instance, shares its balancing resources with Spain and Great Britain, but it is very important to realize that these three TSOs are not a zone, since Spain and Great Britain cannot exchange services. If the zones definition is not carefully design, it will lead to a distortion in the price formation.

To achieve that the economic signals consider the cost of the balancing resources really involved, the bilateral model splits Spain and France in two subzones, each one with its price.

Box 5.4

Prior to implement these splits, simulations showed how, for example, the cost of the Spanish resources fixed the French cross border balancing energy marginal price at a level much lower than the real cost of the balancing energy sent from France to Great Britain.

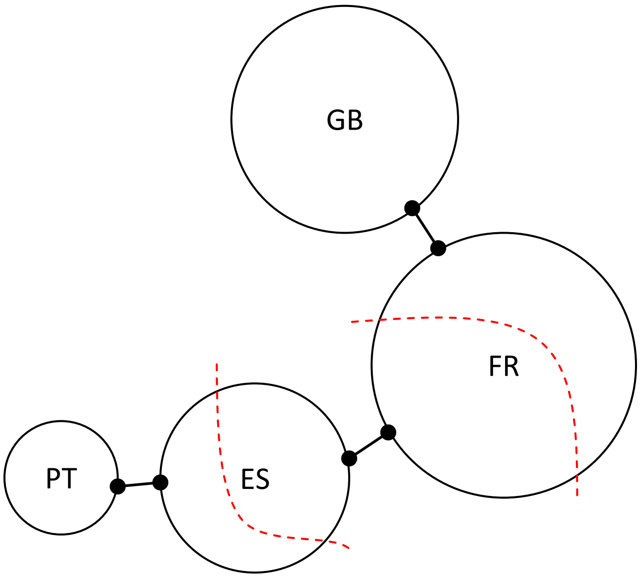

Figure 5.25 – Zones definition by splitting the Spanish and French systems

Having said so, next the results of the platform are included.

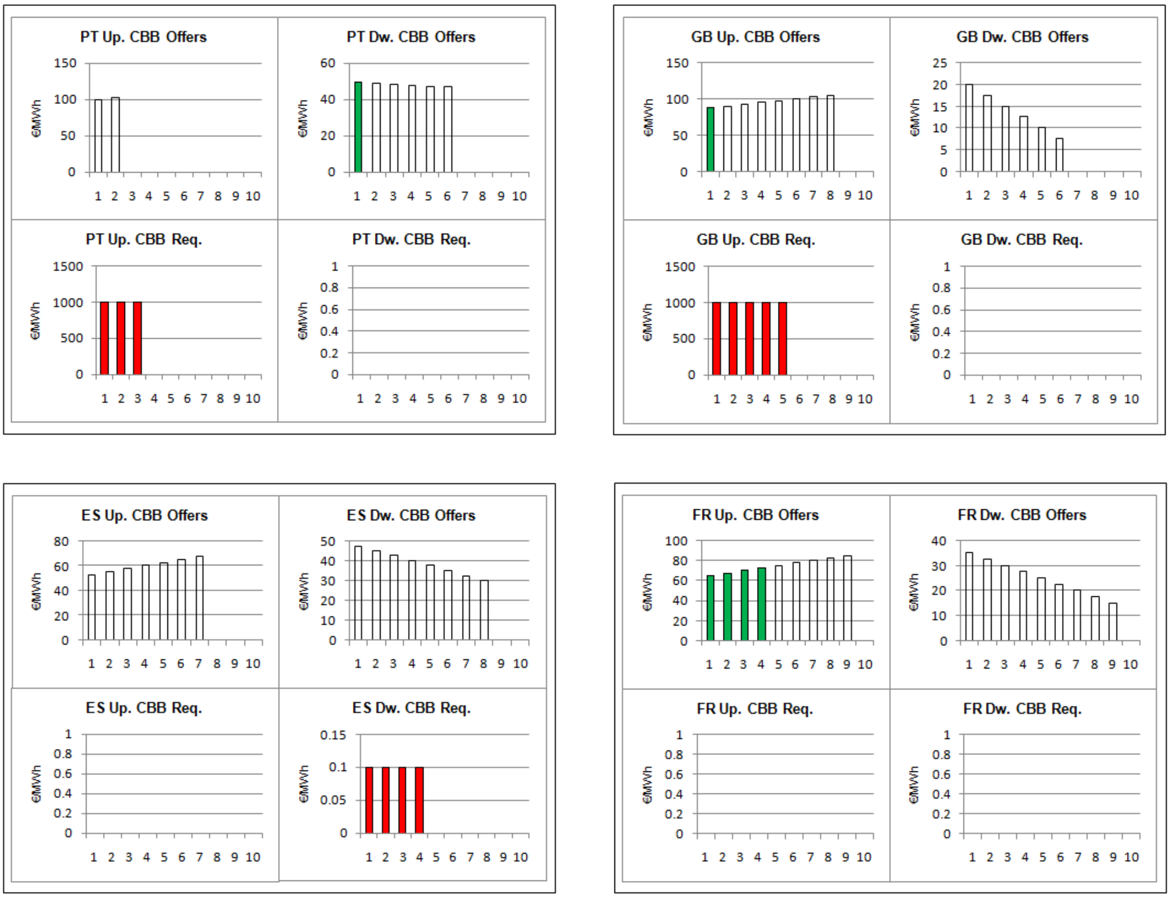

Figure 5.26 – Activated (solid) and not activated (hollow) tenders (bilateral) †

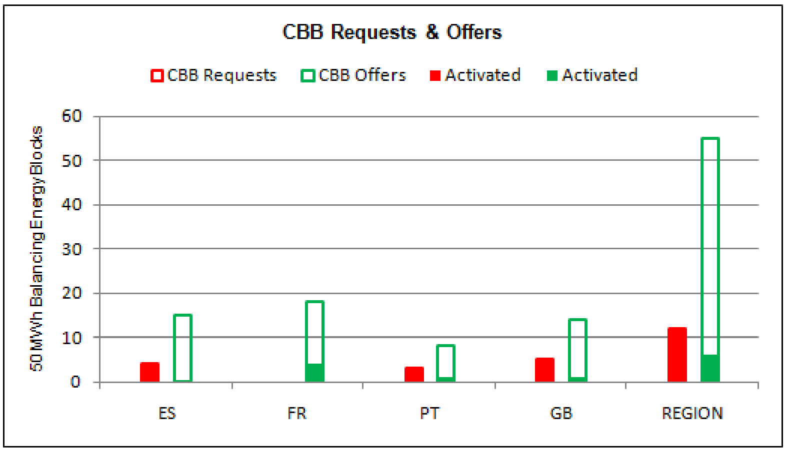

Figure 5.27 – Summary of the tenders' activation outcome (bilateral) †

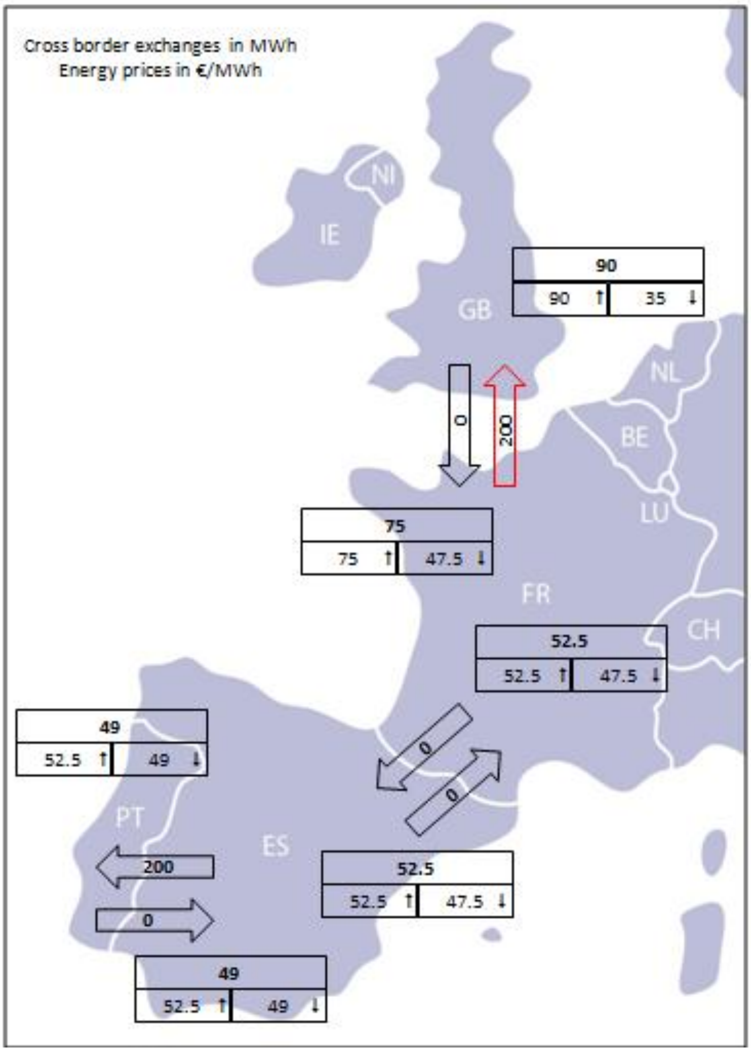

Figure 5.28 – Cross border exchanges (bilateral, interconnection at full capacity in red arrow) and balancing energy prices (↿ upwards, ⇂ downwards) †

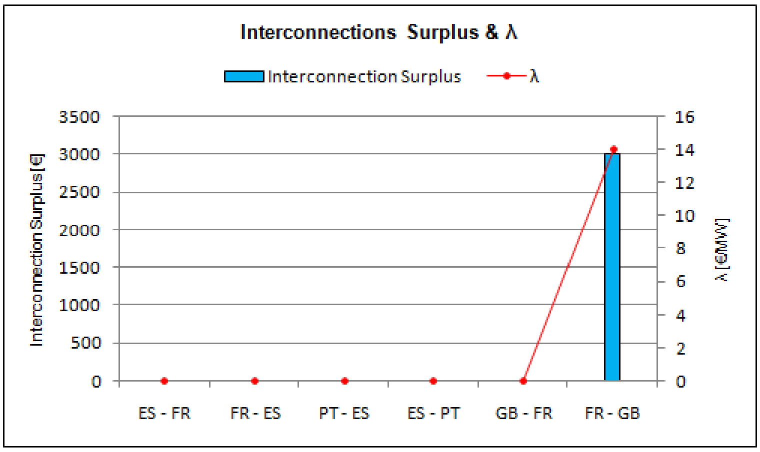

Figure 5.29 – Interconnections economic surplus and Lagrange multipliers (bilateral) †

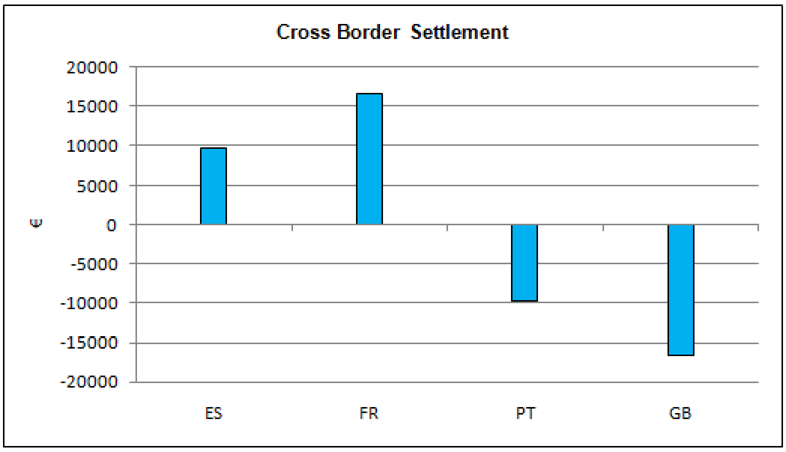

Figure 5.30 – Cross border settlement. Platform financially neutral (bilateral) †

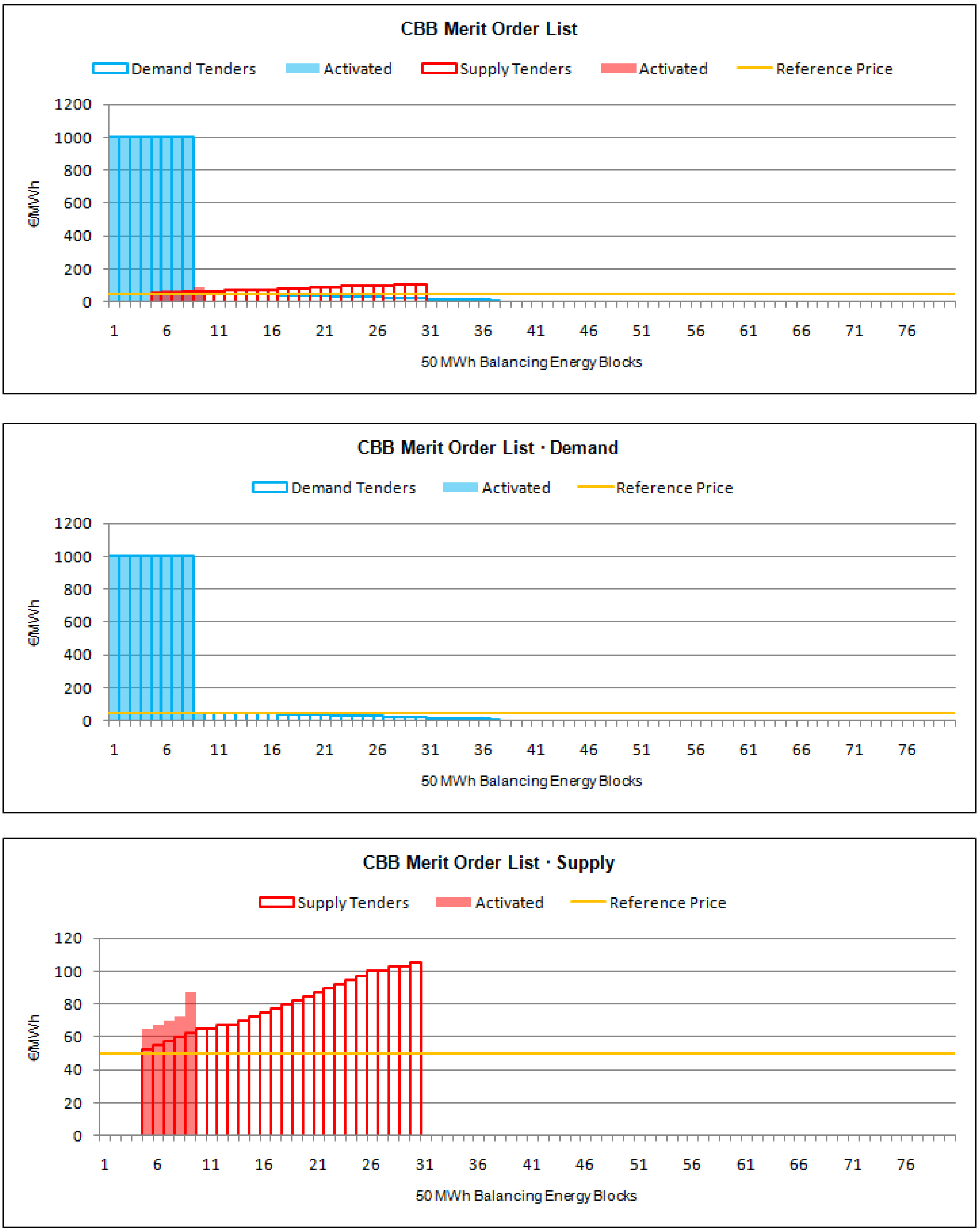

Figure 5.31 – Merit order list (bilateral) †

	CROSS BORDER BALANCING PLAFORM					
	TSO perspective					
	Req. Activated [MWh]	Req. Pending [MWh]	Marginal Price [€/MWh]	Energy Settlement [€]	Interconn. Surplus [€]	Settlement [€]
ES_{PT}	200	0	49	9800	0	9800
ES_{FR}			52.5			
FR_{ES}	0	0	52.5	15000	1500	16500
FR_{GB}			75			
PT	150	0	49	-9800	0	-9800
GB	250	0	90	-18000	1500	-16500

	INTERNAL BALANCING ENERGY MARKETS			
	BSP perspective			BRP perspective
	BSPs Energy [MWh]	Energy Price [€/MWh]	BSPs Settlement [€]	BRPs Settlement [€]
ES	0	0	0	9800
FR	200	Pay as bid	13750	1250
PT	50	49	-2450	-7350
GB	50	Pay as bid	4375	-22375

Reference Price [€/MWh]
50

Table 5.8 – Summary of the mechanism impact in the internal balancing markets (bilateral) †

5.3.4 Price convergence and market liquidity

The main consequences of this evolution in the available transmission capacity or limits to the cross border exchange that are worth to highlight are the price convergence in the region and the increase in the volume of balancing energy traded or liquidity.

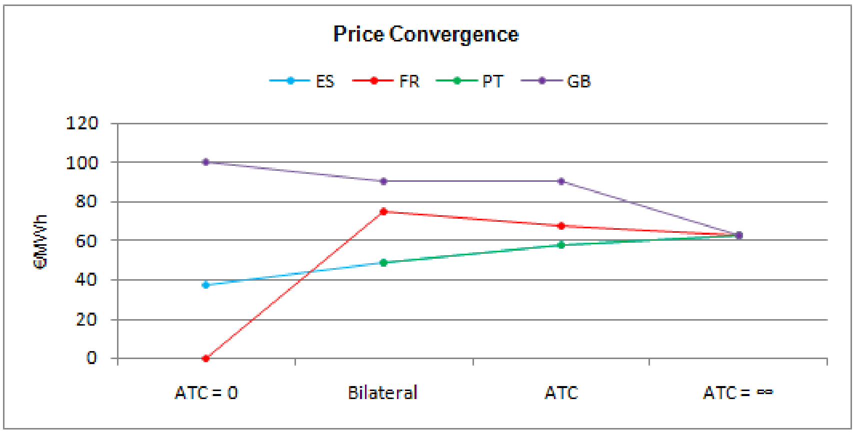

Figure 5.32 – Price convergence[15]

[15] The value for PT at ATC = 0, 10000 €/MWh, has been removed not to distort the information. Anyway, it is important to remember that this imply a non-served energy situation.

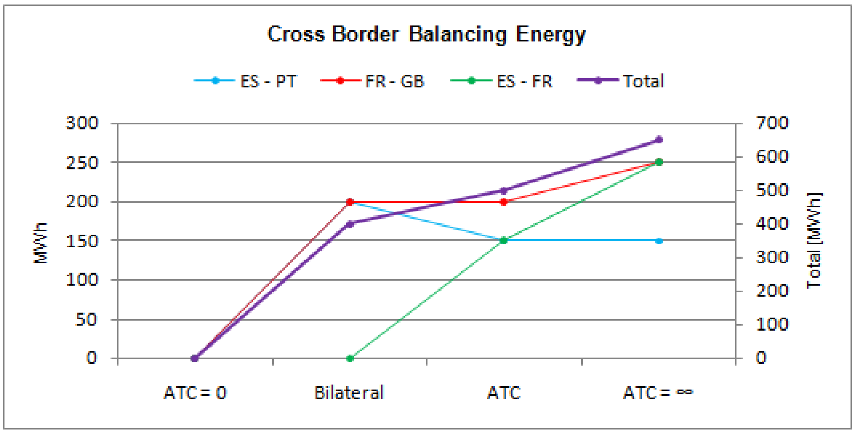

Figure 5.33 – Market liquidity

Box 5.5

It could be striking that when comparing these three cases the regional social welfare is not mentioned, only energy volumes and prices. The reason of this absence is that the social welfare is not really a good parameter when it comes about comparing because of the use of instrumental prices to value the requirements. They are respectively very high and very low with respect to the offers —see any merit order list—, thus the area between the demand and supply curves depends mainly only on the requirements, having little sensitivity to the activation of one offer or another. This effect distorts the interpretation of the results, making that some cases seem similar when they are not. And this does not happen when using balancing energy and prices. The next graph is a good example of the foregoing. Be careful when interpreting it.

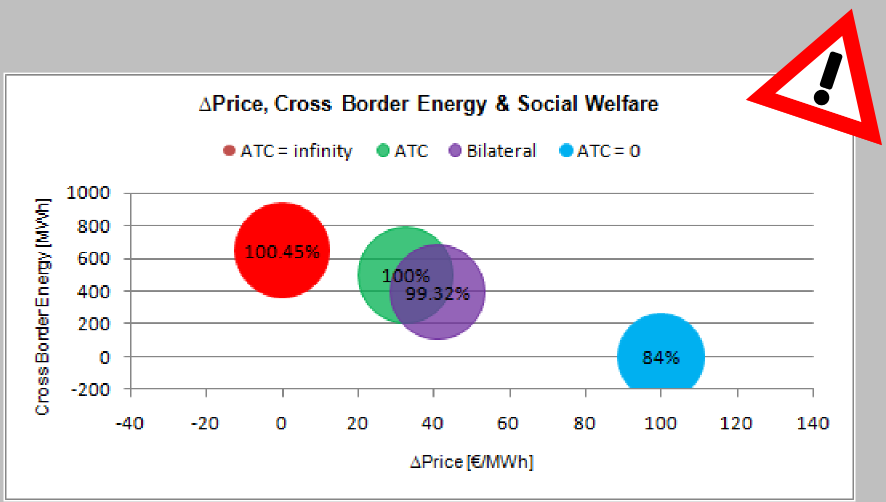

Figure 5.34 – Regional social welfare distorting effect

5.4 THE IMPACT OF THE BIDDING RULE

The platform implements the European target model for the exchange of balancing energy in the long run, which means a common merit order list by sharing all the resources available in each system. This is a very demanding objective. Therefore, it is reasonable to envisage an interim solution to be temporarily applied in the short-term and ease the transition.

Under this approach, TSOs do not share all their offers, but only the surpluses. And now it is when the margin, introduced at the beginning of the chapter, comes into the picture. Each TSO saves for its internal use the necessary offers up to cover its margin, sending to the platform the rest.

They keep submitting all the requirements, but this way of bidding influences how they price them. Now, there is no reason to use instrumental prices, since the willingness to pay or charge can be fixed according to the cost of the put aside offers.

Box 5.6

Before realizing that instrumental prices should not apply under this scheme, the platform showed senseless results. All TSOs cleared all their requirements in the platform using more expensive offers, and therefore, increasing the cross border balancing energy prices and wasting the internal resources.

This gives rise to two situations: surpluses correspond to the first part of the bidding curve or to the last part of the bidding curve. Both are illustrated in the following subsections, changing only the bidding rule with respect to the base case.

5.4.1 Surpluses in the first part of the bidding curve

Probably, the next figure is the most relevant and descriptive of the situation, because it shows the change with respect to the base case. They are the resources and needs that the platform will allocate maximizing the regional social welfare.

Figure 5.35 – Offers (green) and requirements (red) sent to the cross border balancing platform, and reference price (orange) (surpluses in the first part of the bidding curve) †

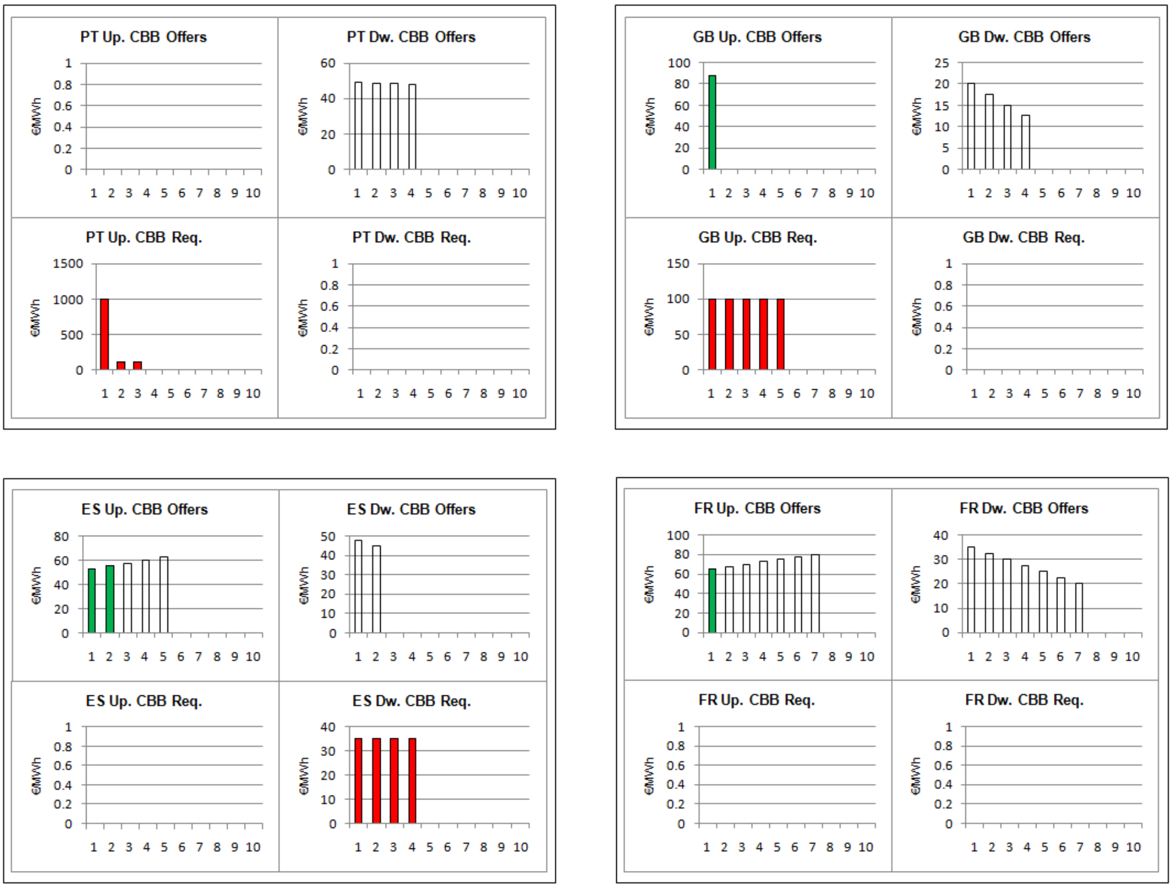

Figure 5.36 – Activated (solid) and not activated (hollow) tenders (surpluses in the first part of the bidding curve) †

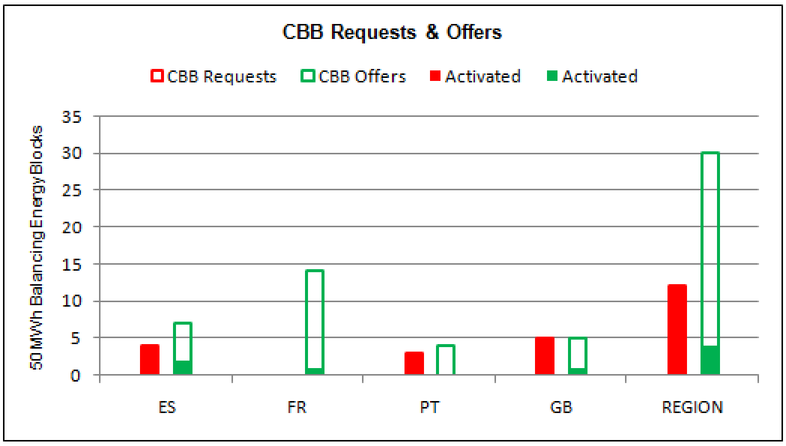

Figure 5.37 – Summary of the tenders' activation outcome (surpluses in the first part of the bidding curve) †

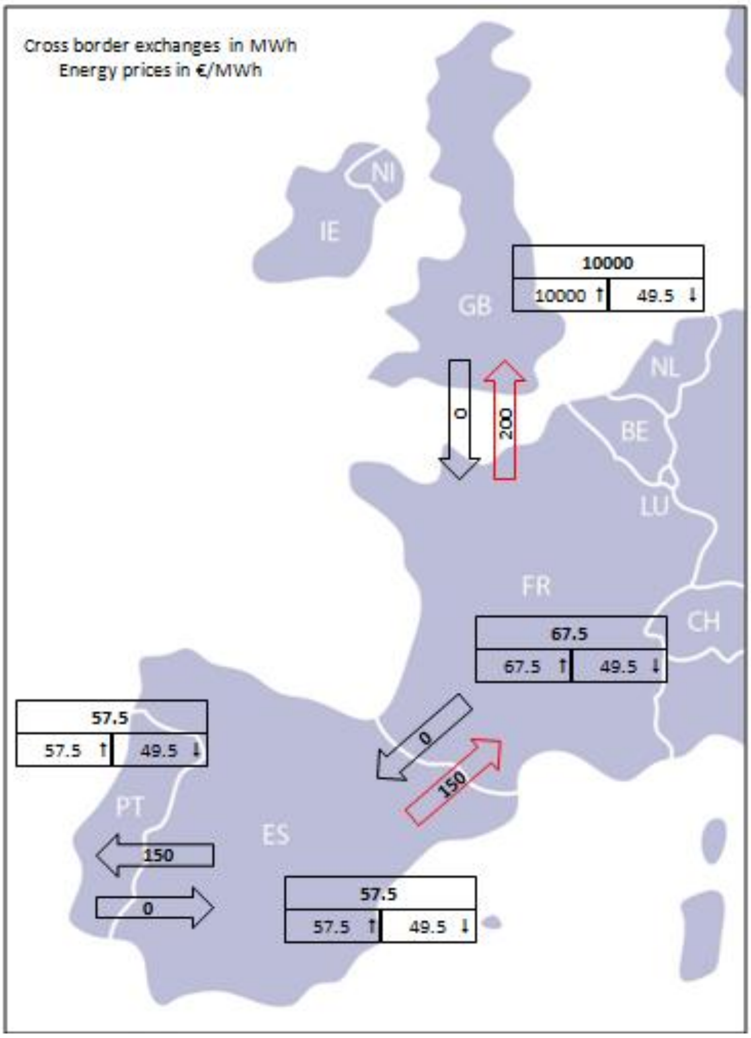

Figure 5.38 – Cross border exchanges (surpluses in the first part of the bidding curve, interconnections at full capacity in red arrows) and balancing energy prices (↑ upwards, ↓ downwards) †

This example is very similar to the base case except one result: the price in Great Britain. It has enough internal resources, but, from the platform perspective, it has no more offers regionally available, and the energy is consequently priced.

This is the risk TSOs incur when saving resources while they take part in the regional mechanism.

Interconnections economic surplus and settlement figures are not included since they are distorted by this high price.

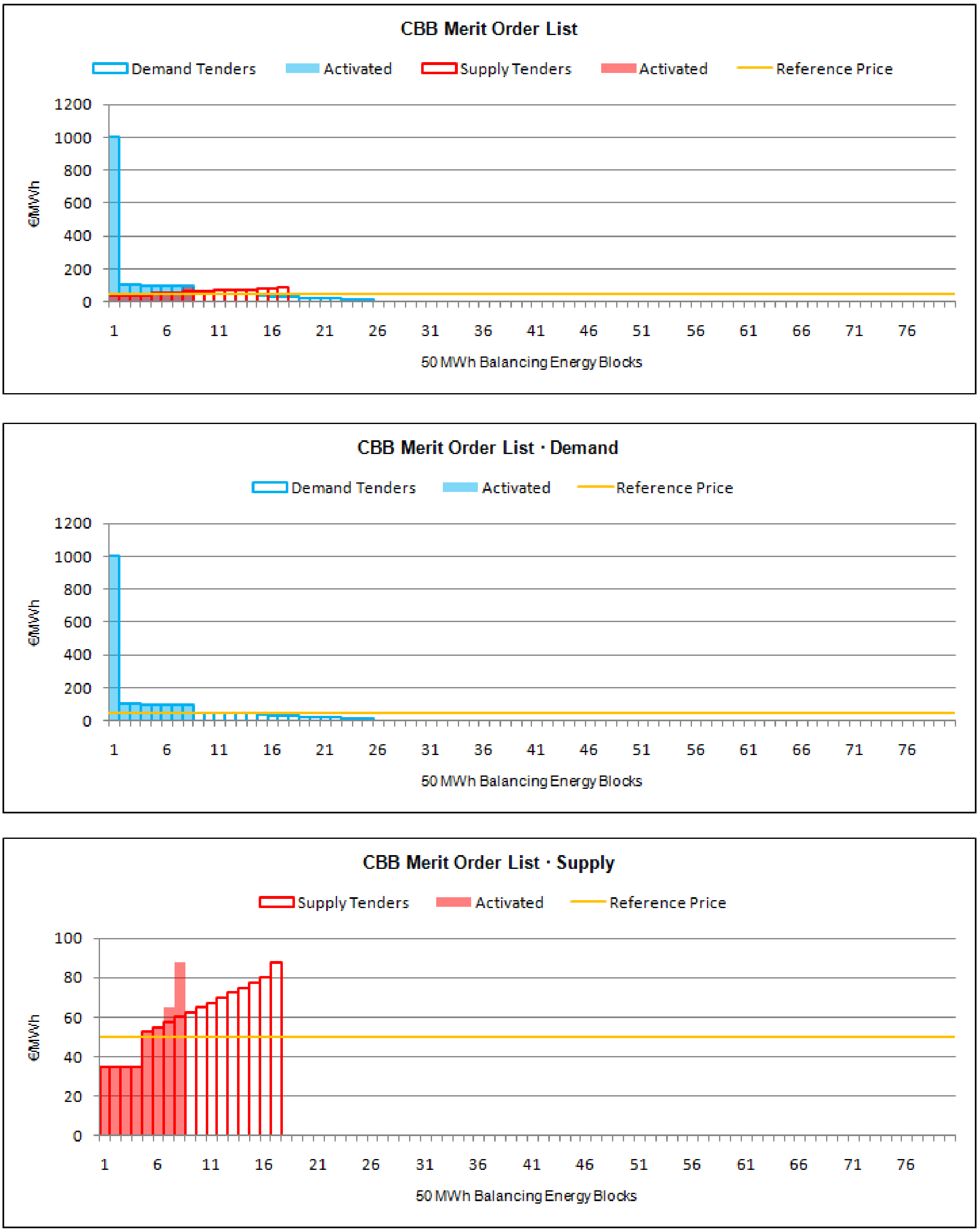

Figure 5.39 – Merit order list (surpluses in the first part of the bidding curve) †

	CROSS BORDER BALANCING PLAFORM					
	TSO perspective					
	Req. Activated [MWh]	Req. Pending [MWh]	Marginal Price [€/MWh]	Energy Settlement [€]	Interconn. Surplus [€]	Settlement [€]
ES	200	0	57.5	17250	750	18000
FR	0	0	67.5	3375	994000	997375
PT	150	0	57.5	-8625	0	-8625
GB	250	0	10000	-2000000	993250	-1006750

	INTERNAL BALANCING ENERGY MARKETS			
	BSP perspective			BRP perspective
	BSPs Energy [MWh]	Energy Price [€/MWh]	BSPs Settlement [€]	BRPs Settlement [€]
ES	100	57.5	5750	11500
FR	50	Pay as bid	3250	125
PT	0	0	0	-8625
GB	50	Pay as bid	4375	-2004375

Reference Price [€/MWh]
50

Table 5.9 – Summary of the mechanism impact in the internal balancing markets (surpluses in the first part of the bidding curve) †

5.4.2 Surpluses in the last part of the bidding curve

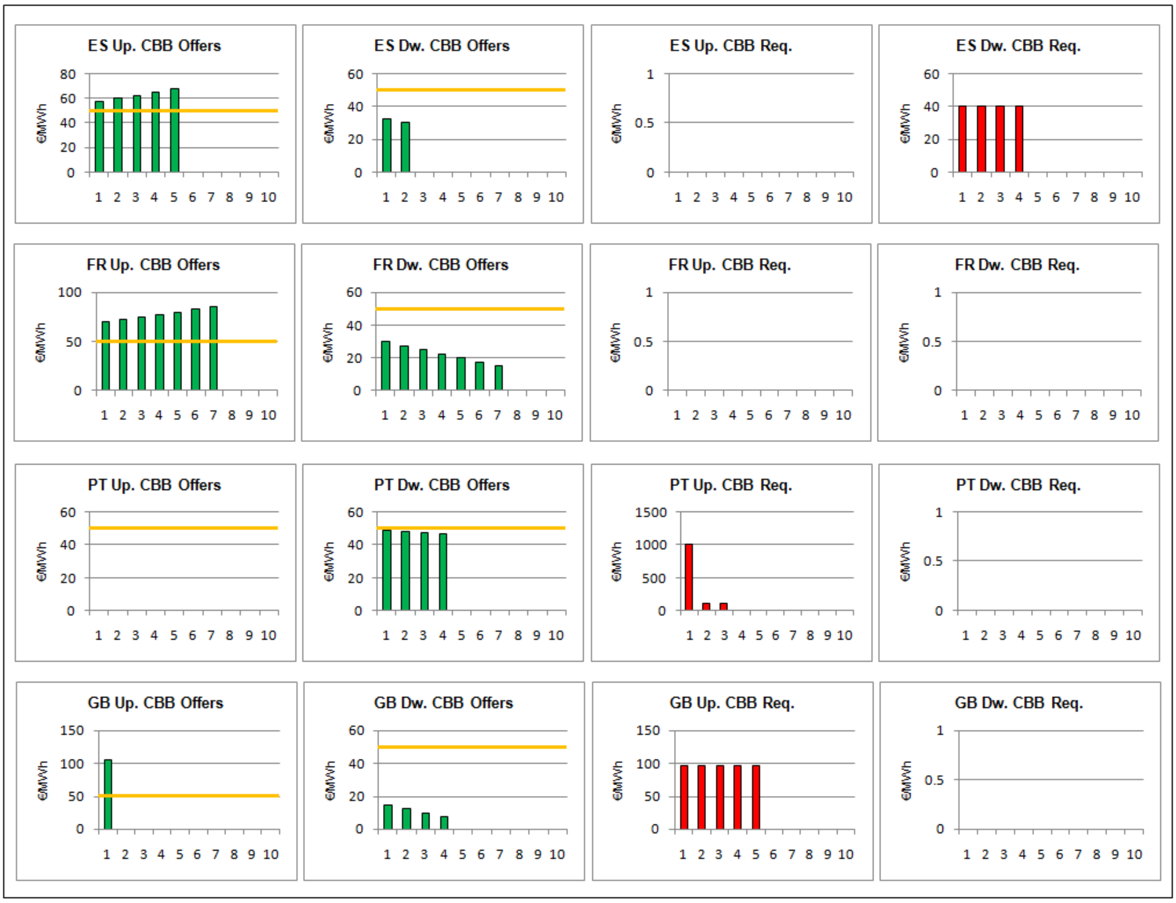

Figure 5.40 – Offers (green) and requirements (red) sent to the cross border balancing platform, and reference price (orange) (surpluses in the last part of the bidding curve) †

Figure 5.41 – Activated (solid) and not activated (hollow) tenders (surpluses in the last part of the bidding curve) †

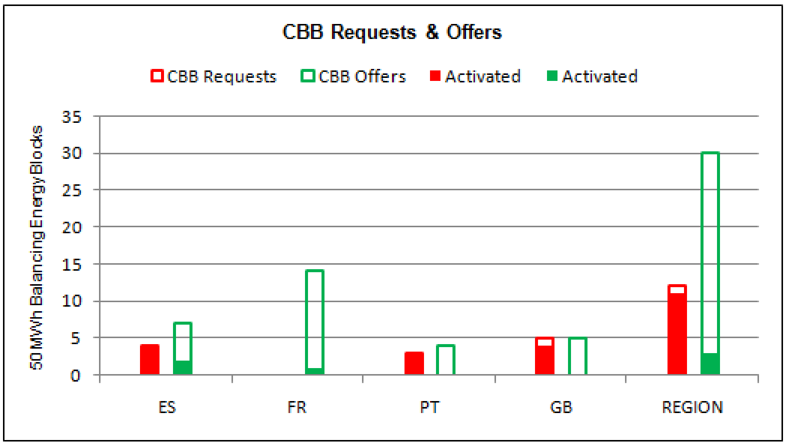

Figure 5.42 – Summary of the tenders' activation outcome (surpluses in the last part of the bidding curve) †

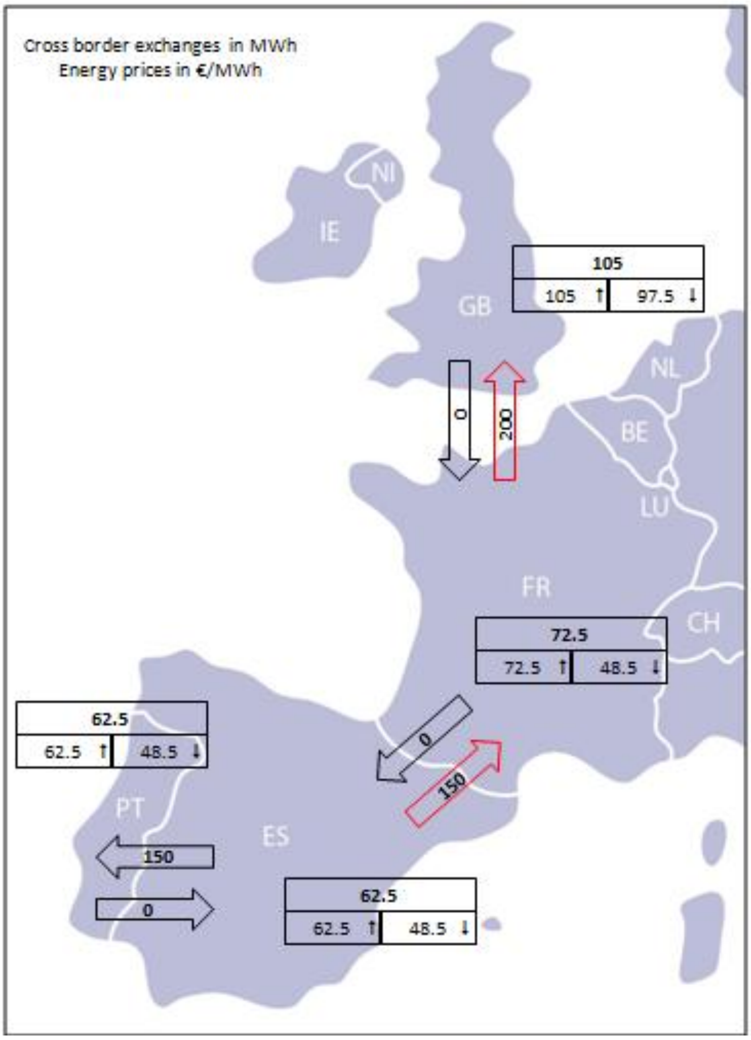

Figure 5.43 – Cross border exchanges (surpluses in the last part of the bidding curve, interconnections at full capacity in red arrows) and balancing energy prices (↿ upwards, ⇂ downwards) †

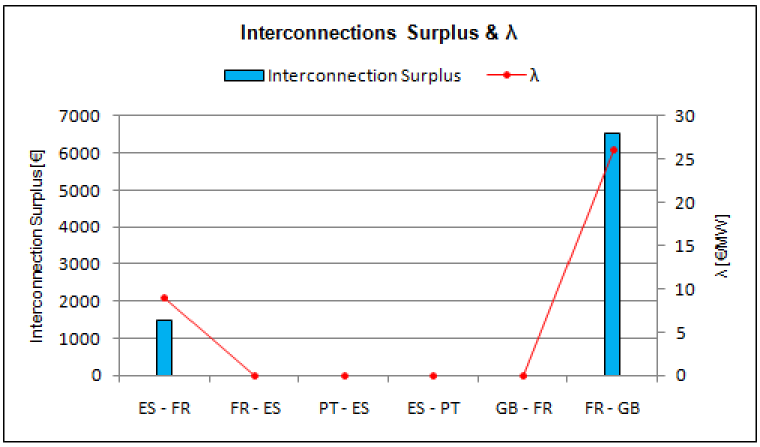

Figure 5.44 – Interconnections economic surplus and Lagrange multipliers (surpluses in the last part of the bidding curve) †

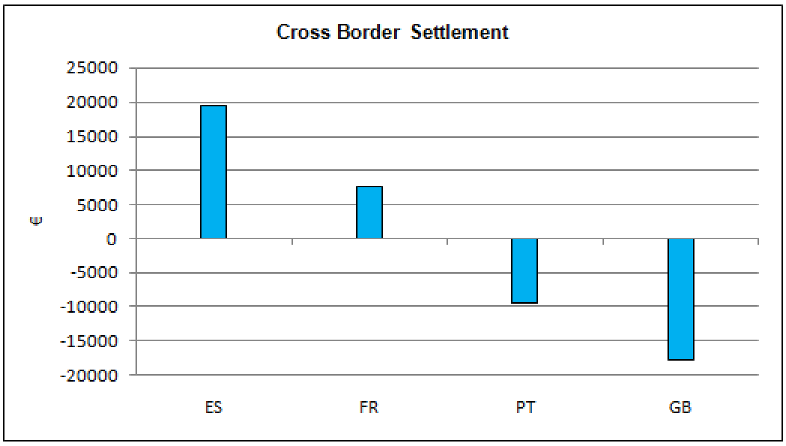

Figure 5.45 – Cross border settlement. Platform financially neutral (surpluses in the last part of the bidding curve) †

By comparing this result to the base case (figure 5.7 and figure 5.43), it reveals the inefficiency of this bidding rule, since it increases the prices for the same balancing needs, while wasting more competitive resources internally saved.

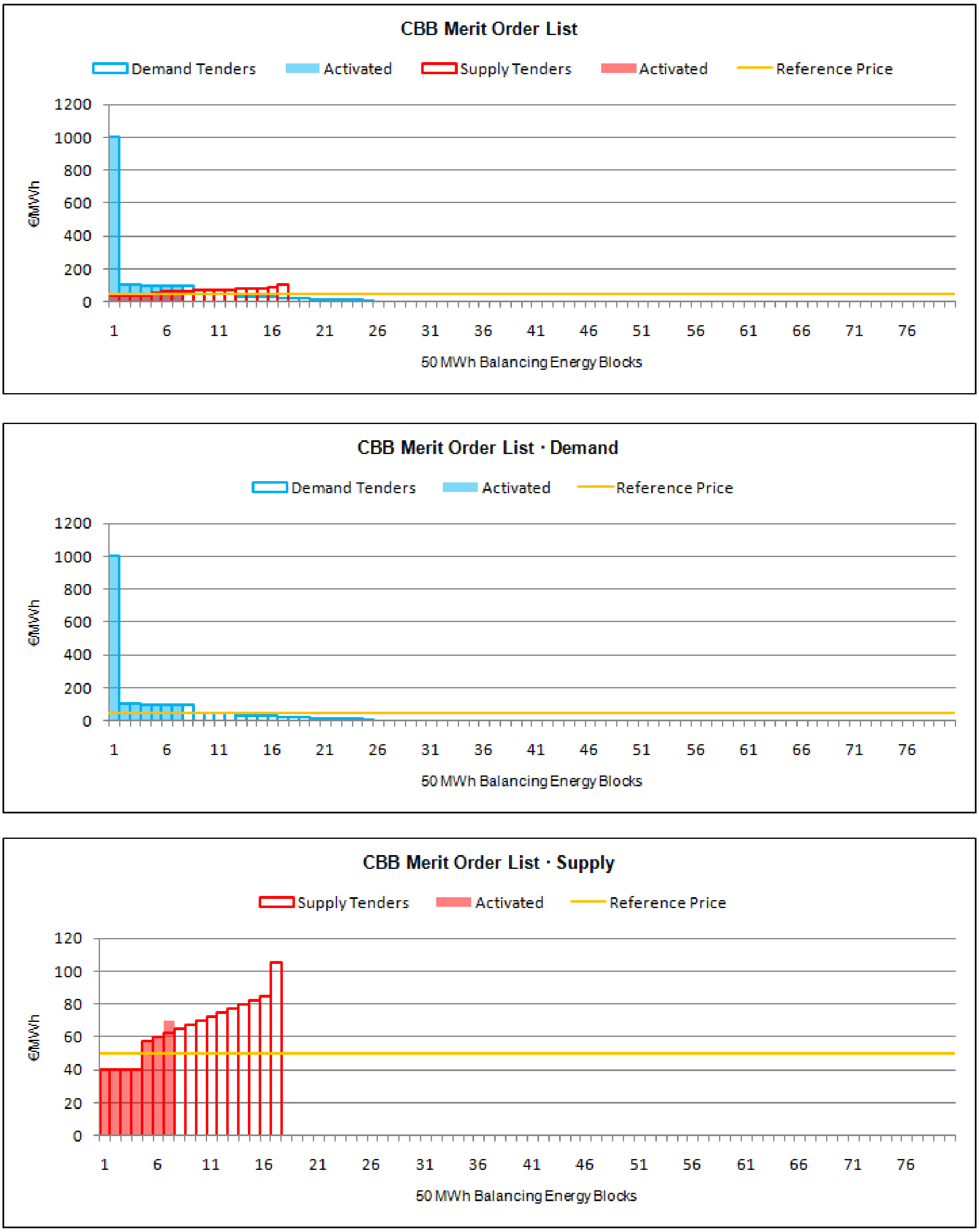

Figure 5.46 – Merit order list (surpluses in the last part of the bidding curve) †

	CROSS BORDER BALANCING PLAFORM					
	TSO perspective					
	Req. Activated [MWh]	Req. Pending [MWh]	Marginal Price [€/MWh]	Energy Settlement [€]	Interconn. Surplus [€]	Settlement [€]
ES	200	0	62.5	18750	750	19500
FR	0	0	72.5	3625	4000	7625
PT	150	0	62.5	-9375	0	-9375
GB	200	50	105	-21000	3250	-17750

	INTERNAL BALANCING ENERGY MARKETS			
	BSP perspective			BRP perspective
	BSPs Energy [MWh]	Energy Price [€/MWh]	BSPs Settlement [€]	BRPs Settlement [€]
ES	100	57.5	5750	13000
FR	50	Pay as bid	3250	375
PT	0	0	0	-9375
GB	50	Pay as bid	4375	-25375

Reference Price [€/MWh]
50

Table 5.10 – Summary of the mechanism impact in the internal balancing markets (surpluses in the last part of the bidding curve) †

5.5 COMPUTING PERFORMANCE

The following sketch outlines the structure of the platform for a computational point of view, showing the modules and their relationships.

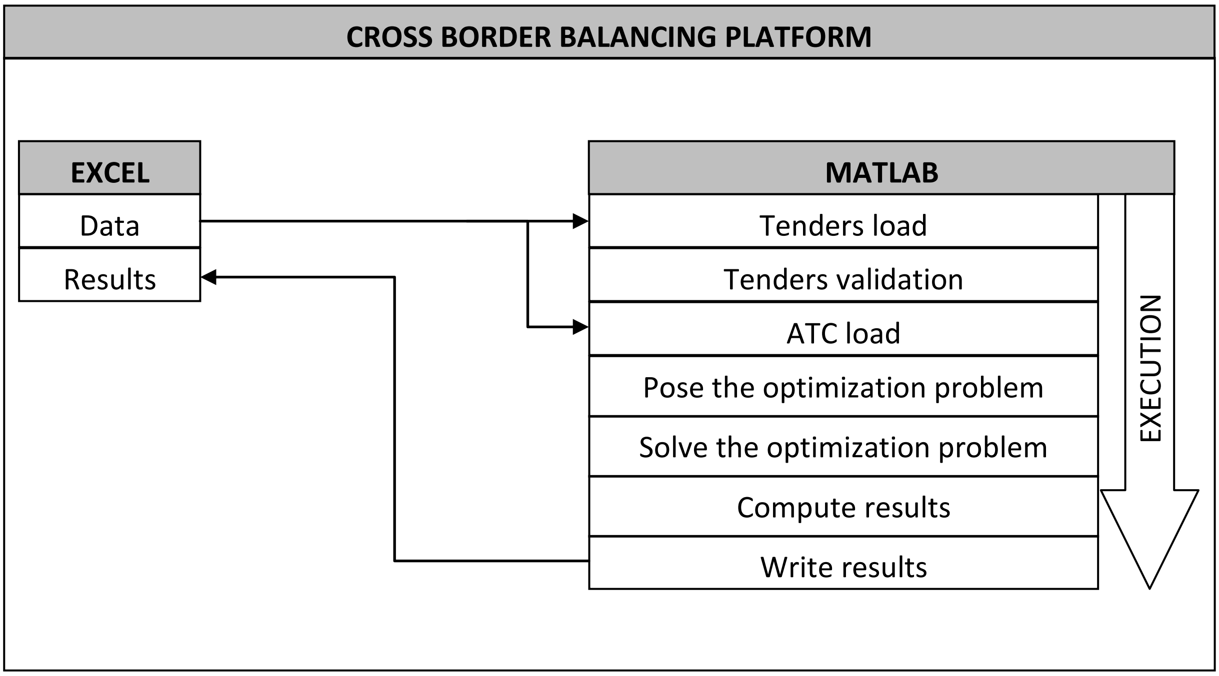

Figure 5.47 – Platform computational structure

When executing the code, a wait bar pops up to trace the progress and remaining time.

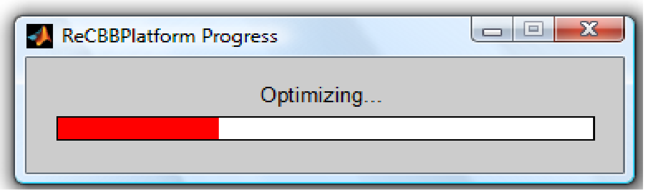

Figure 5.48 – Wait bar

Finally, the platform gives information about the computing performance of the algorithm, very useful to debug the code and asses the software time demand.

Computing Performance	
Linear optimization result	1
Linear optimization iterations	9
Integer optimization result	1
Integer optimization iterations	16
Integer optimization elapsed time [s]	0.86
Total elapsed time [s]	491

Table 5.11 – Algorithm computing performance

CHAPTER 6
CONCLUSIONS

Coming back to the main objective of this work, namely, to design a regional market for manually-activated balancing energy exchange based on optimization techniques for its clearing, this research provides some relevant findings to consider when dealing with the implementation of a mechanism following a TSO-TSO model with a common merit order list.

Moreover, the analysis through simulations of how the model behaves also yields important results about the influence of some key variables in the mechanism outcome.

6.1 CONCLUSIONS TO THE MARKET DESIGN

It is necessary to avoid the non-desirable offer-offer allocation effect, both between systems and within the same system. The trade must focus on balancing services, putting aside energy commercial transactions.

Instrumental prices must effectively reflect the TSOs willingness to procure the needed balancing energy to meet their requirements. Therefore, they must cohere with offers prices, including a cap and floor is necessary.

The clearing outcome and the corresponding balancing energy exchanges and zones do not depend on the pricing methodology, which must fulfill with the following rules: it must be cost-reflective with respect to the balancing resources activated; it must mean an incentive for BRPs to keep balanced; prices must be equal within a non-congested zone; and balancing services flows must have economical sense.

That is why the marginal price must be fixed according to the balancing resources used and, if no BSP results cleared, according to the net balancing requirement.

For the platform to be financially neutral in its function as central counterpart in the settlement process, the economic surplus resulting from the interconnections —if some is at full capacity—, must be given back to the incumbent TSOs.

TSOs must be also financially neutral, so the corresponding procedure has to be applied for the allocation of any economic surplus as a result of the settlement processes.

The merit order list does not show a matching between one balancing energy block and other —graphically— on top of it. It is necessary to be careful when interpreting its meaning.

6.2 CONCLUSIONS TO THE PERFORMANCE ANALYSIS

The available transmission capacity between electric systems plays a fundamental role in the integration of balancing markets, as it does any other market rule —for instance, bilateral trading— preventing energy from freely flowing.

Its impact on regional price convergence and volumes of cross border balancing energy exchanged is huge.

Regarding the bidding rule, if not all the balancing resources are shared in the platform, saving TSOs some of them for their internal use, the next three main conclusions can be drawn.

There is no reason to use instrumental prices, since balancing requirements can be priced according to the put aside offers.

TSOs risk being settled at the non-served energy price, since from the platform perspective it could seem that there are not enough balancing resources, when in reality there are.

On the other hand, prices yielded by the regional mechanism may not reflect the real cost of the balancing resources, highly pricing them in comparison with the outcome of a common merit order list sharing all the available balancing resources.

6.3 FUTURE RESEARCH

On the grounds of this work, there are interesting issues to tackle both to complement its content keeping within the same scope and to extent it beyond. Hereunder, some suggestions:

- Compare the results of the model to a real situation under the current mechanism.
- Platform governance and financing.
- Deeply review the effect of marginal pricing in regional markets on pay-as-bid national markets with respect to imbalance settlement.
- Analyze the impact of simultaneously changing two variables, both available transmission capacity and bidding rule.
- Implement the use of divisible blocks, allowing offers partial activation.
- Include new interconnections between currently non-connected systems.
- Add new systems to the regional model.

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[ACER12] ACER. Framework Guidelines on Electricity Balancing. FG-2012-E-009. September 2012.

[ENTS14] ENTSO-E. Network Code on Electricity Balancing. August 2014 —adoption in process.

[ENTS14_1] ENTSO-E, Ancillary Services Working Group. Survey on ancillary services procurement and balancing market design. February 2014.

[ENTS14_2] ENTSO-E. Yearly statistics and adequacy retrospect 2013. 15 December 2014.

[ENTS14_3] ENTSO-E. Balancing Pilot Projects. December 2014.

[CNMC14] Comisión Nacional de los Mercados y la Competencia. Circular 2/2014, de 12 de marzo, de la Comisión Nacional de los Mercados y la Competencia, por la que se establece la metodología relativa al acceso a las infraestructuras transfronterizas, incluidos los procedimientos para asignar capacidad y gestionar la congestión, así como la metodología relativa a la prestación de servicios de equilibrio entre sistemas gestionados por distintos operadores del sistema. BOE núm. 65, de 17 de marzo de 2014.

[CNMC14_1] Comisión Nacional de los Mercados y la Competencia. Resolución por la que se aprueba el procedimiento de intercambio transfronterizo de energías de balance. Marzo de 2014.

[REE_14] Red Eléctrica de España. Cross border balancing services in the Spanish electric system. June 2014.

RECOMMENDED WEBPAGES

ACER - www.acer.europa.eu/Pages/ACER.aspx
CEER - www.ceer.eu/portal/page/portal/EER_HOME
ENTSO-E - www.entsoe.eu/Pages/default.aspx
IESOE - www.iesoe.eu/iesoe/
REE – www.ree.es
REN - www.ren.pt/
RTE - www.rte-france.com/
NG - www2.nationalgrid.com/uk/

RECOMMENDED VIDEOS AND GAMES

¡Cómo tiramos de la luz! El juego del equilibrio eléctrico (Spanish)
www.ree.es/es/educaree/videos/como-tiramos-de-la-luz

CONTROLA game
www.ree.es/es/educaree/juego-controla

APPENDICES

APPENDIX 1
GLOSSARY OF TERMS

APPENDIX 2
LIST OF EXCEL AND MATLAB FILES

APPENDIX 1
GLOSSARY OF TERMS

A

ACER or the Agency. Agency for the Cooperation of Energy Regulators.

ATC or AVAILABLE TRANSMISSION CAPACITY. Cross border capacity that remains vacant after the last binding intraday market session and therefore available for balancing energy trading between TSOs.

B

BALANCING. All actions and processes through which TSOs balance the system —generation-demand— in real time, and thus, maintain the system frequency within a predefined range.

BALANCING ENERGY. Energy [MWh] injected or withdrawn by generators or loads at their TSOs request to perform balancing.

BRP or BALANCING RESPONSIBLE PARTY. A market-related entity or its chosen representative responsible for keeping a given schedule, assuming financial responsibility in case of deviations.

BSP or BALANCING SERVICE PROVIDER. A market participant providing balancing services to its TSO.

C

CBB or CROSS BORDER BALANCING. Mechanism for the exchange of balancing energy between TSOs.

CoBA or COORDINATED BALANCING AREA. A cooperation with respect to the exchange of balancing services, sharing of reserves or operating the imbalance netting process between two or more TSOs.

CONTROL AREA. A coherent part of the interconnected system, operated by a single TSO responsible for P-f control for physical loads and generation units connected.

E

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

F

FRR or FREQUENCY RESTORATION RESERVES. Operating reserves used to restore frequency to the nominal value and power balance to the scheduled value after sudden system imbalance occurrence. This category includes operating reserves with an activation time typically up to 15 minutes — depending on the specific requirements of the synchronous area. Operating reserves of this category are typically centrally activated and can be activated automatically or manually.

G

GATE CLOSURE. Deadline for the participation in a given market or mechanism.

M

MARGIN. Reserve kept by a TSO above the foreseeable requirement for security reasons.

MERIT ORDER LIST. In the balancing markets a merit order list is a list of all valid balancing offers submitted by BSPs and sorted out in order of their prices.

P

P-f CONTROL. Active power-system frequency control.

R

RR or REPLACEMENT RESERVES. Operating reserves used to restore the required level of operating reserves to be prepared for a further system imbalance. This category includes operating reserves with activation time from 15 minutes up to hours.

S

SWE. Southwest Europe region, which encompasses Portugal, Spain and France.

T

TSO. Transmission system operator.

Z

ZONE. Set of TSOs that are able to share their balancing resources without causing any congestion, so a unique balancing energy price can be established within the zone.

APPENDIX 2
LIST OF EXCEL AND MATLAB FILES

Regional model

ReData&Results.xlsx
ReCBBPlatform.m
ReMPesScript.m
ReMPfrScript.m
ReMPptScript.m
ReMPgbScript.m

Bilateral model

BiData&Results.xlsx
BiCBBPlatform.m
BiMPesfrScript.m
BiMPesptScript.m
BiMPfresScript.m
BiMPfrgbScript.m
BiMPptScript.m
BiMPgbScript.m