Impact of tertiary reserve sharing in Portugal

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Abstract
Ancillary services play a fundamental role in the operation of electricity systems. In the Iberian Peninsula, since mid-2014, ancillary services have gained a transnational dimension, namely through the introduction of cross-border balancing replacement reserves between the Portuguese and the Spanish Transmission System Operators (TSOs). This paper evaluates the impact of replacement reserves on the Portuguese electricity system, from the onset of this mechanism until the end of 2017, as a new contribution to earlier studies. It also describes the pecuniary impact of tertiary transactions, the identification, and categorization of possible different scenarios of tertiary mobilization, and the respective impact on the internal tertiary mobilization. On the one hand, the Iberian electricity system is one of the most influenced by a high penetration of intermittent renewables, and therefore one of the best candidates to experience increased benefits from the platform. On the other hand, the Portuguese TSO is one of the most peripheral TSOs in Europe that benefits more from the market integration in various dimensions of the electricity sector.

Keywords: *System Operator; Ancillary Services; Tertiary Reserve; Electricity Market; Cross-Border Exchange*

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1. Introduction

The European power system is expected to integrate a considerable amount of renewable energy in the medium term [1]. In the Portuguese case, there is currently a considerable penetration of renewable energy. Data from 2014 mentioned that wind generation alone produces 24.1% of the total electricity produced in Portugal - more than coal, which has 22.6% and approximately twice that of natural gas, with 12.9%. Furthermore, the outlook is for the share of renewable energy to increase [2]. From the System Operator's (SO) point of view, this degree of renewable penetration raises new challenges to balance management due to the limited predictability and controllability of the renewable resources [3], [4]. On the other hand, the European Commission's political goal is to incentivize the further development of the internal Electricity Market and a harmonized balancing market across Europe, promoting the improvement of cooperation between all energy actors, in which cross-border exchanges (CBX) are included [5], [6], [7].

The European Network of Transmission System Operators for Electricity (ENTSO-E) defines operating reserves for balancing actions in three categories: primary, secondary, and tertiary [8]. The tertiary

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control reserve, known as the Manual Frequency Restoration Reserve *(mFRR*), is the mechanism that allows the SO to maintain equilibrium among consumption, generation, and programmed interconnection [9].

Until recently in Europe, each country generally had its own balancing market design, which applied to its own control area and internal energy suppliers [3], [10], [11]. Like other regions, such as Northern Europe, and in the framework of the Electricity Regional Initiative South West Europe, the involved TSOs (REN, REE, and RTE in Portugal, Spain, and France, respectively) have been working on the implementation of a Cross-Border Balancing reserve regulation mechanism [1], [12], [13]. In 2013, two bilateral provisional solutions between REN-REE and REE-RTE were considered to allow the implementation of cross-border balancing mechanisms, more specifically the sharing of Replacement Reserves (*RR*) in a TSO-TSO model, according to the Network Code on Electricity Balancing published by ENTSO-E [14]. This temporary solution was based on and adapted from the cross-border mechanism implemented between National Grid (the English TSO) and RTE (the French TSO), called BALIT (balancing inter-TSO) and was designed and developed by RTE [15]. Meanwhile, the involved actors are studying the design and development of a long-term regional and permanent solution (REN-REE-RTE) multi-TSO platform, extensible to other interconnected areas. The exchange of tertiary reserves between Iberian countries started in June 2014 [16].

The introduction of the tertiary cross-border mechanism has the purpose of increasing and generating a certain level of market competition. The possibility of partial market coupling to the tertiary exchanges will increase the economic welfare in the electricity sector. As major example, the electricity market introduced in the Iberian Peninsula in the last decade yielded positive results in terms of integration for both countries. When the SPOT Market started, a considerable quantity (more than 80%) of market splitting was presented, motivated by the lower price of energy on the Spanish side. After more than a dozen years of the MIBEL's operation, the periods of market splitting have been reduced to less than 5% in some periods, with the electricity lower on the Portuguese side [17].

The goal of this work is to contribute to the literature by analysing the economic impact of the introduction of cross-border balancing services, in particular, the tertiary reserve mechanism in the Iberian electricity system from the Portuguese TSO perspective. The introduction of cross-border balancing mechanisms started operating between Portugal and Spain in mid-June 2014 [14]. As such, we will consider for this study the period between July 1, 2014, and December 31, 2017 [18].

To this end, we provide a brief description of the Portuguese tertiary electricity market in the following section. In Section 3, a description of the economic value of the exchange transactions is presented, comparing these transactions with the previous situation, the exclusive national tertiary market. Section 4 specifies the calculation process for evaluating the economic results. Section 5 presents the results on a daily and monthly basis followed by conclusions.

2. Methodology

To evaluate the gains of cross-border transactions from the Portuguese point of view, it was necessary to identify and organize the transactions occurring during the period for which the tertiary (or replacement) reserve was traded.

This period was divided into two groups: buy (acquisition) or sell (provide) Replacement Reserves (RR). For each period (hour), it was necessary to verify the mobilization of the internal RR. After that observation, the next step is to calculate the virtual scenario where the internal mobilization of the tertiary reserve is simulated as if the cross-border transaction had never occurred. After crossing the virtual mobilization with the tertiary that was effectively mobilized, six distinct patterns were identified that allow for categorizing cross-border transactions: three for acquisition and three for provision. Using this categorization, the third step compares the economic result of the cross-border transaction with the virtual impact of the internal energy mobilization.

3. Tertiary Reserve: Importance, Market, and Operationalization

The energy sold in the spot market, i.e., the quantity of equilibrium Qe, does not always match the reality of the national consumption needs [8], [19], [20]. It is almost impossible to predict the exact consumption at a given hour.

Over each hour, consumption exhibits dynamic behaviour, with several upward or downward variations caused by multiple natural and social factors. Renewable generation, particularly wind generation, has a significant impact, on market results [21]. The difficulty in predicting wind resources with high accuracy has an impact on the energy sold in the spot market [22], [23].

After the spot market, two different "markets" are organized at the national level [3], [24], [25]. These are the tertiary reserve downward and upward markets for each of the TSO included in the Iberian Electricity Market (MIBEL) [11].

Table 1 resumes the tertiary balancing market during the 2015 to 2017 period [26]. In the Portuguese case, the generation units that did not sell their energy on the spot market, submit to the respective System Operator a price that they are willing to receive to produce an additional quantity of energy [25]. When all producers submit their prices (and respective quantities) to the SO, they are organized by ascending price (cheapest to most expensive) [24].

If the SO needs to mobilize a given quantity of energy upward, Qu (MWh), it will pay the marginal upward price, Pu (€/MWh) to the respective(s) producers(s). All suppliers who produce this extra quantity of energy, requested by the SO will receive Pu for the energy they provide, which corresponds to the price of the last (most expensive) MW produced. This price is generally higher than the spot price, Ps, and corresponds to an "over-cost" for the electricity system. This over-cost is the difference between the tertiary regulation price upwardly mobilized and the market price (or spot price) [3], [10].

In the case of tertiary activated upward, the upward over-cost is calculated by the given function (1):

$$OCu = (Pu - Ps) * Qu \tag{1}$$

where Pu is the price of the tertiary activated upward (€/MWh) and Ps is the spot price (€/MWh). Qu is the quantity of tertiary reserve activated upward (MWh).

The generation units that sold their energy to the spot market submit to the SO the quantities and the corresponding price they are willing to refund to reduce or stop production. When all producers submit their prices (and respective quantities) to the SO, his prices are arranged in descending order. In other words, the agents who are available to refund more € to stop/reduce production are prioritized on the list.

If the System Operator needs to mobilize a given quantity of energy downward, Qd, the respective producer(s) will pay (refund) the electric system the downward price, namely, Pd.

All suppliers who reduce this quantity of energy requested by the SO will refund the system the Pd that corresponds to the price of the last (cheapest) MW reduced [3], [10]. Importantly, this producer(s) had already received Ps for the energy sold on the spot market. Generally, Pd is lower than Ps, and in this case, there occurs an over-cost to the electricity system: the difference between the spot price and the tertiary regulation downward price. In the case of the tertiary downward activation, the downward over-cost is calculated by the given function (2):

$$OCd = (Ps - Pd) * Qd \tag{2}$$

Where Pd is the price of the tertiary downward activation (€/MWh). Qd is the quantity of tertiary reserve activated downward (MWh).

A simple example is presented in Fig. 1. In the Portuguese electricity system, one product is only defined for balancing reserves activated manually for the SO. Operationally, mFRR and RR are the same products and commonly defined as a tertiary reserve and Table 2 the respective over-cost generated during the 2015 to 2017 period [26].

4. Economic Value and Procedure of Tertiary Exchanges

The main goal of the cross-border tertiary regulation exchanges is to reduce the over-cost resulting from the gap between the market results and the real consumption needs [27], [28].

When the sharing of a certain quantity of tertiary reserve, Q, occurs between TSO, a business balance activation (BBA) has happened. The BBA can be of two types, from the perspective of the TSO: business balance import (BBI) if the reference TSO imports tertiary reserve from another TSO, or a business balance export (BBE) if the reference TSO exports reserve regulation to another TSO. We analyse the impact of the BBAs from the perspective of the Portuguese system. Hence, the Portuguese TSO (i.e., REN) will be the reference TSO [19].

In the case of BBI, the Portuguese TSO imports from the Spanish TSO a certain amount of reserve regulation, Q, at a certain Price of Balance Import (PBI), which corresponds to the Value of Balance Imports (VBI) [29]:

$$VBI = (Pi - Ps) * Q \tag{3}$$

To calculate the profit on each BBI, we need to examine the alternative path by looking for the Portuguese reserve regulation offers and the corresponding Q at the corresponding price P(Q) in the internal (national) market of reserve regulation [29]. To calculate the profit (or savings) of the operation, we need to compare the cost of the tertiary reserve mobilized, CM, plus the cost of buying this energy from the other TSO, instead of acquiring all our tertiary reserve internally, to the cost of the potential mobilization CPM, see Equation (3).

$$Profit\ of\ BBI = CPM - (VBI + CM) \tag{4}$$

In the case of BBE, the Portuguese TSO sells (exports) to the Spanish TSO a certain Q at a certain Price of Balance Export, PBE (€/MWh) that corresponds to the Value of Balancing Export, VBE (€).

$$VBE = (Pe - Ps) * Q \tag{5}$$

To calculate the profit on each BBE, we consider the value of our sale (VBE) and the difference between the cost of the tertiary reserve mobilized, the cost of mobilization, CM, (the sold energy that was contemplated) and the cost of the tertiary reserve if a tertiary exchange had not occurred, the cost without mobilization, CWM, who represents "only" the national tertiary needs. See Equation (6) [29].

$$Profit\ of\ BBE = VBE - (CM - CWM) \tag{6}$$

Each TSO sends to the platform the offers that are available for providing or acquiring tertiary balancing reserve, as determined by established rules and procedures. The main rule that all TSOs must follow is that any TSO is obligated to send offers for the sharing platform. Therefore, any TSO must consider in the operational planning of reserve calculation the energy provided in the exchange platform because there is no warranty that offers are made. These offers, which the TSO provides for the platform, are the tertiary offers sent by the national market agents for the respective TSO.

Before sending offers to the platform, the TSOs make an analysis here to identify the potential need for tertiary downward and upward with a considerable "degree of certainty". Only a part of the remaining offers is sent to the platform.

The process of assignment of offers by the TSOs is as follows. Up to the 10th minute of the h-1 market period (previous hour), all involved TSOs send the offers (in quantity of energy) that they are available to buy or sell. Each TSO can provide for the platform a maximum of ten offers to sell and/or buy tertiary reserve.

Each offer is a 50 MWh block that is associated with a determined price (€/MWh). As mentioned before, it is not mandatory that any of the TSOs provide offers in any direction (buy or sell) or quantity for the platform. Each TSO has the possibility of activating between one and ten offers to another TSO. After the 10^{th} minute and before the 25th, the platform shows the offers of the involved TSOs, and it is the open trading period. Eventual energy traded in the tertiary exchange platform is added to the interconnection, and it is not possible to mobilize in the real-time [17]. The tertiary exchanges between TSOs do not integrally substitute the national tertiary mobilizations. Only this reserve can be mobilized or demobilized during the period [30].

5. Definition of the virtual situations CPM and CWM

CPM and CWM are scenarios of tertiary reserve that did not happen. These situations would have occurred if the cross-border balance reserve regulation offers had not been activated. To identify the energy and the respective price of the potential mobilization (import) or the scenarios where mobilization (export) has not occurred, it is necessary to compare the energy activation (bought or sold) with the following data information [31]:

- The previous tertiary offers (available by the producers) upward and downward at each hour, where the producers indicate the quantity and the respective price that they are willing to produce for an extra quantity of energy or the quantity and price they are available to refund to the system for its reduction by a determinate quantity of energy [5].
- The tertiary offers (quantity and price) assigned to upward, Qu, and downward, Qd, mobilizations, for each hour [32].

The first step is to observe the tertiary reserve offers upward and extracting all the energy blocks related to thermal units that were stopped. The system operator, if intending to assign an offer from a stopped thermal unit, may consider the dynamic parameters and the related start-up costs. Power plants that do not participate in day or intra-day markets are represented in the upward tertiary offers, but they are not available in real time [32]. The assignment may be planned several hours ahead and with extra costs, such as the start-up costs, and with several constraints related to the dynamic parameters [27]. These tertiary offers are simply not “real-time” offers. After they are removed, we are left with the net tertiary offers.

The second step is to calculate our “virtual” tertiary assignment. As mentioned, if the cross-border balancing services had not occurred, this amount of energy would have been assigned to the internal tertiary market. We need to add Q to our assigned offers Qu or Qd and identify the quantity of energy upward without cross-border balancing mechanisms, Quwb, and the corresponding upward price without cross-border balancing mechanisms, Puwb (Quwb), or the quantity of energy downward without cross-border balancing mechanisms, Qdwb (MWh), and the corresponding downward price without cross-border balancing mechanisms. This corresponds to the potential internal offers assignment [32].

5.1. CPM and Profit of BBI

After the acquisition of tertiary reserve from the Spanish TSO, three situations were identified that could occur and influence the way that the profit is calculated.

The first situation corresponds to the "classical" scenario. In this scenario, upward (Qu) and downward (Qd) mobilizations of tertiary reserves could occur, as shown in Fig. 2. Two specific situations exist that derive from the classical scenario:

The first is the existence of Qu and the non-existence of Qd. The second is Qu=0 and Qd=0. These two particular cases are represented in Figs. 3 and 4, respectively.

The illustrations mentioned above allow the easiest comprehension of the calculation process. Recall that if the BBI had not occurred, the amount of energy upward would have been Quwb and not Qu. So, the potential for cost generated, CPM, is obtained by the following equation:

$$\begin{aligned} CPM(€) &= (Puwb - Ps) * Quwb + (Ps - Pd) * Qd \\ &= (Puwb - Ps) * (Q + Qu) + (Ps - Pd) * Qd \\ &= (Puwb - Ps) * Q + (Puwb - Ps) * Qu + (Ps - Pd) * Qd \end{aligned} \tag{7}$$

As was observed in equation (5):

$$VBI = (Pi - Ps) * Q \tag{8}$$

In this scenario, the cost of internal mobilization is given by equation (7):

$$CM = (Pu - Ps) * Qu + (Ps - Pd) * Qd \tag{9}$$

Therefore, all conditions are met to proceed with the calculations and evaluation of the importation tertiary reserve profit. By re-formulating (4) we have:

$$Profit\ of\ BBI = CPM - (VBI + CM)$$

Carrying out the substitution, we get equation (10):

$$\begin{aligned} Profit\ of\ BBI &= \big((Puwb - Ps) * Q + (Puwb - Ps) * Qu + (Ps - Pd) * Qd\big) - (Pi - Ps) \\ &\quad * Q - \big((Pu - Ps) * Qu + (Ps - Pd) * Qd\big) \\ &= Q * (Puwb - Ps - Pi + Ps) + Qu * (Puwb - Ps - Pu + Ps) \\ &= Qu * (Puwb - Pu) + Q * (Puwb - P) \end{aligned} \tag{10}$$

In the second scenario, we observe that a tertiary downward occurs. However, if BBI did not occur, it would be necessary to mobilize tertiary upward (Q>Qd). Fig. 5 represents this situation.

In this scenario, the potential over-cost, CPM, is given by equation (11):

$$\begin{aligned} CPM &= (Puwb - Ps) * Quwb = (Puwb - Ps) * (Q - Qd) \\ &= (Puwb - Ps) * Q - (Puwb - Ps) * Qd \end{aligned} \tag{11}$$

Retyping equation (3):

$$VBI = (Pi - Ps) * Q$$

The cost of internal mobilization is given by equation (12):

$$CM = (Ps - Pd) * Qd \tag{12}$$

Carrying out the substitution equation (13):

$$\begin{aligned} Profit\ of\ BBI &= (Puwb - Ps) * (Q - Qd) - (Pi - Ps) * Q - (Ps - Pd) * Qd \\ &= Q * (Puwb - Ps + Pi + Ps) - Qd * (Puwb - Ps + Ps - Pd) \\ &= Q * (Puwb - P) - Qd * (Puwb - Pd) \end{aligned} \tag{13}$$

In the third and last scenario, we observe a mobilization of tertiary downward. However, if the BBI had not occurred, then, although there would still have continued to exist a tertiary downward, it would have been smaller. Fig. 6 helps to understand this scenario.

In this case, CPM is given by equation (14):

$$CPM = (Ps - Pdwb) * Qdwb = (Ps - Pdwb) * (Qd - Q) \tag{14}$$

By retyping equation (3) we have:

$$VBI = (Pi - Ps) * Q$$

The cost of internal mobilization, CM, is similar to the previous case, equation (12):

$$CM = (Ps - Pd) * Qd$$

Carrying out the substitution, the BBI profit can be calculated by (15):

$$\begin{aligned} Profit\ of\ BBI &= (Ps - Pdwb) * (Qd - Q) - (Pi - Ps) * Q - (Ps - Pd) * Qd \\ &= Q * (Pdwb - Ps + Pi + Ps) - Qd * (Ps - Pdwb - Ps + Pd) \\ &= Q * (Pdwb - Pi) - Qd * (Pdwb - Pd) \end{aligned} \tag{15}$$

5.2 CWM and the profit of BBE

Conceptually, the following proceedings referring to exportation transactions are similar to the importation situations, only with a different direction. After a sale of the tertiary reserve, three distinct situations can occur.

The first situation, which can be observed in Fig. 7, is the base (or classical) scenario. In this scenario, mobilizations of tertiary reserve upward and downward both exist.

Two particular situations derive from the base scenario. The first one does not have a tertiary upward, hence Qu=0. In the second situation, we do not observe either upward or downward tertiary mobilizations, and hence Qu=0 and Qd=0. Figs. 8 and 9 allow an easier comprehension of the process.

To calculate the potential scenario, the Cost without Mobilization, CWM, we have:

$$
\begin{aligned}
CWM(€) &= (Pu - Ps) * Qu + (Ps - Pdwb) * Qdwb) \\
&= (Pu - Ps) * Qu + (Ps - Pdwb) * (Q + Qd) \\
&= (Pu - Ps) * Qu + (Ps - Pdwb) * Q + (Ps - Pdwb) * Qd
\end{aligned}
\tag{16}
$$

Retyping equation (5):

$$VBE = (Pe - Ps) * Q$$

In this scenario, the Cost of Mobilization is given as equation (17):

$$CM = (Pu - Ps) * Qu + (Ps - Pd) * Qd \tag{17}$$

Therefore, we can calculate the tertiary reserve's exportation profit. Retyping equation (4) we have:

$$Profit\ of\ BBE = VBE - (CM - CWM)$$

Hence, we can obtain the BBE's profit by substituting in (17) as follows:

$$
\begin{aligned}
Profit\ of\ BBE &= (Pe - Ps) * Q \\
&\quad - \big((Pu - Ps) * Qu + (Ps - Pd) * Qd - ((Pu - Ps) * Qu + (Ps - Pdwb) \\
&\quad * Q + (Ps - Pdwb) * Qd))\big) \\
&= Q * (Pe - Ps + Ps - Pdwb) + Qd * (Pd - Ps + Ps - Pdwb) \\
&= Q * (Pe - Pdwb) + Qd * (Pd - Pdwb)
\end{aligned}
\tag{18}
$$

In the second scenario, there was an upward tertiary mobilization. However, if the sale had not occurred, it would have been necessary to mobilize tertiary downward (Q>Qu). It is possible to observe this situation in Fig. 10.

In this case, CWM is given by equation (19):

$$
\begin{aligned}
CWM = (Ps - Pdwb) * Qdwb &= (Ps - Pdwb) * (Q - Qu) \\
&= (Ps - Pdwb) * Q - (Ps - Pdwb) * Qu
\end{aligned}
\tag{19}
$$

By retyping equation (3), we have:

$$VBE = (Pe - Ps) * Q$$

In this scenario, the CM is given by:

$$CM = (Pu - PS) * Qu$$

By substituting in (19), the BBE's profit can be calculated by:

$$\begin{aligned} Profit\ of\ BBE &= (Pe - Ps) * Q \\ &- \Big((Pu - Ps) * Qu - \big((Ps - Pdwb) * Q - (Ps - Pdwb) * Qu\big)\Big) \\ &= Q * (Pe - Ps) - Qu * (Pu - Ps) + (Ps - Pdwb) * Q - (Ps - Pdwb) \\ &* Qu = Q * (Pe - Ps + Ps - Pdwb) + Qu * (Ps - Pu - Ps + Pdwb) \\ &= Q * (Pe - Pdwb) + Qu * (Pu - Pdwb) \end{aligned} \tag{20}$$

The third and last scenario has a mobilization of tertiary upward. However, if the BBE had not occurred, then there would have still been a tertiary upward, but it would have been smaller. Fig. 11 supports the understanding of this scenario.

The CWM, in this case, is given by (21):

$$CWM = (Puwb - Ps) * Quwb = (Puwb - Ps) * (Qu - Q) \tag{21}$$

By retyping (3), we have:

$$VBE = (Pe - Ps) * Q$$

The CM is given by:

$$CM = (Pu - Ps) * Qu$$

Therefore, the BBE's profit in the third case can be calculated by:

$$\begin{aligned} Profit\ of\ BBE &= (Pe - Ps) * Q - \big((Pu - Ps) * Qu - (Puwb - Ps) * (Qu - Q)\big) \\ &= (Pe - Ps) * Q - (Pu - Ps) * Qu + (Puwb - Ps) * Qu - (Puwb - Ps) \\ &* Q = (Pe - Ps - Puwb + Ps) + Qu * (Ps - Pu + Puwb - Ps) \\ &= Q * (Pe - Puwb) - Qu * (Pu - Puwb) \end{aligned} \tag{22}$$

6. Analysis of the Results

First, a general (macro) analysis of the obtained results is performed, with the aid of some previous conclusions and findings. Next, a more detailed analysis is performed, arranging the results in a different manner to enable two different types of reflections: i) a daily analysis (short-term vision) where we can understand the behaviour and the characteristics of both electricity systems over a complete market day;

ii) a more long-term perspective where we can understand the evolution of these cross-border exchanges over the complete period of analysis, realized in a trimestral base.

6.1. General Perspective

During the analysis period (3.5 years), tertiary reserves were shared, BBAs, in 3821 hours. Out of the total BBAs, 2948 were BBIs and 873 were BBEs. From this information, it is possible to make some preliminary conclusions [33]:

First conclusion: The percentage of hours when BBAs occurred was 3821/21925 or ~17.5%. For 82.5% of the time, the reserve regulation prices are very similar in both Iberian TSOs, and it was not "potentially profitable" to buy or sell tertiary reserves in the remaining hours of the analysis period. The prices and quantities of the tertiary regulation reserves of the Iberian TSOs are directly influenced by climate conditions; both TSOs have in the portfolio a considerable quantity of renewable energy production, mainly hydro and wind generation. When a "windy" day occurs in Portuguese territory, there will be a very large probability that we will have a “windy” day in Spain [34]. Moreover, when long periods of rain occur in Portugal (wet years), there is a large probability they also occur in Spain to [35]. Additionally, both TSOs share three hydraulic interconnections: three rivers that are shared by both countries in the production of electricity (two in the Douro River, and one in the Tejo River). This fact helps to understand the correlation between the characteristics of both TSOs [10].

Second conclusion: We find that 77% of the BBAs are BBIs and only 23% are BBEs. Allegedly, the existence of more market players on the Spanish side, with greater relevance at the production level, contributes to the improvement of the competitiveness and in turn generates tertiary reserve offers that are cheaper on the Spanish side than on the Portuguese one.

Considering Fig. 12, and as far as the Spanish TSO is concerned, it was verified that, on average, when tertiary reserves are shared, the quantity offered to sell, for most of the hours, is very close to the maximum tertiary reserve allowed (500 MW). Concerning the acquisition of tertiary reserve, the value that is offered is also nearly the maximum (but not as high as in the exportation cases), with a relative decrease in off-peak periods. The Portuguese TSO, whether in the acquisition or in the availability of energy, presents a predisposition to transact a smaller value than the Spanish TSO. In the generality of hours, there is more importation availability, with the exception of peak periods when, as with the Spanish TSO, it is observed an increased availability to export.

As seen in Fig. 13, it is possible to observe the prices at which both TSOs were available to buy and sell tertiary reserves. In the situation of acquisition, as well as the availability of energy, the Portuguese TSO employs a higher price; it is willing to sell for a higher price than the Spanish TSO but is also available to buy energy for a higher value. Furthermore, we observe a decrease in buying and selling prices, in both TSOSs, during the off-peak periods, since both have more energy available. The price evolution shows a similar tendency in both countries, although it is more visible in exportation scenarios due to the time difference of one hour between the two countries.

The analyses presented in Figs. 12 and 13 corroborate the tendency of the actual transactions, as explicated in the general considerations. The importer profile of the Portuguese TSO, allied to the lowest prices of Spanish TSO (to import and export), validates the earlier conclusions. We observe that, for the generality of the hours, in exportation or importation scenarios, the Spanish TSO offers close to the maximum of energy allowed by the platform (system), while the Portuguese TSO only provides 60% to 80% of the maximum allowed. This fact is related to the dimensions of both electricity systems, connected with their domestic consumption. In Spain, the energy consumption is five to six times higher, compared to Portugal, so the impact of a transaction of 500 MW is significantly different for the two different systems.

Now the tertiary offers will be analysed, as submitted by both TSO, in a long-term perspective. Figs. 14 and 15 show the evolution of the offers.

In particular, Fig. 14 shows the amount of energy available for the transaction, for both TSO. Starting with the Spanish TSO, it shows itself to be almost totally available to export, as well as at high disposal to import. These results corroborate the conclusions obtained previously, regardless of the dimensions of the two systems. In what concerns the Portuguese TSO, the long-term behaviour is relatively consistent with the daily analysis.

A general predisposition to import, with the exception of the 2nd and 3rd quarters of 2015, is patent. It is possible to observe an increase in available energy (import and export) to trade during the five initial quarters. In the remaining period, a decrease of the exportation availability and stabilization of the import trend is verified. The predisposition for importation of the Portuguese TSO is easily identified.

Fig. 15 shows the average value (€/MWh) of available offers, in both TSO. In what concerns the price disposal for importation, the tendency is similar during the analysis, with oscillations both in Portugal and Spain. The Portuguese TSO is the one that is available to buy energy for a higher price. Concerning the average value at which the TSOs are disposed to export, in almost all quarters (with the exception of one) the Spanish TSO is the most competitive TSO.

This analysis considered the price and the quantities of offers by both TSOs. No analysis was made of the actual transactions. This study will be carried out subsequently. However, the evaluation already carried out, mainly from the long-term perspective, shows an initial predisposition on the part of the Portuguese TSO for importation, which predicts that there will be a balance on the transactions, at the end of the period under review.

6.2. Daily analysis RESTART

Fig. 16 shows the effective transactions from a daily perspective. First, it is possible to perceive that there are more transactions during peak periods than off-peak periods, although it is a slight difference.

Historically, the results of spot market show Portugal as an importer, in off-peak periods. The main reason for this trend is the existence of nuclear power plants in the Spanish electricity system [36]. The existence of this type of power plant reduces the price of electrical energy, mainly in off-peak periods. The "necessity" of working in a full power regime is the key motive [25], [37]. In the peak periods, the sale of tertiary reserves from the Portuguese TSO is more visible.

The main motive is the existence of high penetration of hydropower plants in the Portuguese electricity system (not too pronounced), which allows the covering of the peak periods agilely and quickly compared to thermal power plants [35].

One pertinent observation is the reduction of transactions in the first hour of each intraday market, IM (H01, H05, H09, H12, H16 and H22, which correspond respectively to IM2, IM3, IM4, IM5, IM6, and IM7) [25]. This reduction is more pronounced in the H05, H12, and H16 (IM3, IM5, and IM6). This situation occurs because the Spanish TSO did not offer energy (to buy or sell) in this period. In each IM, the market producers may modify their tertiary prices [21]. The predictable motive is the existence of a new price offer sent by the producers, which was not received in time to elaborate the offers. This time constraint is originated by the existence of different platforms from different entities. The existence of more market producers on the Spanish side increases the difficulty of receiving the market offers in time to elaborate the final tertiary curve offers. From the Portuguese side, the existence of fewer market players reduces this problem because of the easier coordination it makes possible [20].

Fig. 17 shows the average profit per hour. It is possible to revalidate some conclusions mentioned above: The savings (relatively to BBIs) are more pronounced in off-peak periods, and the selling profits (BBEs) are higher in the remaining periods.

6.3. Long-run considerations

In Fig. 18, it is possible to observe the evolution of the BBAs in the sharing mechanism period of analysis. The predominance of BBIs at the beginning of the transactions is clearly observable. In the case of the first and the second quarters, 88% of the real transactions are BBIs. Only 12% are BBEs. During the remaining period, it is possible to observe a slight decrease in the BBI transactions compared to the BBEs. The general tendency during the overall period of analysis is to have more occurrence periods of BBI, with 77% of the transactions and 23% of BBEs.

The main conclusion about the sharing mechanism is positive, because of the increase in the indirect competition of market agents. The predominantly importing transactions (from the Portuguese perspective) develop towards a more equilibrium situation (not sufficient yet), with the direct decrease of the Portuguese tertiary prices. The harmony created by the balanced division between the quantities traded proves the efficiency in the creation of this market.

In Fig. 19 depicts the revenue value of the transactions: the savings provided by the assignations and the profit from the sales. The revenues are directly related to the amount of energy traded in each period (observed in the previous figure). The importation trend of the Portuguese TSO reveals substantial profits when compared with the exportation scenario [38]. Tables 3 and 4 the results provided by the previous figures.

7. The future of ancillary services in Europe

The introduction of the cross-border balancing reserves generates advantages for both TSO, in particular for the Portuguese TSO (the subject of this study). However, cooperation among several TSOs could improve economic results. Currently, under the supervision of ENTSO-E, three main projects are under development.

7.1 TERRE Project

The TERRE project (Trans European Replacement Reserve Exchange) was incorporated in a group of pilot-projects with the objective of exploring the feasibility of the new concept introduced in the "Network Code on Balancing Electricity", one of the European grid codes for the market field. TERRE studies set up and operate a multi-TSO platform capable of aggregating all the offers for Replacement Reserves (RR) and optimizing the allocation of RR across the different TSOs involved. It is moving toward the cross-national exchange of RR. The participants are the TSO from Portugal, Spain, France Italy, Switzerland, England and Scotland [39]. The tertiary reserve is used for correcting a system imbalance from the Spot Markets. These reserves are employed to restore the required level of operating reserves to be prepared for a further system imbalance. The implementation of TERRE will help to gather experience and knowledge that will then contribute to the implementation, at the European level, of the target model for cross-border electricity balancing, as identified in the draft electricity balancing network code [40].

7.2 MARI

The MARI project (Manually Activated Reserves Initiative) intends to implement a common European platform for the exchange of balancing energy from frequency restoration reserves with manual activation (mFRR). Due to the capital importance of an efficient balancing mechanism for an integrated electricity market, 19 European TSOs decided to work on the design of a mFRR platform in order to address the connection with the establishment of a platform. These TSOs decided to work on a technical solution, which not only reflects the views of the founding parties, but could also be acceptable for potential new parties joining the initiative. The launching of this project is not expected before 2022 [41].

7.3 PICASSO

The PICASSO project (Platform for the International Coordination of Automated Frequency Restoration and Stable System Operation) was born as a regional project, denominated by IGCC (Intra Grid Control Cooperation) initiated by eight TSOs from the center of Europe. APG, Elia, Tennet, RTE, 50Hertz, Amprion, Tennet (Germany), and TransnetBW agreed to initiate a project to achieve the capability for a common automatic Frequency Restoration Reserves (aFRR). Since inception, the project has grown and became a broad European project. The main objective of PICASSO is to design, implement and operate an aFRR Platform with the goal of improving the economic and technical efficiency, within the limits of system security, and integrating the European aFRR markets, while respecting the TSO-TSO model [42].

8. Conclusions

The introduction of the cross-border exchange mechanisms, and particularly of the tertiary reserve, is the new reality for both participating SOs in the Iberian Peninsula. As a new contribution to earlier studies, this paper evaluated the economic impact of this mechanism in Iberia, from the Portuguese system's perspective. After three and a half years of this trading mechanism's implementation, profits exceed 10.5 M€. This corresponds to an average gain of more than 3 M€/year, only for the Portuguese electricity system. Comparing this value with the average tertiary over-cost, it was 32.22 M€, which corresponds to almost 10% of the tertiary balancing costs. The profits obtained from the cross-border tertiary transactions would allow the market agents that are imbalanced (in a determined period) to proceed with their imbalance settlement at a more competitive price. On this basis, the cross-border exchange tertiary is a solution to be considered in the future. Besides the economic advantages that were studied in this paper, the improvement is undeniable not only for the SOs who must deal with this new reality, but also for the market participants, especially suppliers, who must adapt their tertiary offers taking into consideration this new paradigm [43]. What was once a national market is now tending to toward a European [44]. The introduction of more players in this sharing mechanism allows one to foresee improvement of the economic results for all stakeholders [45]. The introduction of new projects, such as TERRE, MARI, and

PICASSO, will allow changes to take place in the European Panorama relative to ancillary services, in particular the secondary and replacement reserves. The competition among market players will increase and more dynamic behaviour will be introduced to the interconnection programs.

Acknowledgment

P.M.S. Frade acknowledges the support provided by Albino Marques (System Operator Director), Paulo Marques (Head of the National Dispatch), Pedro Pereira (Head of Markets Operation), and finally Manuel Sá Cruz (former MSc student at FEUP). J.P.S. Catalão acknowledges the support by FEDER funds through COMPETE 2020 and by Portuguese funds through FCT, under Projects SAICT-PAC/0004/2015 - POCI-01-0145-FEDER-016434, POCI-01-0145-FEDER-006961, UID/EEA/50014/2013, UID/CEC/50021/2013, UID/EMS/00151/2013, and 02/SAICT/2017 - POCI-01-0145-FEDER-029803.

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References

[1] K. S. Lidia Puka, "The politics and economics of cross-border electricity infrastructure:," *Energy Research & Social Science,* 2014.

[2] REN, "Caracterização da Rede Nacional de Transporte a 31 de Dezembro de 2014," [Online]. Available: http://www.mercado.ren.pt/PT/Electr/ActServ/AcessoRedes/CaractRNT/BibRelAno/CaracterizacaodaRNT2014.pdf. [Accessed 06 08 2015].

[3] ERSE, "Manual de Procedimentos do Gestor do Sistema Elétrico," [Online]. Available: http://www.erse.pt/pt/electricidade/regulamentos/operacaodasredes/Documents/MPGGS%20SE%20consolidado_Abril2014_vs%20PExterno.pdf. [Accessed 10 10 2015].

[4] O. E. A. B. J. C. Nikolaos Paterakis, "Qualification and Quantification of Reserves in Power Systems Under High Wind Generation Penetration Considering Demand Response," *IEEE - Sustainable Energy,* 2015.

[5] ENTSO-E, "Cross Border Exchanges," [Online]. Available: https://transparency.entsoe.eu/balancing/r2/crossBorderBalancing/show.

[6] J. E. S. d. Haan, "Cross-Border Balancing in Europe PhD Thesis," geboren te Kempen, Duitsland, 2016.

[7] Comissão Europeia, "Single Market Process Report," [Online]. Available: https://ec.europa.eu/energy/en/topics/markets-and-consumers/single-market-progress-report.

[8] ENTSO-E, "Load Frequency Control and Reserves," [Online]. Available: http://www.mercado.ren.pt/PT/Electr/Paginas/default.aspx.

[9] B. Dallinger, H. Auer and G. Lettner, "Impact of harmonised common balancing capacity procurement in selected Central European electricity balancing markets," *Applied Energy,* vol. 222, pp. 351-368, 2018.

[10] J. P. S. Paiva, Redes de Energia Elétrica. Uma análise Sistémica, Lisboa: IST Press, 2015.

[11] L. M. Amaral, Energia e Mercado Elétrico, Lisboa: Booknomics, 2006.

[12] TSO's of SouthWest Europe, “Cross-border balancing model among TSO's - BALIT Project,” 7th SG SWE Lisbon 3rd December 2013, 2013.

[13] S. J. G. L. D. T. G. Tobias Aigner, “The effect of Large-scale Wind power on System Balancing in Northen Europe,” *Sustainable Energy-IEEE,* 2012.

[14] RTE, REN, REE, “Cross-border balancing model border balancing model,” [Online]. Available: http://www.ceer.eu/portal/page/portal/EER_HOME/EER_ACTIVITIES/EER_INITIATIVES/ERI/South-West/Meetings1/SG_meetings/5th_SW_SG/DD/Deliverable%20I%204%20(TSO-TSO%20Balancing)%205th%20SG%20Final_b.pdf. [Accessed 12 12 2015].

[15] RTE, “Cross Border Balancing: General Overview of BALIT mechanism,” [Online].

[16] South-West region: Eletricity Regional Initiative workplan 2011-2014, [Online]. Available: http://www.acer.europa.eu/en/electricity/regional_initiatives/documents/final%20swe%20regional%20work%20plan%202011-2014.docx.

[17] N. C. Figueiredo, P. P. d. Silva and P. A. Cerqueira, “Evaluating the market splitting determinants: evidence from the Iberian spot electricity prices,” *Energy Policy,* vol. 85, pp. 218-234, 2015.

[18] REN, “Sistema de Informação de Mercados de Energia - Energia de Regulação,” [Online]. Available: http://www.mercado.ren.pt/PT/Electr/Paginas/default.aspx. [Accessed 2016 05 05].

[19] A. A. R. A. H. Reinier Van der Veen, “Agent based analysis of the impact of the imbalance pricing mechanism on market behavior in electricity balancing markets,” *Energy Economics,* 2012.

[20] C. F. J.P. Chaves Avila, “The Spanish intraday market design: A successful solution to balance,” *Renewable Energy,* 2015.

[21] ChristophWeber, “Adequate intraday market design to enable the integration of wind energy,” *Energy Policy,* 2010.

[22] P. F. J. R. Camila Fernandes, “Participation of intermittent renewable generators in balancing,” *Renewable Energy.*

[23] F. M. Y. S. G. Oggioni, “Evaluating the impacts of prioritary dispatch in the European electricity market,” *Energy Economics,* 2014.

[24] D. S. K. G. A. Tobias W. Haring, “Incentive Compatible Imbalance Settlement,” *Power Systems - IEEE.*

[25] MIBEL, “Operadores de Mercado,” [Online]. Available: http://www.mibel.com/index.php?mod=pags&mem=detalle&relmenu=88&relcategoria=1057&idpag=97. [Accessed 12 12 215].

[26] REN - Redes Energéticas Nacionais, “Annual Market Report,” [Online]. Available: http://www.mercado.ren.pt/EN/Electr/MarketInfo/Publications/BibInfAnual/AnnualReport2013_2017.pdf. [Accessed 22 06 2018].

[27] Elia, Tennet, KEMA, “Cross-Border Exchange of Balancing Energy and Operational Reserves: Benefits and Issues,” Bruxelas, 2013.

[28] G. S. I. V. David Newberry, “The Benefics of Integrating European Electricity Markets,” *Energy Policy,* 2016.

[29] REE-ESIOS, “Transparency Data - Cross Border Balancing Offers,” [Online]. Available: https://www.esios.ree.es/en/analysis/688?vis=1&start_date=18-12-2016T00%3A00&end_date=18-12-2016T23%3A00&compare_start_date=17-12-2016T00%3A00&groupby=hour.

[30] ACER, “Final SWE Regional Work Plan 2011-2014,” [Online]. Available: https://www.ceer.eu/documents/104400/3667857/Regional_Work_Plan_2011_2014+SW+v1.2.pdf/57c40da4-8585-e110-9aed-f9595b56b273?version=1.0. [Accessed 05 05 2018].

[31] REN, “REN- Informação de Mercado 2012 a 2016,” [Online]. Available: http://www.mercado.ren.pt/PT/Electr/InfoMercado/PressReleases/BibInfAnual/MercadoEletricidadeSinteseAnual2012_2016_jan_nov.pdf. [Accessed 2016 11 10].

[32] REN, “Informação em Tempo Real,” [Online]. Available: http://www.centrodeinformacao.ren.pt/PT/InformacaoExploracao/Paginas/EstatisticaDiaria.aspx.

[33] REE-ESIOS, “Trasparency Data - Cross Border Balancing Offers,” [Online]. Available:

https://www.esios.ree.es/en/analysis/688?vis=1&start_date=18-12-2016T00%3A00&end_date=18-12-2016T23%3A00&compare_start_date=17-12-2016T00%3A00&groupby=hour. [Accessed 18 12 2016].

[34] W. e. a. c. d. u. a. a. a. b. m. f. e. p. A. c. s. i. Spain, "I. González-Aparicio; Z. Kapetaki; E. Tzimas," *Applied Energy,* vol. 222, pp. 216-227, 2018.

[35] EDP, "Dados Ibéricos de 2014," [Online]. Available: http://www.edp.pt/pt/aedp/sectordeenergia/Dados%20Ibricos/FOL_Dad_Ibericos_PT_WEB.pdf.

[36] J. Jenkins, Z. Zhou, R. Ponciroli, R. Vilim, F. Ganda, F. d. Sisternes and A. Botterud, "The benefits of nuclear flexibility in power system operations with renewable energy," *Applied Energy,* vol. 222, pp. 872-884, 2018.

[37] OMEL, "Participacion del Régimen Especial en el Mercado de Producion," Madrid, 2008.

[38] C. BrancucciMartínez-Anido, M. ndenbergh, L. d. Vries, C. Alecu, A. Purvins, G. Fulli and T. Huld, "Medium-termdemand for European cross-border electricity," *Energy Policy,* 2013.

[39] ENTSO-E, "Proiect TERRE," 18 06 2018. [Online]. Available: https://docstore.entsoe.eu/Documents/Network%20codes%20documents/NC%20EB/180618_RR_TSOs-response-to-public-consultation-on-RRIF-Art-19.1-of-the-EBGL.PDF. [Accessed 28 08 2018].

[40] ENTSO-E, "Network codes - TERRE," [Online]. Available: https://electricity.network-codes.eu/network_codes/eb/terre/. [Accessed 28 08 2018].

[41] ENTSO-E, "Manually Activated Reserves Initiative," [Online]. Available: https://electricity.network-codes.eu/network_codes/eb/mari/. [Accessed 28 08 2018].

[42] ENTSO-E, "PICASSO," [Online]. Available: https://electricity.network-codes.eu/network_codes/eb/picasso/. [Accessed 28 08 2018].

[43] R. v. d. V. Gerard L. Doorman, "An analyis of design options for the markets for cross-border balancing of electricity," *Utilities Policy,* 2013.

[44] J. Torriti, "Privatisation and cross-border energy trade: From internal market to European Supergrid?," *Energy,* 2014.

[45] O. G. Roland Meyer, "Cross-border effects of capacity mechanisms: Do uncoordinated market design changes contradict the goals of the European market integration?," *Energy Economics,* 2015.

FIGURES

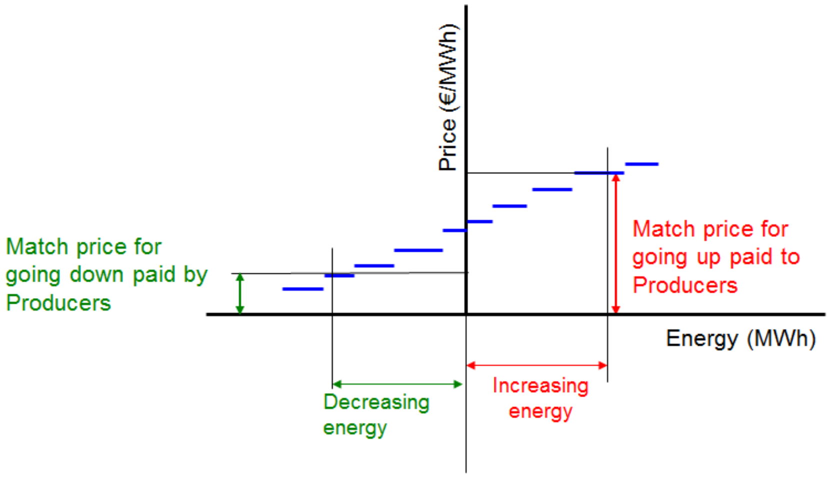

Fig. 1 - Tertiary reserve mobilization.

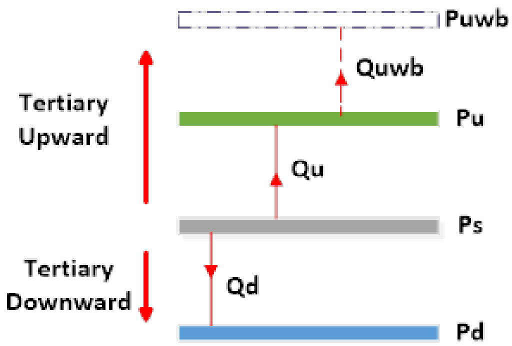

Fig. 2 - Mobilization of tertiary reserve in the classical scenario in CPM situation.

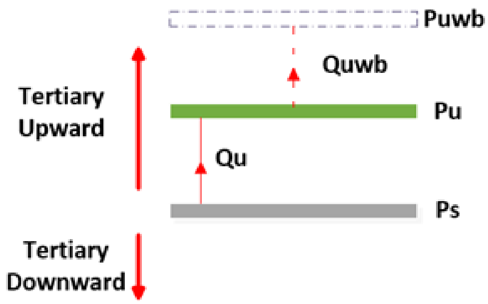

Fig. 3 - Tertiary reserve in the classical scenario in CPM situation (Qu=0).

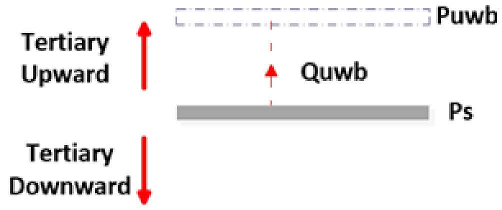

Fig. 4 - Tertiary reserve in the classical scenario in CPM situation (Qu=Qd=0).

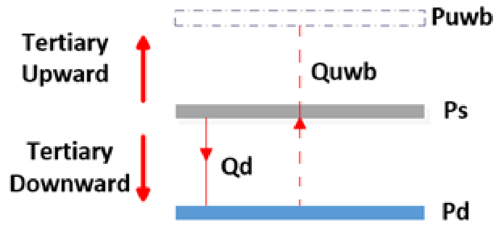

Fig. 5 - Tertiary reserve in the second scenario in CPM situation.

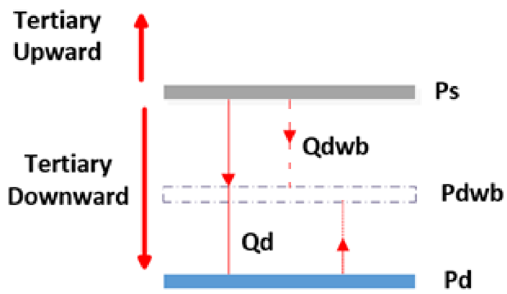

Fig. 6 - Tertiary reserve in the third scenario in CPM situation.

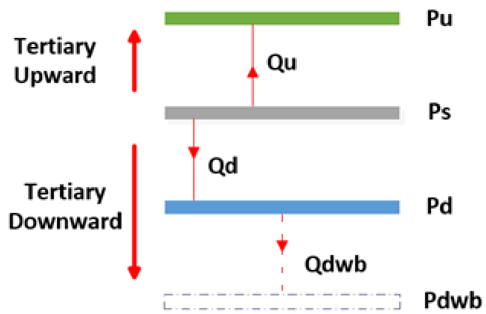

Fig. 7 - Mobilization of tertiary reserve in the classical scenario in CWM situation.

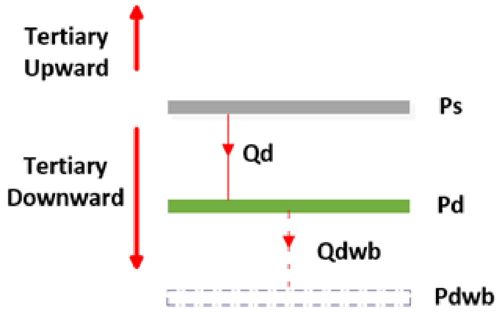

Fig. 8 - Tertiary reserve in the classical scenario in CWM situation (Qu=0).

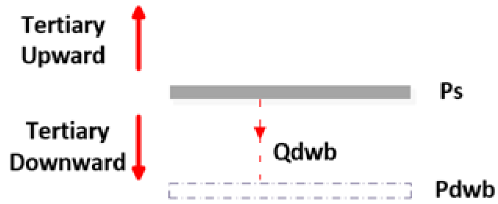

Fig. 9 - Tertiary reserve in the classical scenario in CWM situation (Qu=Qd=0).

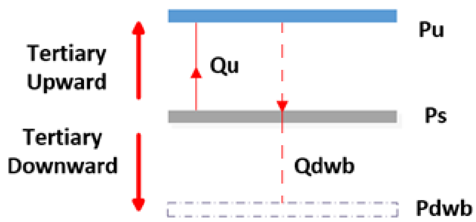

Fig. 10 - Tertiary reserve in the second scenario in CWM situation.

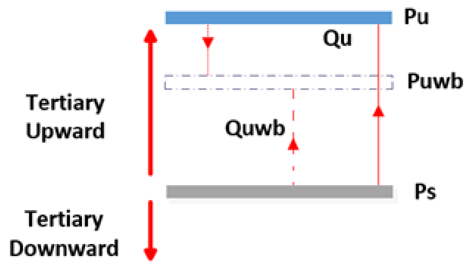

Fig. 11 - Tertiary reserve in the third scenario in CWM situation.

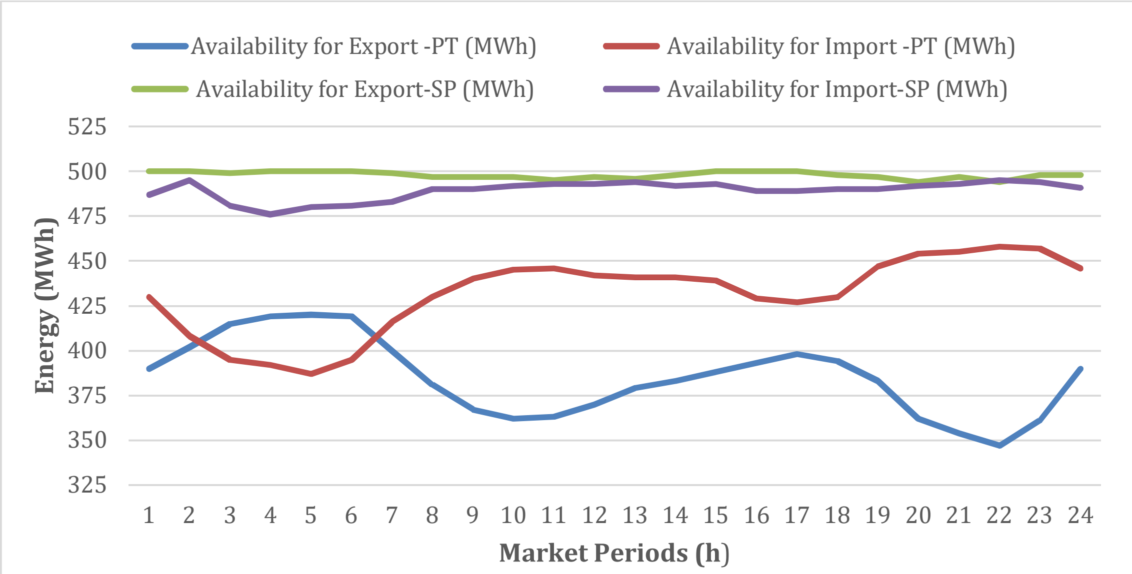

Fig. 12 – Available energy to trade between Portugal and Spain.

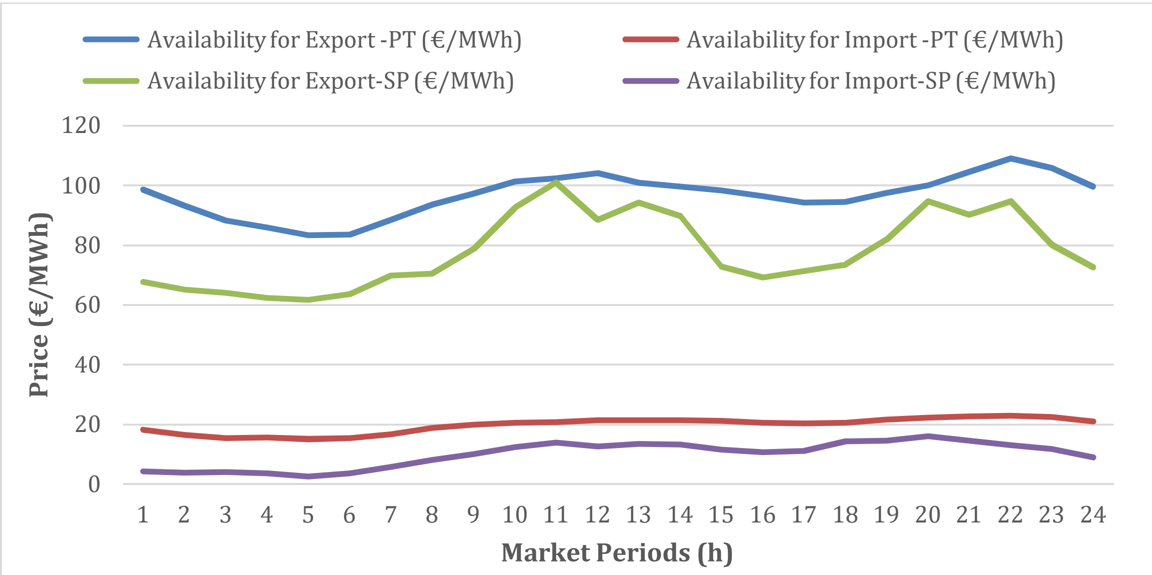

Fig. 13 – Available price to trade between Portugal and Spain.

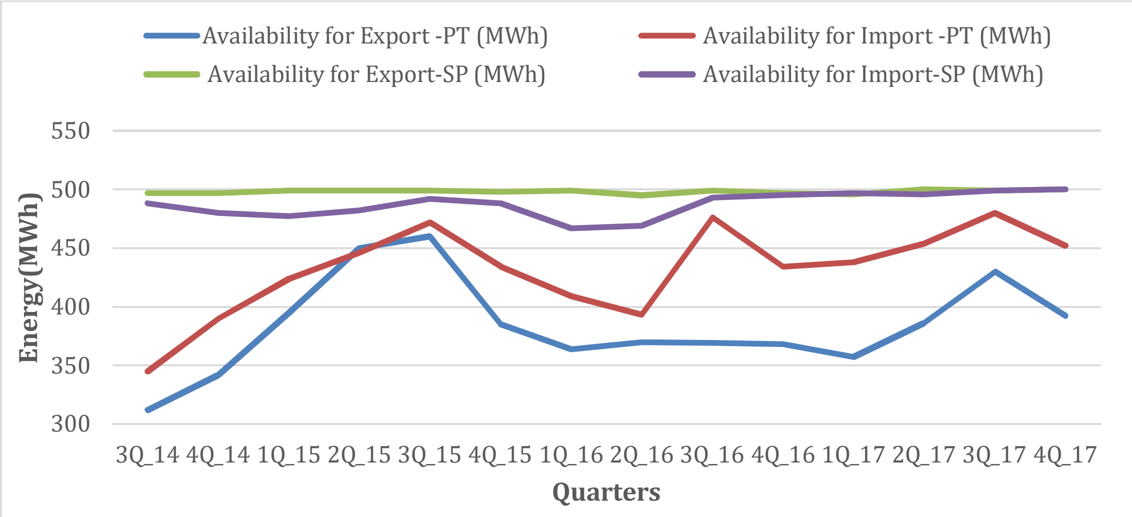

Fig. 14 - The amount of energy available for the transaction between Portugal and Spain.

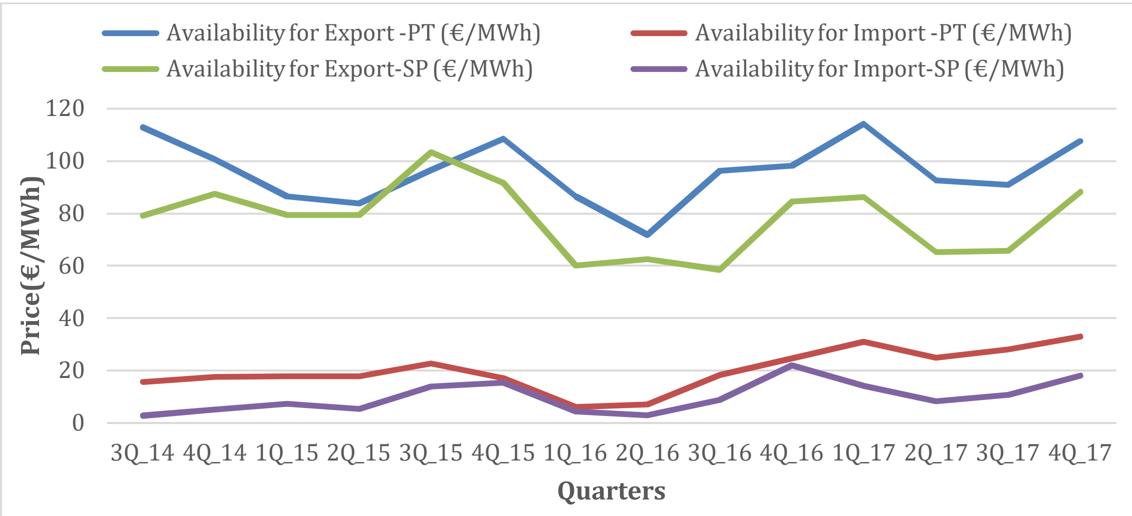

Fig. 15 - The available transaction price between Portugal and Spain.

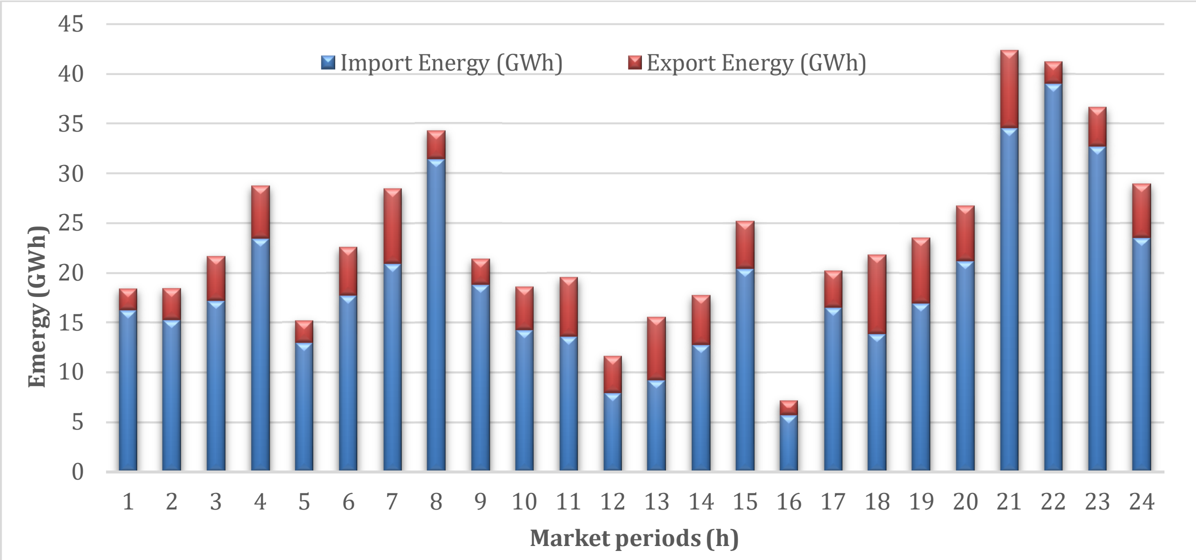

Fig. 16 - Effective energy transactions between Portugal and Spain in a Daily perspective.

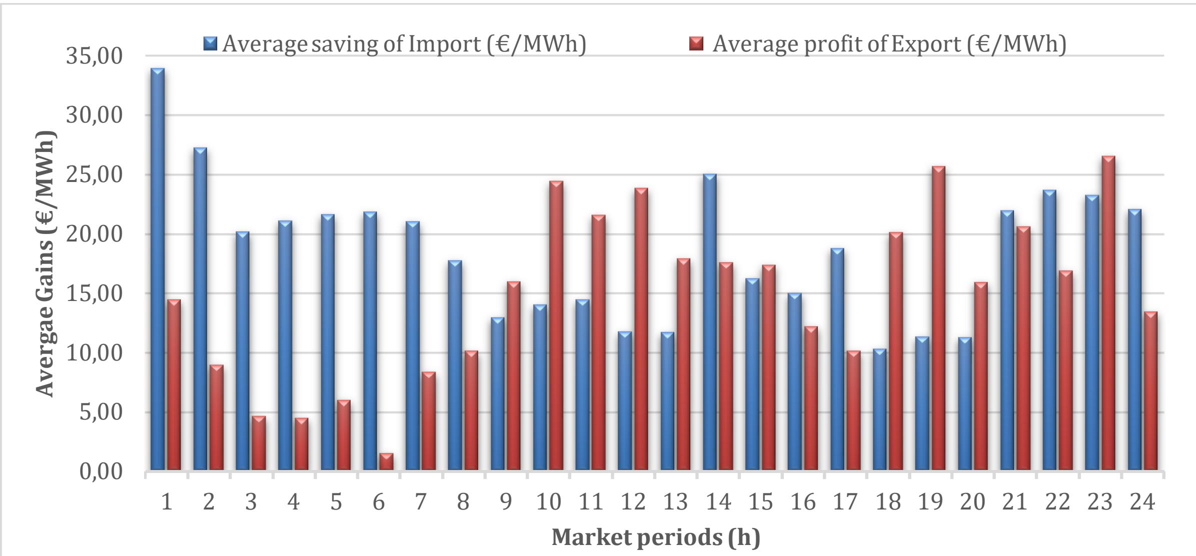

Fig. 17 – Average profit of the energy transactions between Portugal and Spain.

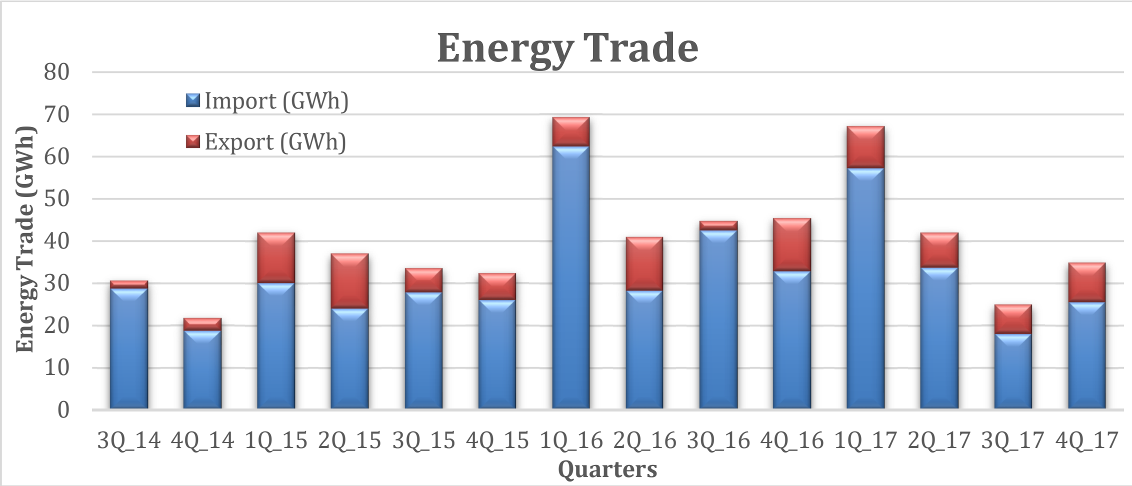

Fig. 18 – Energy traded between Portugal and Spain.

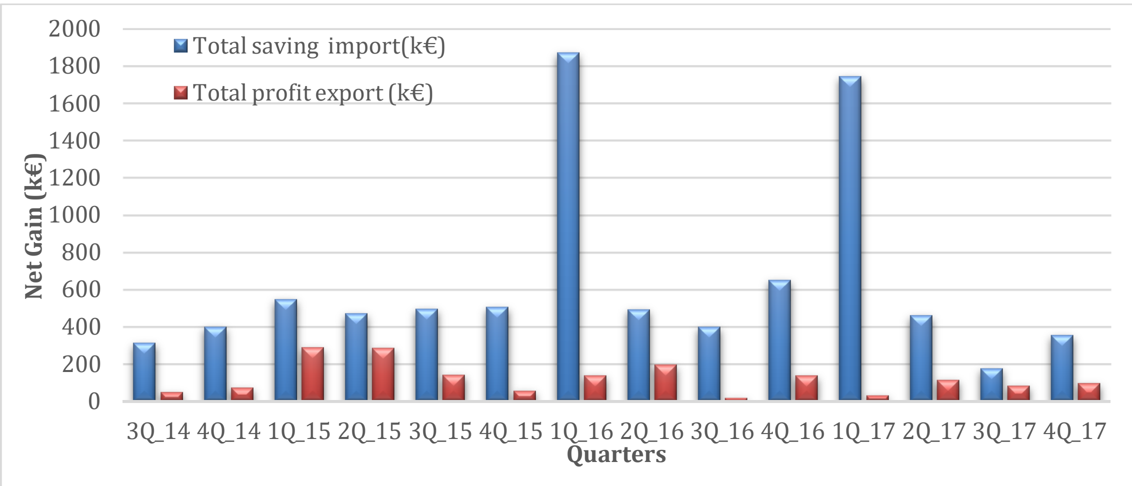

Fig. 19 – The net profit of transactions between Portugal and Spain.

TABLES

Table 1 – Tertiary Balancing Results

	Spot Price (€/MWh)	Tertiary Upward (€/MWh)	Tertiary Upward (GWh)	Tertiary Downward (€/MWh)	Tertiary Downward (GWh)
2015	51.2	68.2	693	29.0	1269
2016	40.1	54.0	1154	22.8	1284
2017	53.2	71.3	971	36.8	1308

Table 2 – Over-cost Results

	Over-cost Upward (M€)	Over-cost Downward (M€)	Total Over-cost (M€)
2015	11.78	15.38	27.17
2016	16.04	19.96	36.00
2017	17.58	15.92	33.50

Table 3 – Energy Trade

Energy sold	109.3 GWh
Energy assigned	455.5 GWh
Energy Trade	564.8 GWh

Table 4 – Economic Results

Profit of sold	8,879,090 €
Saving of buying	1,705,560 €
Total profit	10,584,650 €