Cooperation in Ancillary Services: Portuguese Strategic Perspective on Replacement Reserves

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Abstract
Market cooperation in the electrical sector is crucial for competitiveness improvement. In the particular case of ancillary services, it was only carried out within a national context until the recent past. In the Iberian case, since the middle of 2014, a bilateral mechanism has allowed tertiary reserve sharing between the Portuguese and the Spanish Transmission System Operators (TSOs). This mechanism generates gains for the Portuguese electrical system. However, with a high level of cooperation, these gains could be improved. The Portuguese TSO is one of the most peripheral TSOs in Europe and, as such, it considerably benefits from market integration, in the various dimensions of the electrical sector. Hence, as a new contribution to earlier studies, this paper evaluates, from the Portuguese strategic perspective, what would happen to revenues when sharing replacement reserves without any restriction, considering a full integration of Europe's southwest countries in contrast to the traditional bilateral solution that is currently in place. The new methodology used in this paper is a cross-comparative evaluation between different bilateral combinations of TSOs' offers. A comprehensive study is presented and conclusions are duly drawn.

Keywords: System Operator; Ancillary Services; Tertiary Reserve; Electrical Market Integration.

1. Introduction

Ancillary services are crucial for the stable operation of electricity systems and, in particular, the tertiary reserve is a key factor for the real-time balancing of mismatches between consumption and generation [1]. For Transmission System Operators (TSOs) in the European electricity system, this type of operation reserve is generally acquired via a market-based mechanism [2].

In [3], an overview of balancing market designs has been presented. A significant distinction has been made between design aspects associated with the procurement of balancing services and the ones associated with delivery and settlements. In [4], several fundamental issues have been listed for the design of ancillary services. The improvement of intermittent sources in electricity systems would lead to more fluctuation of production and would increase the tertiary reserves' requirements for system operators [5].

In [6], hypothetical scenarios have been investigated for the European electricity system until the year 2030. The benefits of interconnections have been presented in [7] to improve the effectiveness of cross-border trade. Moreover, a case study of Central Western Europe has been drawn in [8].

In [9], a model to determine bidding prices and quantities for reserve offers has been proposed for procuring reserves and clearing the day-ahead energy market, considering scheduled reserve capacity and transmission constraints. A methodology to optimize the share of the net transfer capacity between balancing areas for reserve exchanges, has been presented in [10] and [11]. The effect of hydro inflow, in the Nordic system, on the optimal cross-border transmission capacity allocation has also been studied in [12]. Furthermore, the potential benefits of incorporating balancing markets in the Northern European power system have been addressed in [13]. The electrical regional initiative of southwest Europe, which involves the TSOs of Portugal, Spain and France, worked through implementation of cross-border ancillary services, in particular a tertiary sharing mechanism [14]. In 2013, the decision to implement two bilateral solutions was taken and these solutions started to operate in the middle of 2014 [15]. These solutions were based on a mechanism implemented between the French and the British TSOs (RTE[1] and the National Grid) [16].

This bilateral solution allows tertiary exchanges between REN[2] and REE[3], and between REE and RTE [17]. For the Portuguese electricity system, one of the most peripheral TSOs in Europe, the implementation of this bilateral mechanism generates interesting gains [7].

However, the profits could be improved if a high level of cooperation could occur. Hence, as a new contribution to earlier studies, this paper evaluates, from the Portuguese strategic perspective, what would happen to revenues when sharing replacement reserves without any restriction, considering a full integration of Europe’s southwest countries in contrast to the traditional bilateral solution that is currently in place. The new methodology used in this paper is a cross-comparative evaluation between different bilateral combinations of TSOs’ offers. The energy and respective prices are compared for offers of tertiary reserve available in the first step, and in the second step for the effective tertiary transactions [18]. After the bilateral comparison between all TSOs, the most competitive combinations are identified in terms of direction of transaction, assignation, or availability of energy. When a TSO is unable to transact energy with another one, a constraint is identified and the loss of economic value is calculated. In this paper, the reference TSO is the Portuguese one, so when the French TSO is the most competitive buyer (the French TSO is able to pay a higher price than the Spanish one) or seller (the French TSO is able to

[1] Réseau de Transport d'Électricité, the Electricity Transmission System Operator of France
[2] Rede Eléctrica Nacional, the electricity transmission system operator of Portugal
[3] Red Eléctrica de España, the electricity transmission system operator of Spain

sell at a lower price than the Spanish one), a constraint is identified and the loss of economic value is calculated.

2. Portuguese electricity system: tertiary reserve activation

The Iberian Electricity Market (MIBEL) was created in 2006. Its participants are market agents belonging to the Portuguese and Spanish TSO's. After the day-ahead market, seven intraday markets occur that allow the market intervenient to adjust or re-adapt strategies during the market period [1]. To introduce and better understand the reality of the Portuguese electrical system and its idiosyncrasies, particularly in relation to tertiary activation, a few considerations and calculations are presented. In the particular case of the Portuguese electrical system, the definition of tertiary reserve embraces the manual Frequency Restoration Reserve and the Replacement Reserve. Operationally, these types of reserves are blended.

The consumption of electricity supplied from the public grid in 2015 was 48,964 GWh, 0.3% more than in 2014, when it was 48,825 GWh. Consumption in 2015 was 6.2% below the all-time maximum recorded in 2010 [19]. The average spot price was 50.2 €/MWh in 2015 and 41.9 €/MWh in 2014. The difference between the spot prices is explained by the difference in climatic conditions in-between these years. In Portugal, 2015 was a dry year, whilst 2014 had higher levels of precipitation. It is possible to observe the capability factor of the hydropower plants: in 2015 it was 0.74, whilst in 2014 it was 1.27. The hydro capability factor is given by the expression:

$$HCF_i = \frac{EhT_i}{EhAv_{40(1971-2010)}} \tag{1}$$

Where EhT is turbinable affluent energy per time period and $EhAv_{40(1971-2010)}$ corresponds to the statistics' average covering forty (40) years, from 1971 to 2010. Regarding wind generation, the capability factor was 1.02 in 2015 and 1.11 in 2014. The wind capability factor is given by the expression [19]:

$$WCF_i = \frac{EwT_i}{EwAv_{10(2003-2013)}} \tag{2}$$

Where EwT_i is energy produced in the time period and $EwAv_{10(2003-2013)}$ corresponds to the statistics' average covering ten (10) years, from 2003 to 2013 [20]. These previous events are the main reasons for the price difference [21].

In the Portuguese case, the generation units that did not sell their energy on the spot market, submit to the respective SO a price that they are willing to receive to produce an additional quantity of energy. If the SO needs to mobilize a given quantity of energy upward, Q_{up} (in MWh), it will pay the marginal upward price, P_{up} (in €/MWh) to the respective market agent(s). All suppliers who provide this extra quantity of energy requested by the SO will receive P_{up} for the energy they provide, which represents to the price of the last (most expensive) MW provided [22].

On the other side, the market agents which sold their energy to the spot market, submit to the System Operator the quantities and the respective prices they are willing to refund to reduce or even stop the production. If the SO intends to mobilize a given quantity of energy downward, Q_{dw}, the respective market agent(s) will pay (refund) the electrical system with the downwards price, namely, P_{dw}. All suppliers who reduce this quantity of energy requested by the SO will refund the system with the amount of P_{dw} that corresponds to the price of the last (cheapest) MW reduced. It is important not to forget that this producer(s) had already received Ps for the energy sold on the spot market [23].

As an example of the tertiary balancing of the Portuguese electrical system, in terms of price and energy, two years will serve as the basis for analysis (2014 and 2015):

The tertiary reserve activated upward was 693 GWh with an average price of 68.2 €/MWh, and the one activated downward was 1269 GWh with an average price of 29 €/MWh. In 2014, the tertiary upward activated was 1423 GWh with an average price of 58.5 €/MWh and the downward one was 596 GWh with an average price of 18.4 €/MWh. The tertiary activation aims to fill the gap between the real consumption needs and the energy traded in spot markets and restores the secondary frequency control in the boundaries of its control band. The gap is fulfilled by the combination of these two mechanisms [22] [23].

The tertiary activation could be considered as an overcost for the electricity system. The tertiary reserve activated upward, when less energy than required is traded, has a higher cost than the spot price [24]. The price of tertiary activated downward is lower than the spot price; hence the producers refund less money to the electrical system than they received (the spot price). With the previous data, it is possible to calculate the “overcost” generated for the electricity system with tertiary activation. The tertiary activation is the energy assigned to fill the gap between the predicted and the real consumption. From an economic point of view, an imperfection could be considered that could generate an overcost for the electrical system. In the case of tertiary activated upward, the "general" upward overcost is calculated by the given function (3):

$$OC_{up} = (P_{up} - P_{sp}) \times Q_{up} \tag{3}$$

where P_{up} is the price of the tertiary activated upward (€/MWh) and P_{sp} is the spot price (€/MWh). Q_{up} is the quantity of tertiary reserve activated upward (MWh). Substituting the previous values in (1), the overcost generated by tertiary upward activation was 12.474 M€ in 2015 and 9.894 M€ in 2014.

In the case of the tertiary downward activation, the "general" downward overcost is calculated by the given function (4):

$$OC_{dw} = (P_{sp} - P_{dw}) \times Q_{dw} \tag{4}$$

where P_{dw} is the price of the tertiary downward activation (€/MWh). Q_{dw} is the quantity of tertiary reserve activated downward (MWh). Substituting the previous values in (2), the general overcost generated by the tertiary downward activation was 26.903 M€ in 2015 and 33.298 M€ in 2014.

The total overcost is given by equation (5):

$$OC_t = OC_{up} + OC_{dw} \tag{5}$$

The total overcost was 39.377 M€ in 2015 and 43.192 M€ in 2014.

3. Cross-border tertiary exchanges: a new paradigm

Since June 2014, there is the possibility of exchanging the tertiary reserve launched in the Iberian Peninsula countries.

A common platform was developed by the RTE, involving three TSOs (REN, REE, and RTE), plus the English TSO, the National Grid (NG). This platform allows the tertiary reserve to be exchanged in a bilateral and contiguous way. Each TSO sends the prices that are available for selling and/or buying tertiary energy to the platform, determined through established rules and procedures. These offers, that the TSO provides to the platform, are the tertiary offers sent by the national market agents for the respective TSO. The TSO, taking into account the tertiary needs for the next hour, sends to the platform the remaining offers to sell or buy tertiary reserve. Each TSO can provide to the platform a maximum of ten offers to sell and/or buy tertiary reserve. Each offer is a 50 MWh block that is associated to a determined price (€/MWh) [25]. Only bilateral exchanges are allowed. Each TSO can activate between 1 and 10 offers (in a determined direction) to another TSO. The first IN is the one who takes the offer (in the case of disputing offers) [26]. This energy is added to the interconnections resulting from the last intraday market, and said energy is impossible to mobilize in real-time.

Three years from the beginning of the platform's operation (i.e., July 2014 until June 2017), the results can be considered truly positive. Savings of more than 8.5 M€ were generated in the purchase of tertiary reserve by the Spanish TSO and the saving relative was approximately 1.5 M€ in the sale of tertiary reserve. The total gains are higher than 10 M€ [27].

The profit gained was not particularly large, representing a small percentage of the total tertiary requirements and cost, but it allows an expectation of good potential on behalf of this mechanism.

4. The constraint of bilateralism: an integrating strategic perspective

The overcost generated by the tertiary needs was identified in the previous section. The profits obtained from the implementation of the tertiary sharing mechanism were also reported.

However, these profits could be improved. The actual mechanism only allows bilateral transactions between Portugal and Spain, and between Spain and France in a contiguous way [28]. The mechanism also exists between France and Great Britain, but there are some technical and procedural differences when compared to the southwest countries (Portugal, Spain, and France), so this mechanism was not considered in this study. This paper focuses on the study of a hypothetical situation where the three countries in the southwest of Europe could exchange tertiary reserve without constraints through the existence of a multilateral market instead of the two bilateral markets already in existence. Technically, this solution could be easily implemented [29]. However, political and bureaucratic factors create obstacles to the implementation of a common platform that would enhance the dynamism in the transactions and raise even more profit [30]. The main issue with a 3-lateral market is that direct transactions between two non-adjacent TSO's requires the intervention of a third one, which acts as a de facto intermediary. This TSO incurs the operational effort of modifying its interconnections program to satisfy transactions without any internal energy transaction. This paper's goal is to estimate the potential profit (or opportunity) that would be gained by the Portuguese electrical system through a complete cooperation between the three TSOs in the first three years of implementation, proceeding to a thorough analysis of the transactions, which allows the scrutinization of the process in detail.

Traditionally, and almost all-year long, the French electrical system is a large exporter. The main French electrical production is provided by nuclear power plants. Usually, the interconnection capacity between Spain and France is fully congested, or near to its maximum, in the direction from France to Spain, for large periods of time. In 2014, the entrance into production of new interconnections between these countries helped to diminish the periods of full congestion. The improvement of the electrical interconnection between France and Spain, such as the new lines in the Bay of Biscay, will increase the potential of trade between the Iberian system and the rest of Europe. These increases of trade capacity will potentially diminish the period of market splitting between both countries and indirectly allow the improvement of tertiary exchanges, which could affect market behaviour [31] [32].

The calculation and analysis of availability of the *Net Transmission Capacity* (NTC), which allows these transactions, is beyond the scope of this paper.

In the following section, the offers submitted by the three TSOs are discussed. Some simple comments related to the idiosyncrasies of the French electrical system are presented, to aid in the understanding of and to justify the types of offers submitted [33].

5. Three party submitted offers

In this section, a comparison is made between the prices submitted by the three TSOs and the respective evolution, on a daily basis and in the long run. A deeper comparative analysis is carried out for the prices submitted between the French and Spanish TSOs with the objective of evaluating the advantages of a stronger cooperation with the Portuguese TSO.

5.1 Daily basis analysis

Figure 1 shows the available prices for export provided by the three TSOs. The first interesting observation is that the available prices of export tertiary reserves from the French TSO are, in general, the highest from the three TSO's that compound the Southwest electrical region. The existence of a considerable nuclear base portfolio has two considerable effects: on the one hand, the existence of lower electricity production costs, on the other hand there is a less flexible generation to manage the energy balance. In this specific situation the importance of balance management is more important. The lower electricity production costs reflect more on Spot markets, which are not the focus of this work [34] [35]. In the majority of daily periods, the Spanish TSO is the most competitive in terms of submitted offers. The existence of a mixed portfolio helps to explain this observation [32].

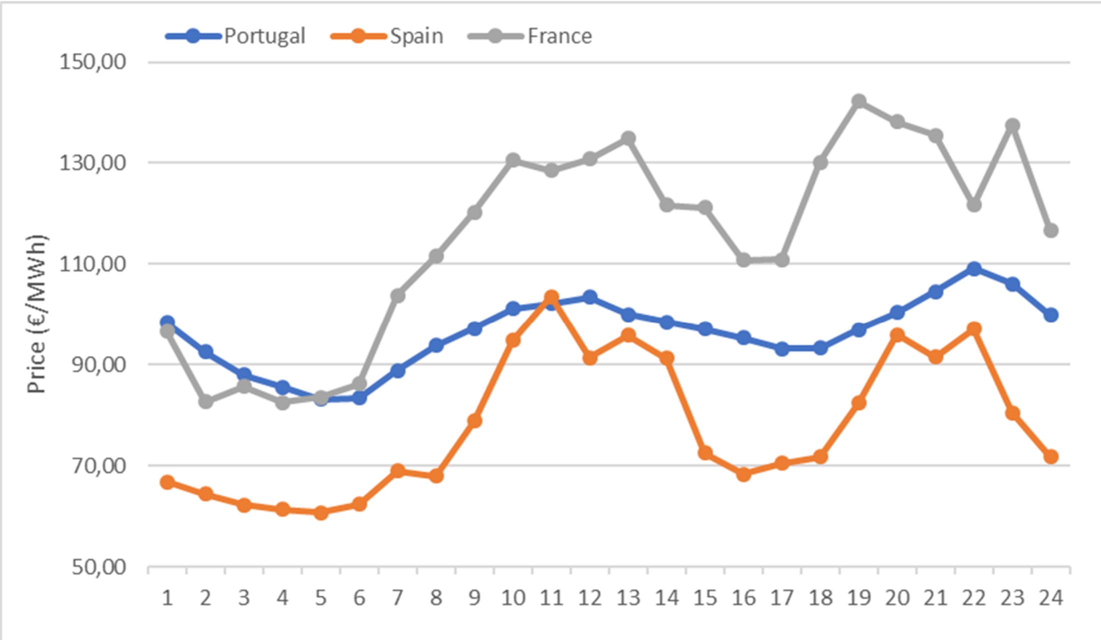

Fig. 1- Export Submitted Offers (daily basis Analysis).

In Fig. 2, it is possible to observe the available prices for import provided by the three TSOs. A uniform tendency during the day can be verified. The Spanish TSO is the one that offers to purchase energy at a lower price while the French TSO offers to purchase it at a higher price. These results indicate a loss of opportunity business between the Portuguese and French TSOs. In the mentioned periods, it could be interesting for the Portuguese TSO to sell tertiary reserve to the French TSO.

As a first conclusion, by analysing only the offers submitted by the TSOs, one can derive that if the market were multilateral, the liquidity of transactions would be improved.

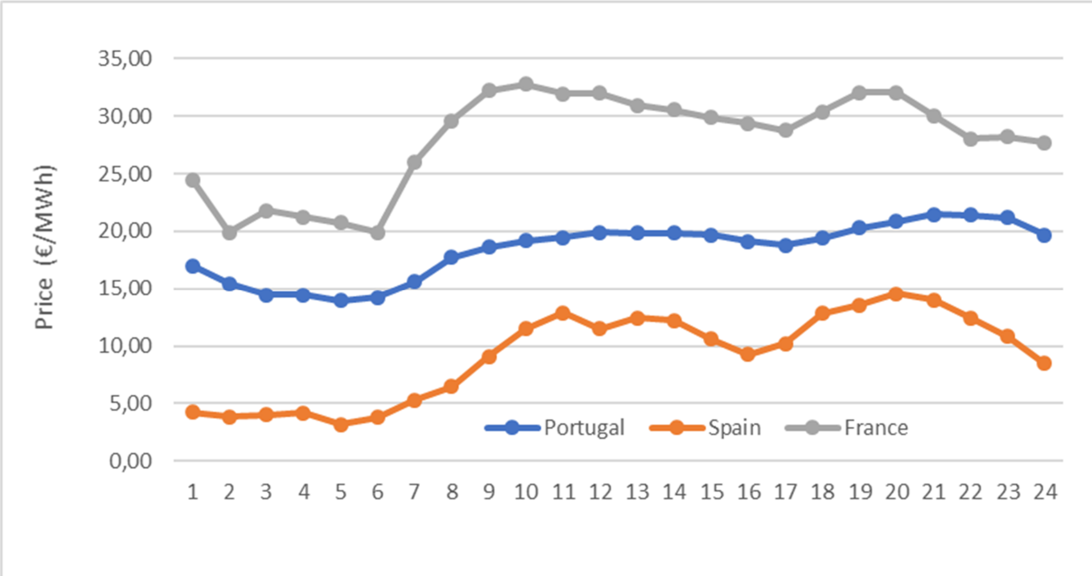

Fig. 2-Import Submitted Offers (daily basis Analysis).

5.2 Long-run analysis

Complementing the daily-basis analysis that was elaborated to observe the market in one day, a long-run analysis allows the investigation of the market in a more strategic way and to observe the market players' evolution tendency. This will be explained according to the first three completed years of the TSO's submitted offers, as organized by quarters.

In Fig. 3, the export prices submitted by the three TSOs are illustrated. The apparently irregular variation of the submitted prices is greater in the French TSO than in the Iberian TSOs. In the Portuguese case, the price is almost controlled, and in the Spanish case, stabilization is carried out. The high number of France's interconnections with different countries when compared to Portugal or even Spain, implies a greater variation in the spot price of electricity and, indirectly, in the tertiary offers. Thus, it is more difficult to identify a simple and continual explanation of the price evolution. An interesting observation is the first quarter of 2016, which represents the winter period in Europe. This period (where electrical consumption is naturally higher) was conjugated with a period of considerable nuclear power plant in outage. This was reflected in every dimension of the market prices including in the offers of replacement reserves, as observed in Figure 3.

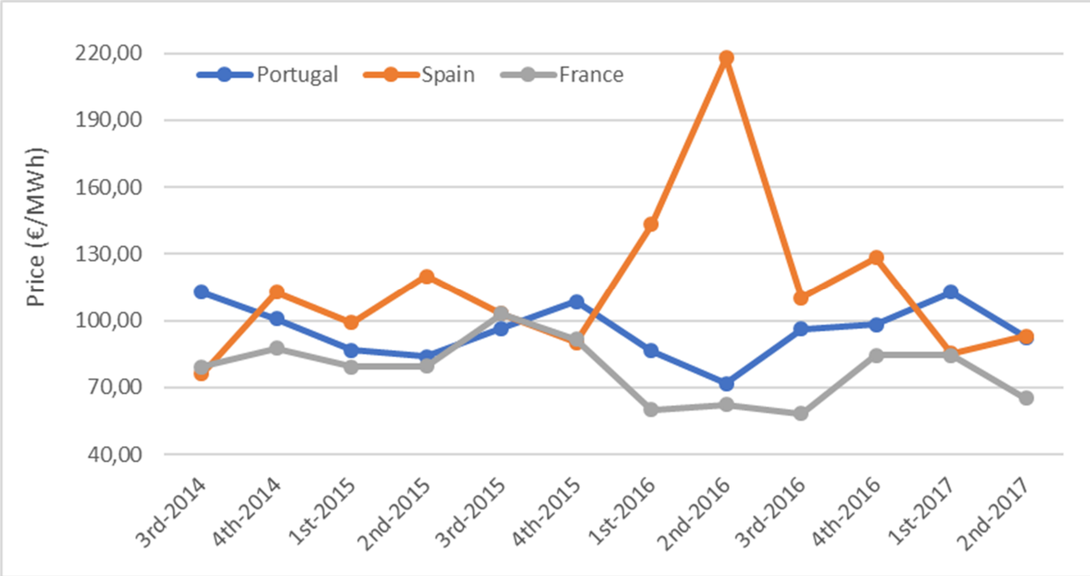

Fig. 3-Export Submitted Offers (long- run analysis)

In Fig. 4, the available prices for import submitted by the three TSOs are shown. The French TSO, as was observed in the daily-basis analysis, is the TSO that is able to buy energy at a higher price. This trend is consistent with the analysis of the evolution occurred during the first three years.

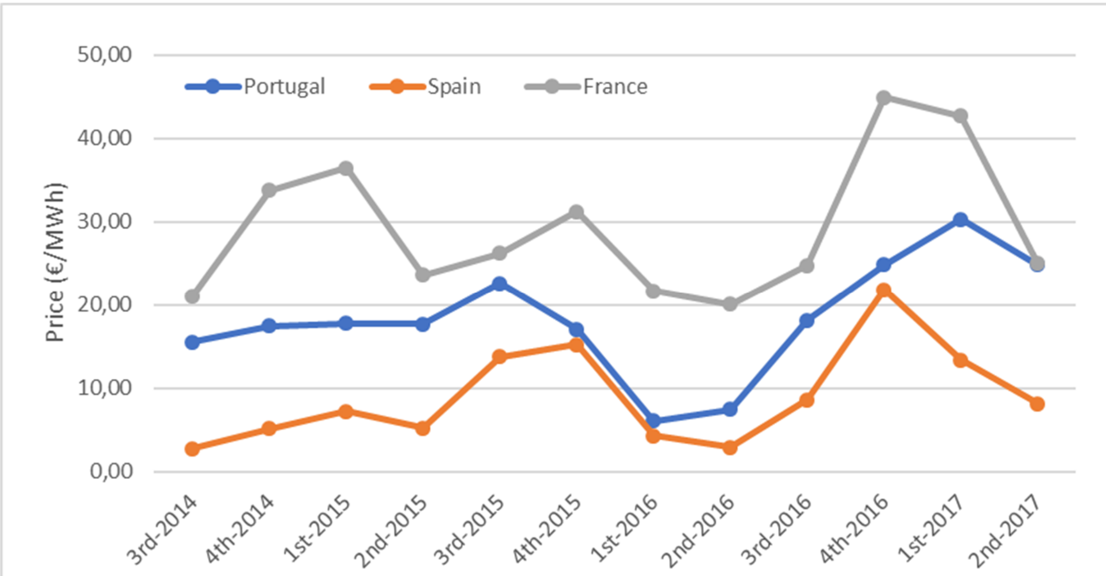

Fig. 4-Import Submitted Offers (long- run analysis).

In May and June, the price decreases again, reaching similar values as those of the Portuguese TSO. One explanation for these prices could be the more severe autumn and winter in France than on the Iberian Peninsula. The decrease in temperature increases electricity consumption. On the other hand, due to considerable penetration of hydraulic power plants in the Iberian countries and taking into account that wet periods occur precisely during winter, the increase of available energy compensates for the increase in consumption [36].

6. Loss of Gains with Non-Cooperation

In the previous section, the offers submitted by the three TSOs have been introduced, indicating an interest in buying or selling tertiary reserve. The first conclusions, which are mainly qualitative, about the absence of a common platform that would allow direct transactions between all TSOs have also been shown. However, as mentioned, only the average value of buying and selling tertiary reserve, at which each TSO proposed to trade, was presented. In order to estimate more accurately the potential earnings from cooperation, it is crucial to know the effective value of the transactions. These values are the result of the comparison made between all TSOs regarding their selling and buying offers. This means that in the case of buying tertiary reserve, these values could be obtained in two different ways: the TSO that is interested in importing accepts the selling offers made by the other TSOs (exporter).

On the other hand, the TSO that is interested in selling (exporting) accepts the buying offers made by the other TSOs. In selling scenarios, the opposite assumption is made. The average price of transactions is a combination of the two possible ways in which they can happen. Now, the effective prices at which the transactions are made are analysed, as well as the cross between the French and Portuguese TSOs' offers, in order to estimate the economic loss from non-cooperation.

In what concerns the structure of the results' presentation, in the previous section, two types of analysis are carried out based on the daily and long-term data, for either import or export scenarios. In this case, in which the potential incomes resulting from greater cooperation will be estimated, the long-term analysis is not crucial for the comprehension of the study or for the intended estimate. The calculation of the potential incomes is presented on an hourly basis because this is the perspective on which market agents' prices and strategies are based.

6.1 Analysis of Traded Exports

Figure 5 shows the effective price of exports traded by the three TSOs.

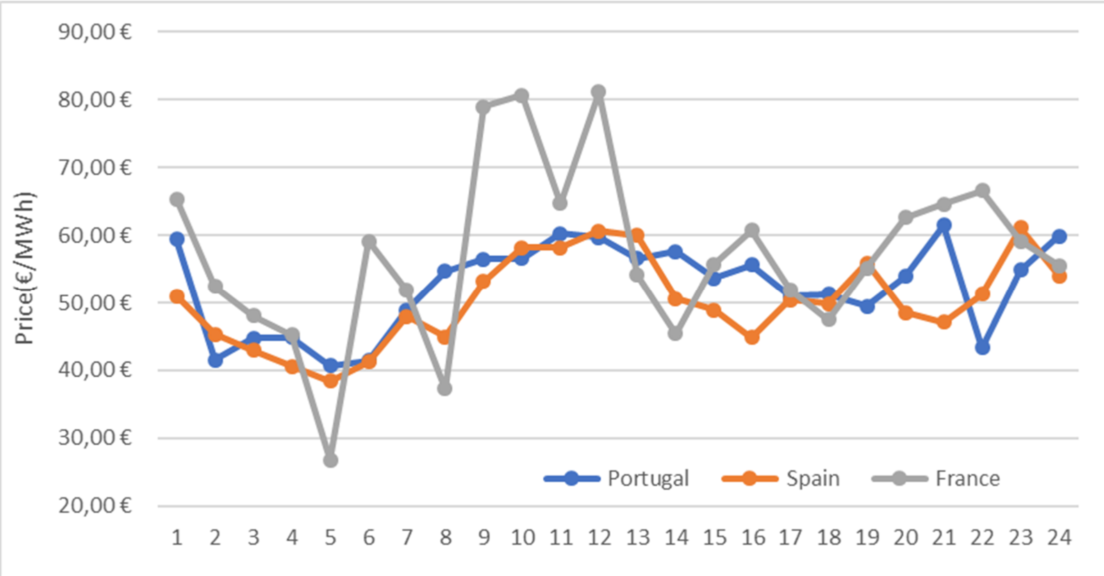

Fig. 5-Effective exportation price.

It is possible to observe and draw conclusions about the imports by the Portuguese electrical system and also from an eventual cooperation. In the periods 05, 08, 13, 14, 18, 19 and 23, the selling price to the French TSO, PsF , is lower than the selling price to the Spanish TSO, PsS , which means that the impossibility of transactions between the French and the Portuguese TSOs generated a decrease in income for both countries.

$$PsF < PsS \rightarrow Loss\ of\ additional\ savings\ when\ buying \tag{6}$$

6.2 Traded Importation Analysis

Figure 6 illustrates the effective import prices of the three TSOs.

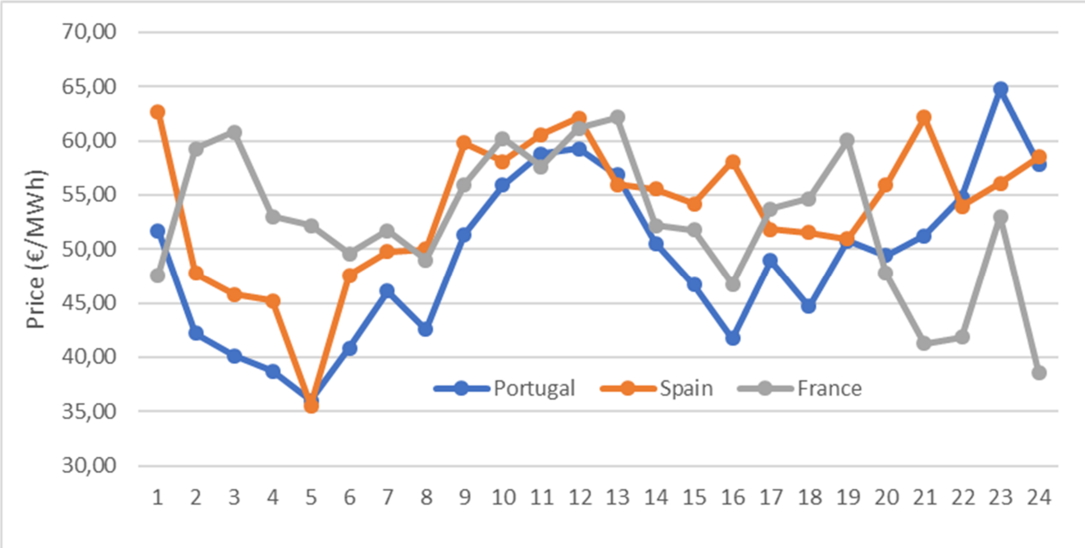

Fig. 6-Effective importation price.

During the majority of off-peak periods, it was the French TSO that bought tertiary reserve at a higher price. In the remaining periods, the competitiveness of the replacement reserve prices is very volatile. In the periods 02, 03, 04, 05, 06, 07,10, 13, 17,18 and 19, the assigned price of the French TSO, PaF , is higher than the assigned price of the Spanish TSO, PaS , which allows a potential loss of transactions to be identified for the Portuguese electrical system, in these hourly periods. If it were possible, the Portuguese TSO could sell to the French TSO instead of the Spanish TSO, when:

$$PaF > PaS \;\rightarrow Loss\ of\ additional\ profit\ from\ selling \tag{7}$$

7. Opportunity gains from a multilateral market for the Portuguese electrical system

This section aims to estimate the opportunity of a high level of cooperation for the Portuguese electrical system, creating a hypothetical multilateral market of tertiary reserve. The starting point is the two existing bilateral tertiary reserve markets, where the agents make offers based on current reality.

If a multilateral market were to exist, as conjectured, the offers, mainly from the French and Portuguese TSOs, which suffer the most restrictions from bilateralism, could have a different strategy. An estimation is carried out so that some conclusions can be drawn from the results [26] [27]

The principle used to calculate the opportunity is based on the offers traded, as identified in the previous section.

7.1 Export opportunity for France

Figure 7 indicates the price of import transactions in Spain and France. In the periods 02, 03, 04, 05, 06, 07,10, 13, 17,18 and 19, the average imported tertiary reserve by France was higher than the Spanish one. In the same periods, the potential tertiary reserve exported, Qetotal, from Portugal to France is the sum of the Portuguese TSO's exports, QPe, and the French TSO's imports, QFi.

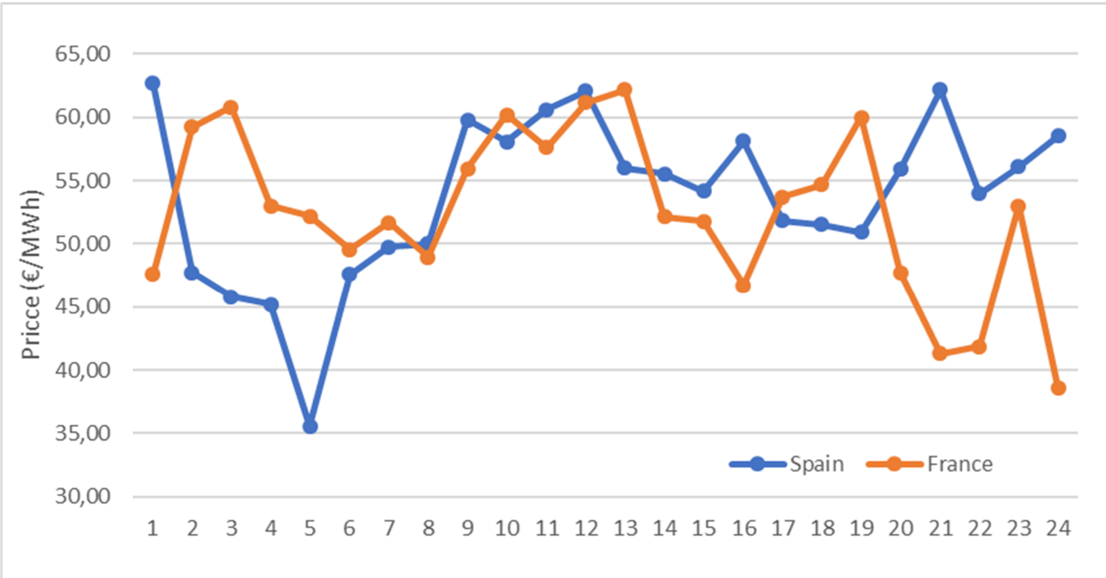

Fig. 7-Export opportunity for France.

$$Qe_{total} = QPe + QFi \tag{8}$$

The additional profit from exportation, APE (in euros), if the multilateral market is implemented, can be given by (9):

$$\begin{cases} PaF > PaS \\ APE = (PaF - PaS) \times Qe_{total} \end{cases} \tag{9}$$

7.2 Import opportunity from France

Figure 8 shows the export prices of the Spanish and French TSOs. In order to identify the potential for importation, principles opposite to those used in the previous point are followed. The hourly periods are identified in which, on average, the French TSO sold tertiary reserve at a lower price than that of the Spanish TSO. Those periods are the ones in which, from the Portuguese TSO's strategic perspective, an improvement in the potential savings could be gained in comparison with the transactions with the Spanish TSO. The potential tertiary reserve imported, Qitotal, in this scenario would be the sum of the Portuguese TSO imports, QPi, and the French TSO exports, QFe.

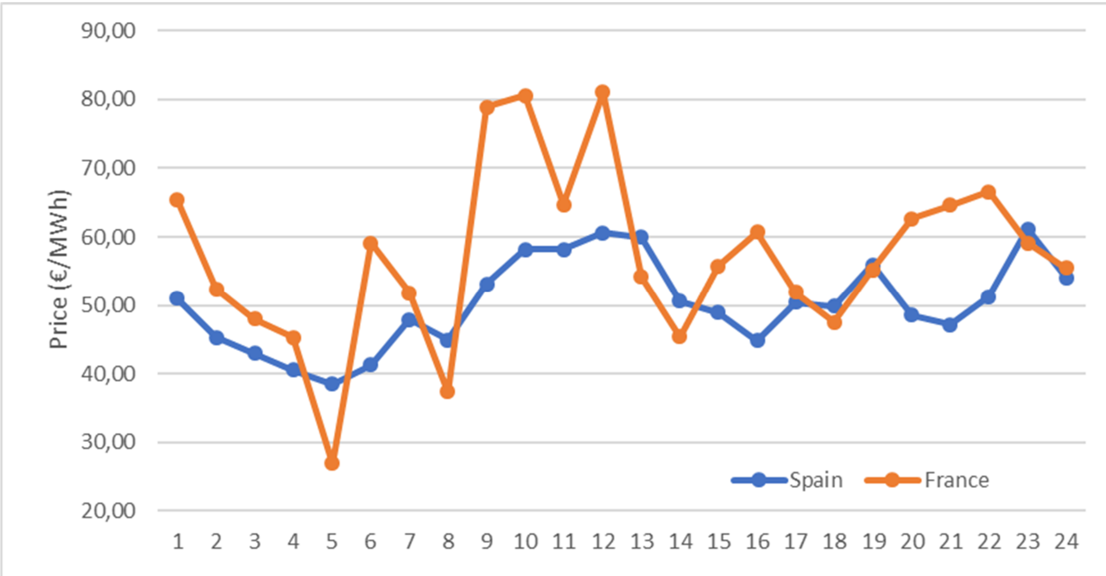

Fig. 8-Import opportunity from France.

$$Qi_{total} = QPi + QFe \tag{10}$$

The additional savings from importation, ASI (in euros), if the multilateral market is implemented is given by (11):

$$\begin{cases} PsF < PsS \\ ASI = (PsS - PsF) \times Qi_{total} \end{cases} \tag{11}$$

7.3 Calculation of Opportunity Gains

In the previous points, the Spanish and French TSOs' prices for exports and imports were considered to identify the potential transactions that could improve between the Portuguese and Spanish TSOs.

Otherwise, the hours in which, on average, the French TSO price is more competitive than that of the Spanish TSO were identified. In this point, the opportunity gains are calculated or estimated. The additional gains are the sum of APE and ASI and can be calculated by the following equation:

$$AG = APE + ASI \tag{12}$$

Table 1 to 3 show, in a condensed form, the hourly periods and respective values, with respect to the opportunity generated for the Portuguese electrical system, if the multilateralism of the market were real and effective. For each hourly period (of the 24 hours of the day), it is possible to consider two kinds of transactions: selling or buying tertiary reserve, which means there are 48 possible transactions [26]. Regarding the previous data, it is possible to observe that, in the first year, 13 transactions between Portugal and France would be, on average, more profitable for the Portuguese electrical system than the actual transactions with Spain [37]. In the second year, 14 would be more profitable and in the third year, 22.

Regarding the majority of results, the final values of the potential economical incomes, if Portugal and France could transact with each other, are 2,317,070 € in what concerns APE and 991,991 € in what concerns ASI, which results in a value higher than 3,308,981 € for AG.

Considering these results, the potential incomes would be considerably higher in the cases of importation of tertiary reserve when compared to exportation.

The total profits gained through the selling and buying operations of tertiary reserve would result in incomes of 1,554,952 € and 8,521,288 €, respectively, achieving a total of 10,076,240 €. If we add up the increment of the profits resulting from the existence and implementation of multilateralism, the total incomes for the Portuguese electrical system could surpass 13,385,221 €, as shown in Table 4.

Comparing the actual profits resulting from the bilateral solution already implemented with the possible results obtained from the existence of a multilateral tertiary-reserve market between the three countries, the latter option would generate an increment of income of approximately 30% for the Portuguese electrical system. However, it is our belief that the obtained results are conservative considering the possibility of multilateral transactions between Portugal, Spain, and France.

The analysed results have as their basis the values practiced in two existing distinct bilateral markets (Portugal–Spain and Spain–France). The cooperation of the third agent would automatically lead to an increase of tertiary reserve's sharing demand, and a reorganization of the prices for either buying or selling. The major idea of a European Unique Electrical Market, in its most varied dimensions (where the tertiary exchanges are included), is intended to be embraced by all players, without the risk of harming the peripherical TSO's. The idea of free fees increases the competitiveness between market agents and improves the cooperation between all the players involved. This study did not consider any type of transmission fees charged by any TSO [10] [31] [33].

7.4 General Statistics Overview

In this point, a summary of the results' descriptive statistics will be analysed. This analysis will be done according to a monthly basis collection of data, during the 36 months of the study, to understand a long run perspective. Two situations will be the focus: the import and the export scenarios for each TSO. The price (in €/MWh) and quantities (MWh) traded will be observed. In contrast with the previous analysis, in this statistical study, the data will not be observed in an hourly basis. The main reason for this distinction is that the number of hours in which the replacement reserves are traded is relatively low for each TSO. This generates a considerable quantity of periods with 0 MWh traded, which leads to a deviated statistical analysis, instead of an adequate one. In a monthly analysis, this problem is not an issue.

7.4.1 Exportation Scenario

In **table 5** it is possible to observe the TSOs' price in the exportation scenario. Statistically, one can observe that the French TSO is the most competitive and the Portuguese one is the less competitive. The standard deviation in the French TSO is higher, which indicates a less concentrated amount of transactions' prices around the mean. This alludes to a good distribution of the replacement reserve's prices. However, a negative skewness indicates a bigger amount of offers slightly above the average value. Considering the range, the Spanish TSO is the one who has less reach. The maximum value of the Portuguese one is considerably higher than the others. In terms of the minimum value, the French one is considerably lower than the others.

Table 6 shows the TSOs' exportation quantities. In this situation, the French TSO is the most competitive when selling tertiary reserve, with its amount of energy exported being the lowest. The Spanish TSO is the one who exports the most, with a considerable difference from their peers. After the analysis of the previous tables, it is possible to conclude that the French TSO sells low quantities, but when the selling occurs, it is cheaper when compared to the other sellers, on average.

7.4.2 Importation Scenario

In **table 7** it is possible to observe the price of the TSO's in the importation scenario. Statistically, the Portuguese TSO is the one who bought tertiary reserve at the lowest? price. The standard deviation in the Portuguese TSO is higher, indicating a less concentrated amount of transactions around the mean. This indicates well-distributed prices of bought tertiary reserve. The slight negative skewness also indicates a good distribution regarding the bought tertiary. The minimum value of the Portuguese TSO importation is considerably lower than the other ones. In terms of the maximum value, the French is the TSO, on average, that bought replacement reserve at a higher price.

In **table 8** it is possible to observe the quantity of import activation. The Spanish TSO is the player who imports less tertiary reserve, with a significant difference from both the French and the Portuguese. Another observation can be made: the Spanish TSO is the one who bought energy at a more expensive price. Analysing the statistical tables, it is possible to conclude that the Spanish TSO is mostly an exporter and the other two TSO's use this market mainly to buy replacement reserve. It is important to remember that the conditions verified are different for Spain (it is possible to trade with Portugal and France) when compared to Portugal and France (both can only trade with Spain).

8. Future Perspective: The TERRE Project

The European Network of Transmission System Operators for Electricity (ENTSO-E) is developing a project based on the "Network Code on Balancing Energy", as defined by this institution. This project aims to create a mechanism for sharing tertiary reserve (and other services) that is more cooperative, and integrative when compared to the actual bilateral mechanisms implemented in the southwest of Europe. This project is called the "Trans European Replacement Reserve Exchange" (TERRE) [38] [39].

Several TSOs are involved in this project, namely ADMIE (Greece), the National Grid (Great Britain), REE (Spain), REN (Portugal), RTE (France), Swissgrid (Switzerland), and Terna (Italy). EIGRID (Ireland) and SONI (Northern Ireland) are observers in this project. The main goal is to create and manage a single and centralized platform with the capacity to agglutinate the tertiary offers and allocate them in an optimized way, with the aim of fulfilling the differences (for all TSOs) between the energy traded on the market and the real consumption needs. Several benefits are expected from the implementation of this project, such as improvements in the competitiveness and efficiency of this kind of market, in the operational security of the participating TSOs and in the facilitation of cooperation based on electricity generated by renewable resources [40].

9. Conclusion

The importance of the coupling of electrical markets is crucial for improving the competitiveness and welfare provided by the market environment. The gains achieved by the bilateral sharing of tertiary reserve between the Iberian countries confirm this idea. However, a high level of cooperation would enable high gains for the European electrical systems. The original study provided in this paper, based on the first three years of implementation of a tertiary reserve sharing mechanism, showed that the constraint generated by a bilateral market instead of a multilateral market involving the southwest systems' operators, generated lower profits and diminished the economic welfare, with greater impact on peripheral countries, as in the case of the Portuguese electrical system. The losses from non-cooperation were around 30% of the total value of transactions. Balancing mechanisms are crucial for a proper management of the electrical systems. Like other cooperation processes in the electrical field, as with the spot market, the importance of the creation and cooperation of ancillary services markets is crucial to develop a more unified European electrical environment. The TERRE project, to be led by ENTSO-E, understands this need and addresses such a mechanism to allow in-depth cooperation in this field.

References

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

[2] M. Scherer, M. Zima and G. Andersson, “An integrated pan-European ancillary services market for frequency control,” *Energy Policy,* vol. 62, pp. 292-300, 2013.

[3] R. A. V. d. Veen and R. A. Hakvoort, “The electricity balancing market: Exploring the design challenge,” *Revue E magazine,* Vols. 43-B, pp. 186-194, 2010.

[4] Y. Rebours, “A Comprehensive Assessment of Markets for Frequency and Voltage Control Anciliary Services,” The University of Manchester (2008) PhD thesis, 2008.

[5] P. Havel, “Utilization of Real-Time Balancing Market for Transmission System Control Under Uncertainty,” *IEEE TRANSACTIONS ON POWER SYSTEMS,* vol. 29, pp. 450-457, 2014.

[6] M. MacDonald, “Impact Assessment on European Electricity Balancing Market,” 2013. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/20130610_eu_balancing_master.pdf. [Accessed 10 10 2017].

[7] G. S. I. V. David Newberry, “The Benefics of Integrating European Electricity Markets,” *Energy Policy,* vol. 94, pp. 253-263, 2016.

[8] K. Van den Bergh, B. H. R., K. Bruninx, E. Delarue, W. D'haeseleer and B. Hobbs, “Benefits of coordinating sizing, allocation and activation of reserves among market zones,” *Electric Power System Research,* vol. 143, pp. 140-148, 2017.

[9] Y. Gebrekiros, G. Doorman, H. Farahmand and S. Jaehnert, “Benefits of cross-border reserve procurement based on pre-allocation of transmission capacity.,” in *Proceedings of IEEE*, Grenoble, 2013.

[10] Y. Gebrekiros and G. Doorman, “Optimal transmission capacity allocation for cross-border exchange of Frequency Restoration Reserves (FRR),” in *Proceeding of the Power Systems Computation Conference*, Wroclaw, Poland, 2014.

[11] K. V. d. Bergh, K. Bruninx and E. Delrue, “Cross-border reserve markets: network constrains in cross-border reserve procurment,” *Energy Policy,* vol. 113, pp. 193-205, 2018.

[12] Y. Gebrekiros, G. Doorman and S. Jaehnert, “Sensitivity analysis of optimal transmission capacity reservation for cross-border exchange of reserve capacity in Northen Europe,” in *European Energy Market*, Cracow, Poland, 2014.

[13] T. A. H. Farahmand, G. Doorman and D. H.-H. M. Korpas, “Balancing market integration in Northen European continent: a 2030 case study,” *IEEE Trans. Sustain Energy,* vol. 3, pp. 918-930, 2012.

[14] ENTSO-E, “Electricity in Europe 2015,” 05 01 2017. [Online]. Available: https://www.entsoe.eu/Documents/Publications/Statistics/electricity_in_europe/entsoe_electricity_in_europe_2015_web.pdf.

[15] P. Frade, J. Santana, M. Shafie-khah and J. Catalão, “Impact of tertiary reserve sharing in Portugal,” *Utilities Policy,* 2019 (forthcoming).

[16] Agency for the Cooperation of Energy Regulators, “ACER - Regional Initiatives,” [Online]. Available: http://www.acer.europa.eu/en/electricity/regional_initiatives/meetings/6th%20stakehodler%20group%20meeting%20of%20the%20eri%20sw%20region/document%20library/1/point%204%20121025_swe-eri-sg__rcc_balancing.pdf. [Accessed 04 011 2016].

[17] J. Torriti, “Privatisation and cross-border energy trade: From internal market to European Supergrid?,” *Energy,* vol. 77, pp. 635-640, 2014.

[18] ENTSO-E, “Survey on Ancillary Services Procurement & Balancing market design,”

09 2012. [Online]. Available: https://www.entsoe.eu/Documents/Publications/Market%20Committee%20publications/WGAS_Survey_final_10.03.2017.pdf. [Accessed 01 04 2017].

[19] REN, "REN Techincal Data 2015," 14 12 2016. [Online]. Available: https://www.ren.pt/files/2016-04/2016-04-04142047_7a820a40-3b49-417f-a962-6c4d7f037353$$7319a1b4-3b92-4c81-98d7-fea4bfefafcd$$fe7585fb-f92a-49f7-9574-43f66d7223c6$$File$$pt$$1.pdf.

[20] Eurelectric, "Hydro in Europe: Powering Renewables," [Online]. Available: https://www3.eurelectric.org/media/26690/hydro_report_final-2011-160-0011-01-e.pdf. [Accessed 28 04 2018].

[21] P. C. Bhagwat, J. C. Richstein, E. J. L. Chappin and L. J. d. Vries, "The effectiveness of a strategic reserve in the presence of a high portfolio share of renewable energy sources," *Utilities Policy,* vol. 39, pp. 13-28, 2016.

[22] T. W. Haring, D. S. Kirschen and G. Andersson, "Incentive Compatible Imbalance Settlement," *Power Systems - IEEE,* vol. 30, pp. 3338 - 3346, 2015.

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

[24] R. A. v. d. Veen, A. Abbasy and R. A. Hakvoort, "Agent based analysis of the impact of the imbalance pricing mechanism on market behavior in electricity balancing markets," *Energy Economics,* vol. 34, pp. 874-881, 2012.

[25] ACER, "Final SWE Regional Work Plan 2011-2014," [Online]. Available: energy-regulators.eu/portal/page/portal/ACER_HOME/Activities/Regional_Initiatives/Electricity_Regional_Initiatives/Regional%20Roadmaps/South-West. [Accessed 07 07 2016].

[26] REN, "REN- Real Time Information Electricity," [Online]. Available: http://www.centrodeinformacao.ren.pt/EN/Pages/CIHomePage.aspx. [Accessed 12 12 2016].

[27] REN, "REN-Sistema de Informação de Mercados de Energia-Síntese Anual 2012-2016," [Online]. Available: http://www.mercado.ren.pt/PT/Electr/InfoMercado/PressReleases/BibInfAnual/MercadoEletricidadeSinteseAnual2012_2016.pdf.

[28] ACER, "ACER BALIT," [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 01 07 2016].

[29] O. G. Roland Meyer, "Cross border effects of capacity mechanisms: Do uncoordinated market design changes contradict the goals of the European market integration?," *Energy Ecomics,* vol. 51, pp. 9-20, 2015.

[30] C. B. Martínez-Anido, M. Vandenbergh, L. d. Vries, C. Alecu, G. F. A. Purvins and T.Huld, "Medium-term demand for European cross-border electricity transmission capacity," *Energy Policy,* vol. 61, pp. 207-222, 2013.

[31] ACER / CEER, "Annual Report on the Results of Monitoring the Internal Electricity Markets in 2015," [Online]. Available: http://www.acer.europa.eu/official_documents/acts_of_the_agency/publication/acer%20market%20monitoring%20report%202015%20-%20electricity.pdf. [Accessed 02 02 2017].

[32] Regulatory Commission of Energy of French Republic, "CRE-Report on French electricity and gas interconnections," 06 2016. [Online]. Available: http://www.cre.fr/en. [Accessed 03 02 2017].

[33] ENTSO-E, "Cross-Border Physical Flow," [Online]. Available: https://transparency.entsoe.eu/transmission-domain/physicalFlow/show?name=&defaultValue=false&viewType=MAP&areaType=BORDER_BZN&atch=false&dateTime.dateTime=29.04.2017%2000:00|CET|DAY&border.values=CTY|RU!BZN_BZN|10Y1001A1001A49F_BZN_BZN|10Y1001A1001A39I&d. [Accessed 02 02 2017].

[34] OCDE, "OCDE-Nuclear Energy Agency (France Data)," [Online]. Available: https://www.oecd-nea.org/ndd/pubs/2016/7300-ned-2016.pdf. [Accessed 12 10 2016].

[35] P. G. Maria Lykidi, "How to manage flexible nuclear power plants in a deregulated electricity market from the point of view of social welfare?," *Energy,* vol. 85, pp. 167-180,

2015.

[36] G. L. Doorman and R. v. d. Veen, “An analyis of desing options for the markets for cross-border balancing of electricity,” *Utilities Policy,* vol. 27, pp. 39-48, 2013.

[37] RTE-French Electrical Data, [Online]. Available: http://www.rte-france.com/en/eco2mix/eco2mix-mix-energetique-en. [Accessed 12 12 2016].

[38] ENTSO-E, “TERRE Project,” [Online]. Available: https://consultations.entsoe.eu/markets/terre/user_uploads/20160307__terre_consultation.pdf. [Accessed 02 02 2017].

[39] REN, “REN-Projecto TERRE,” [Online]. Available: http://www.mercado.ren.pt/EN/Electr/Communication/News/Pages/News_20160316_01.aspx. [Accessed 02 02 2017].

[40] A. D. Hansen and M. Altin, “Provision of enhanced ancillary services from wind power plants - Examples and challenges,” *Renewable Energy,* vol. 97, pp. 8-18, 2016.

Tables

Table 1

General Data of potential transactions – Profit of transactions in 1st year

Market Hours	Increase of the Potential Profit with Import for France (€/MWh)	Potential of Import to France (MWh)	ASI(€)
1	0,08	2250	187,5
12	11,73	2550	29916,28
17	8,33	4900	40803,39
18	12,72	4100	52140,69
20	4,16	6050	25149,85
22	20,09	3900	78359,91
23	6,22	6800	42278,71
24	4,16	7900	32894,02
Total		**38450**	**301730,4**
Market Hours	**Increase of the Potential Profit with Export for France (€/MWh)**	**Potential of Export to France (MWh)**	**APE(€)**
7	1,25	3950	4950,67
9	1,43	6050	8663,02
10	4,10	7350	30099,36
12	6,43	5500	35374,43
19	6,45	9950	64130,92
Total		**32800**	**143218,39**

Table 2

General Data of potential transactions – Profit of transactions in 2nd year

Market Hours	Increase of the Potential Profit with Import for France (€/MWh)	Potential of Import to France (MWh)	ASI(€)
8	10,27	8400	86259,04
10	2,20	4250	9347,12
14	10,30	4650	47888,93
24	7,19	9700	69739,77
Total		**27000**	**213234,86**
Market Hours	**Increase of the Potential Profit with Export for France (€/MWh)**	**Potential of Export to France (MWh)**	**APE(€)**
2	0,16	3250	532,80
6	1,69	2750	4656,67
8	18,11	9050	163906,81
9	6,19	8650	53511,63
10	4,01	8650	34666,29
11	1,36	10900	14838,22
13	8,65	9700	83868,45
17	1,52	6800	10331,47
18	8,46	14450	122221,78
19	8,26	16100	133035,58
Total		**90300**	**621569,69**

Table 3

General Data of potential transactions – Profit of transactions in 3rd year

Market Hours	Increase of the Potential Profit with Import for France (€/MWh)	Potential of Import to France (MWh)	ASI(€)
2	3,01	8250	24809,52
3	6,35	7250	46019,09
5	24,20	7100	171803,4
8	1,47	19150	28158,93
13	9,20	4300	39542,13
14	2,23	5550	12398,7
15	1,90	8950	16977,26
17	0,52	8800	4562,02
18	6,56	5550	36394,52
19	6,68	8350	55798,03
23	3,11	13000	40482,23
Total		**96250**	**476945,9**
Market Hours	**Increase of the Potential Profit with Export for France (€/MWh)**	**Potential of Export to France (MWh)**	**APE(€)**
2	25,01	6300	157572,4
3	29,88	5850	174791,5
4	16,92	5600	94741,11
5	29,96	4150	124330,5
6	14,64	4800	70280,73
7	4,15	13000	53932,98
13	13,85	20500	283889,3
17	5,76	14000	80620,16
18	3,37	17650	59451,55
19	10,51	24750	260214,8
23	11,81	16300	192456,8
Total		**132900**	**1552282**

Table 4

General Results

First Year	
Profit of Sales	694 842,15 €
Saving of Assignation	1 731 492,75 €
APE	143 218,39 €
ASI	301 730,36 €
Second Year	
Profit of Sales	544 370,56 €
Saving of Assignation	3 377 794,00 €
APE	621 569,69 €
ASI	213 234,86 €
Third Year	
Profit of Sales	315 739,16 €
Saving of Assignation	3 412 001,07 €
APE	1 552 281,87 €
ASI	476 945,86 €
Potential Gain (with Multilateral Market)	**13 385 220,72**
Total Gain (Bilateral Market)	**10 076 239,68**

Table 5

Statistical summary data – Exportation Price

Price -Portugal		***Price -Spain***		***Price -France***	
Mean	53,63	Mean	51,68	Mean	48,56
Standard Error	2,47	Standard Error	2,30	Standard Error	3,19
Median	53,39	Median	51,23	Median	49,87
Standard Deviation	14,82	Standard Deviation	13,79	Standard Deviation	15,65
Variance	219,67	Variance	190,07	Variance	244,87
Skewness	0,78	Skewness	0,13	Skewness	-0,77
Range	76,58	Range	57,35	Range	77,67
Minimum	25,48	Minimum	23,76	Minimum	5,82
Maximum	102,06	Maximum	81,11	Maximum	83,48

Table 6

Statistical summary data – Exportation Quantity

Quantity –Portugal		***Quantity -Spain***		***Quantity -France***	
Mean	2797	Mean	27925	Mean	1689
Standard Error	330	Standard Error	2594	Standard Error	410
Median	2600	Median	22250	Median	600
Standard Deviation	1979	Standard Deviation	15564	Standard Deviation	2461
Variance	3917992	Variance	242251357	Variance	6057730,2
Skewness	1,120	Skewness	0,875	Skewness	1,695
Range	8050	Range	64250	Range	8450
Minimum	200	Minimum	7750	Minimum	0
Maximum	8250	Maximum	72000	Maximum	8450
Sum	100700	Sum	1005300	Sum	60800

Table 7

Statistical summary data – Importation Price

Price -Portugal		***Price - Spain***		***Price -France***	
Mean	49,53	Mean	53,25	Mean	52,43
Standard Error	2,61	Standard Error	2,22	Standard Error	2,35
Median	48,95	Median	53,12	Median	51,60
Standard Deviation	15,65	Standard Deviation	13,32	Standard Deviation	14,08
Variance	245,03	Variance	177,32	Variance	198,24
Skewness	-0,11	Skewness	0,68	Skewness	0,51
Range	63,25	Range	62,05	Range	55,43
Minimum	18,19	Minimum	30,97	Minimum	27,23
Maximum	81,44	Maximum	93,02	Maximum	82,66

Table 8

Statistical summary data – Importation Quantity

Quantity -Portugal		***Quantity -Spain***		***Quantity -France***	
Mean	12261	Mean	4486	Mean	15664
Standard Error	1001	Standard Error	634	Standard Error	2001
Median	10850	Median	3550	Median	13225
Standard Deviation	6007	Standard Deviation	3802	Standard Deviation	12009
Variance	36089302	Variance	14454230	Variance	144206087
Skewness	1,525	Skewness	1,406	Skewness	0,932
Range	27250	Range	16300	Range	47400
Minimum	4050	Minimum	400	Minimum	550
Maximum	31300	Maximum	16700	Maximum	47950
Sum	441400	Sum	161500	Sum	563900