HOW TO INCENTIVIZE SHORT-TERM FLEXIBILITY RESOURCES IN ELECTRICITY BALANCING GROUPS – INTERNATIONAL COMPARISON OF IMBALANCE MECHANISMS IN EUROPE

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The content of this paper reflects the opinion of the author(s) and does not represent the position of any organization. This paper refers to a theoretical approach and is no proof for practical viability of concept. Advantages, disadvantages and framework conditions for practical applicability have to be screened and assessed carefully.

Keywords*: control area imbalance, imbalance mechanism, electricity balancing, balance responsible parties, marginal pricing*

Abstract – An important part for minimizing costs of operation of power systems is to minimize imbalance energy, i.e. unplanned generation and demand deviations from committed program (schedules). The actual design of imbalance settlement mechanisms differs across European countries. To compare different imbalance schemes throughout Europe, control area imbalances of selected countries were analyzed with data from ENTSO-E transparency platform (European network of transmission system operators for electricity) [1]. As the implementation of electricity balancing guideline (EB GL) [2] will determine market integration measures of balancing markets and the main features of future imbalance mechanism design, different advantages and disadvantages of imbalance energy schemes are discussed. Finally, a Merit-Order-List-Model compares the effects of marginal pricing on balancing prices and costs.

1. COMPARISON OF IMBALANCE MECHANISMS IN EUROPE

1.1. Introduction

The paper focuses on a comparison of different imbalance mechanisms in Europe, European electricity market integration and harmonization by the electricity balancing guideline [2]. Main challenges with imbalance mechanisms are presented and a merit-order-list-model to estimate price risks of marginal pricing on balancing prices and costs. Specific design issues are discussed more in detail, such as central and decentralized allocation of short-term electricity flexibility. [3] provided a framework for a comparison of electricity balancing markets across Europe and mention that imbalance mechanisms differ across European countries. [4], [5] and [6] presented research for electricity wholesale markets and a comparison of marginal and pay-as-bid pricing. [7] compared imbalance mechanisms of different electricity markets. The interdependencies of imbalance mechanisms with balancing markets and network congestions have been discussed in [8] and [9]. While the first part of the study focuses on a qualitative and quantitative comparison of European imbalance mechanisms the second part of the study try to answer the research question how does a change from pay-as-bid pricing to marginal pricing effect balancing energy prices and costs.

1.2. Control area imbalance

As generation and load of electricity cannot be predicted perfectly (forecast errors) imbalance energy of the balance responsible parties (BRPs) occur. This imbalance energy (electricity) is mostly compensated with imbalance energy of other BRPs within the control area (imbalance mechanism) [10]. The final deviation of the control area after compensation is called the control area imbalance or system imbalance [11]. If the value is positive, there is too little energy in the system and if the value is negative, there is too much energy in the system. This system imbalance is covered with automatic frequency restoration reserves (aFRR) and manual restoration reserves (mFRR) by the transmission system operator (TSO) via activating balance service providers (BSP) (balancing market) [2], [10]. If there are residual imbalances, they are compensated with unintended exchange of connected control areas [2], [11]. The wordings and definitions of this paper are partly from electricity balancing guideline [2].

The payment of BRPs within a control area can be optimized via different imbalance settlement mechanisms. On the one hand, there are control areas where BRPs are obliged to fulfil their schedules (e.g. Germany [12]). It might be inefficient that every BRP is trying to optimize itself in a decentralized way instead of using balance compensation with the short-term electricity flexibility of the whole system and procuring the remaining energy centrally via the TSO. However, this approach leads to less relative overall system imbalance for Germany (DE_LU), as indicated in Figure 1.

On the other hand, there are control areas, where the BRPs are allowed and also incentivized to use their available short-term flexibility capacities to reduce the imbalance of the control area, while offering them via the imbalance mechanism to decrease overall system imbalance (e.g. Netherlands [13]). One advantage of this approach is that flexible capacities, which were not able to be allocated to the other options like intra-day (ID) or balancing market, can be used. One disadvantage is that BRPs sometimes generate slight overcompensation due to information delays at low levels of balancing Merit-Order-List (MOL). Overcompensation means that the BRPs are increasing the system imbalance – this effect is based on several conditions like timing of availability of information, type of generation etc.. Preconditions for this approach are that there is short-term publication of system imbalance by the TSO and that there are no expectable congestions within the control area by reason of the short-term actions of the BRPs (e.g. small control areas).

1.3. Reasons for imbalances

System imbalances are the sum of all BRP imbalances within a control area. There are different reasons for imbalances as indicated in [14] and [15] (not complete list):

- Generation forecast errors (e.g. electricity from variable renewable energy sources (vRES-E))
- Load forecast errors
- Load noise
- Schedules (e.g. product length)
- Changes of BRP position
- Power plant outages
- Infrastructure outages

Power plant outages are random events. The load forecast error is the sum of load noise over the settlement period and the average deviation [14]. Schedule ramps are imbalances that occur due to the granularity of product definitions that cannot capture load gradients (e.g. hour products or quarter hour products). While there is some periodic pattern in the control area imbalance, reactions of balance responsible parties on imbalance mechanism also influence the system imbalance in some control areas (e.g. compensation or overcompensation).

The vRES-E forecast error varies in different countries according to their way of vRES-E implementation. In systems with a high share of vRES-E, imbalance energy may mainly result from forecast errors of weather-driven generation. Increasing vRES-E penetration increases the risk of significant short-term forecast errors and imbalances. Renewable electricity power plants can cause significant deviation spikes within a short time period. This can be minimized through avoiding grouping these generators within one single balancing group instead distributing amongst several balancing groups, or through manual trading optimization. If they are distributed amongst various BRPs, they can use the short-term flexibility of generators/loads to decrease the imbalances. Imbalances caused by vRES-E can be mitigated through active manual trading and intra-day optimization close to real-time. Prediction methods and meteorological models have improved reducing the relative imbalance energy of vRES-E. In general, balancing groups are able to buy/sell electricity on intra-day and over-the-counter (OTC) markets to update their schedules in the short-term when new information is available. In this way, they already reduce the remaining deviations in the control area imbalance, and thus the costs for overall system balancing. In single-price schemes (implemented e.g. in Austria) balancing groups are incentivized through payments from imbalance mechanism to use their available short-term flexibility resources to counterbalance deviations of the overall control area. A big advantage of this approach is that balancing groups are able to also use their short-term flexibility capacities, which might, for several reasons, not be eligible to participate in the centrally organized balancing energy market operated by the transmission system operator (TSOs), e.g. because it became available after gate-closure-time (GCT). However, forecast errors after gate-closure-time (GCT) and market liquidity will still influence system imbalance with further vRES-E penetration.
Figure 1 shows the relative normalized density functions of system imbalances for Germany (DE_LU), Netherlands (NL), Austria (AT), Belgium (BE) and Spain (ES). The data is taken from the Transparency Platform of ENTSO-E [1] and TSO websites [16] and [17]. To be able to compare them, the control area imbalances of different market balancing areas (MBA) were standardized by dividing them with the corresponding yearly electricity consumption of 2015 according to ENTSO-E [18]. The method is a normalized density distribution function with the same area under every curve. Standardization is important to be able to compare the different control areas. The narrow zero curves are those either with strict schedule obligations and short-term trading (e.g. Germany), or control areas permitting BRPs to offer their short-term electricity flexibility via the imbalance mechanism to reduce the system imbalances (e.g. Austria, Belgium, Netherlands). Spain has the broadest density in this comparison, because it has the highest relative imbalances. The reason for the different forms of the imbalance distribution functions are distinct forms and shares of the underlying distribution functions of forecast errors for generation, load, vRES-E, etc. [15]. Observations of the evolution of balancing markets and imbalance mechanisms reveal two trends. On the one hand, the share of vRES-E in total consumption and the resulting maximum values of vRES-E short-term forecast errors are the main drivers for system imbalances. On the other hand, market integration, imbalance netting, forecast improvements and an adequate market design foster a decrease in the average imbalance and balancing costs.

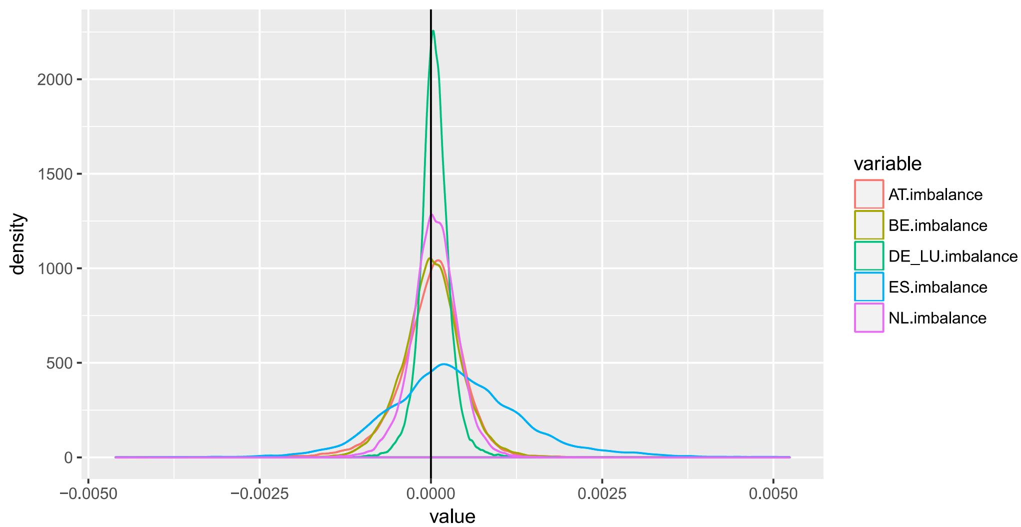

Figure 1: Comparison of distribution functions of balancing area imbalances, standardized per electricity consumption in 2015 for Germany (DE_LU), Netherlands (NL), Austria (AT), Belgium (BE) and Spain (ES) [1], [16], [17], [18], [19].

This comparison has to be interpreted carefully as different imbalance mechanisms and imbalance settlement periods (ISP) influence the net sum of imbalances, as well as the positive and negative imbalances within the imbalance settlement period. As different ISP have to be considered (e.g. 15 minutes and 1 hour), two calculation problems influence the comparison. The imbalance volume is only the balance of energy within a quarter hour, which means that there can be higher absolute activation of balancing energy in both sides and the imbalance might be much smaller. A further problem is also the comparison of values of the 1 hour settlement period with the imbalance values of the 15 minutes settlement period, as compensation within the settlement period is more probable within the longer time period. Furthermore, the size of the control areas as well as the number of control areas within the countries influence the control area imbalances as there are other probabilities of simultaneity and compensation within the country. However, as the imbalance of a control area represents an approximation of activated balancing energy, this comparison provides a suitable indication.

1.4. Different electricity systems and imbalance mechanisms in Europe

European market integration in balancing markets and imbalance mechanisms is proceeding with the guideline for electricity balancing (EB GL) [2], the guideline for system operation (SO GL) [10] and the "Winter Package of the European Union" ("Clean Energy For All Europeans") [20]. Imbalances are strongly interrelated with local characteristics of the power plant park and features of market design of the respective control area. Therefore, there might not be a "one-size-fits-all" solution for an imbalance mechanism for the whole of Europe, but basic elements of the imbalance mechanism will be harmonized [2]. However, there are a lot of interdependencies and interrelations of different electricity systems and their resulting incentives to market participants. Market design and the characteristics of electricity systems influence the activated balancing energy and balancing prices (e.g. aFRR and mFRR), which will set the minimum for imbalance prices in future as mentioned in [2]. The main differences of electricity systems in Europe influencing the respective imbalance mechanisms are shown in Table 1. While France has a pro-active TSO and a slow power plant park (e.g. nuclear), Austria has a reactive TSO and a relevant share of fast power plant park (e.g. pumped-storage power plants). The Netherlands have a short-term publication of imbalances and imbalance prices and BRPs are able to counterbalance the system. In general, control areas with short-term publication of imbalances and imbalance prices, a short imbalance settlement period and a relatively fast power plant park tend to have less relative imbalance energy. Nevertheless, the amount of imbalance energy also depends on other characteristics of the control area and elements of the respective imbalance mechanism, which all have to be adjusted.

Table 1: Main characteristics of electricity systems in Europe influencing imbalances, own representation based on [1], [2], [21].

Characteristics	From	To
Power plant park	Mostly slow power plant park (e.g. coal)	Relevant share of fast power plant park (e.g. pumped-storage power plants)
Dispatch	Central dispatch	Self-dispatch
TSO strategy	Reactive activation of balancing energy	Pro-active activation of balancing energy
Congestions within control area	Probable	Improbable
Gate closure time (GCT) of intra-day market before real time	> 15 min	15 min
Schedule adjustment after GCT	Prohibited to a certain amount	Before and/or after real-time possible
Long term flexibility (> 1 h)	Central via balancing	Central (TSO) and decentralized (BRPs)
Short-term flexibility (<1 h)	Short-term balancing energy bids without capacity procurement of BSPs	Decentralized allocation via BRP optimization or compensation of other imbalances via imbalance mechanism
vRES-E distribution	Central vRES-E BRP	Distributed vRES-E
Imbalance settlement period	1 h or 30 min	15 min
Imbalance pricing	Dual pricing	Single pricing/Hybrid
Procurement of balancing capacity	Static	Dynamic
Balance responsible	Not every market participant	Every market participant

Table 2: Main elements of imbalance settlement [1], [21].

Main elements of imbalance settlement	Countries
Imbalance Settlement Period 15 min	AT, BE, DE, HU, IT, NL, SK, CH
Imbalance Settlement Period 30 min	FR, IE, UK
Imbalance Settlement Period 60 min	CZ, DK, EE, Fl, LV, LT, NO, PL, PT, RO, RS, Sl, ES, SE, HR, BA, GR
Single Pricing (imbalance mechanism)	UK, DE, BE, AT, SK, RS, NL (hybrid)
Dual Pricing (imbalance mechanism)	FR, CH, IE, LV, PL, CZ, HU, Sl, HR, BA, RO, ES
Marginal price of balancing energy as main part of imbalance price	NL, BE, PL, CZ, SK, NO, SE, Fl, DK, GR
Publication of imbalance costs ≤ 1 day	UK, FR, NL, BE, DK, ES, SE, Fl, PL, CZ, BA
Publication of imbalance costs > 1 day	DE, CH, AT, IT, Sl, LV, LT, SK, HU, HR, RO, RS, GR, PT

As shown in Table 2, control areas have implemented imbalance mechanisms with single price systems, hybrid systems or dual price systems. In an one-price system (single pricing) there is only one price per MWh imbalance (same price for long and short position of BRP), which BRPs pay (via settlement party or TSO) to other BRPs [22]. In dual pricing systems there are different prices for long and short position of BRPs. Studies [23] and [24] highlight advantages of the one-price imbalance mechanism. One-price mechanisms accommodates smaller balancing groups better, as two-price mechanisms give the incentive for aggregation of balancing groups to form larger balancing groups (e.g. portfolio effect) [22]. While most control areas apply one imbalance portfolio, they also separate portfolios (e.g. for consumption and generation). The imbalance settlement period of 15 minutes, required by the EB GL, is already implemented in AT, BE, DE, HU, IT, NL, SK and CH [2], [21]. Short-term publication of imbalance prices is important for efficient co-integration of spot and balancing markets, however, this is not yet applied in DE, CH, AT, IT, Sl, LV, LT, SK, HU, HR, RO, RS, GR, and PT [12]. Marginal prices of balancing energy as a main part of the imbalance price have already been adopted in NL, BE, PL, CZ, SK, NO, SE, Fl, DK and GR [1], [21].
Figure 2 represents a comparison of share of the sum of absolute values of control area imbalances of different selected countries per load per year (absolute imbalances in MWh per load in MWh). Very interesting is that 3 countries (DE, NL and FR) have the lowest values of this indicator and have implemented different strategies and imbalance mechanisms. While France has a pro-active TSO and long-term replacement reserves (RR), the Netherlands applies the possibility for BRPs to counterbalance other BRPs reducing overall system imbalance in the short term and Germany implements strict schedule accuracy and penalties for BRPs.

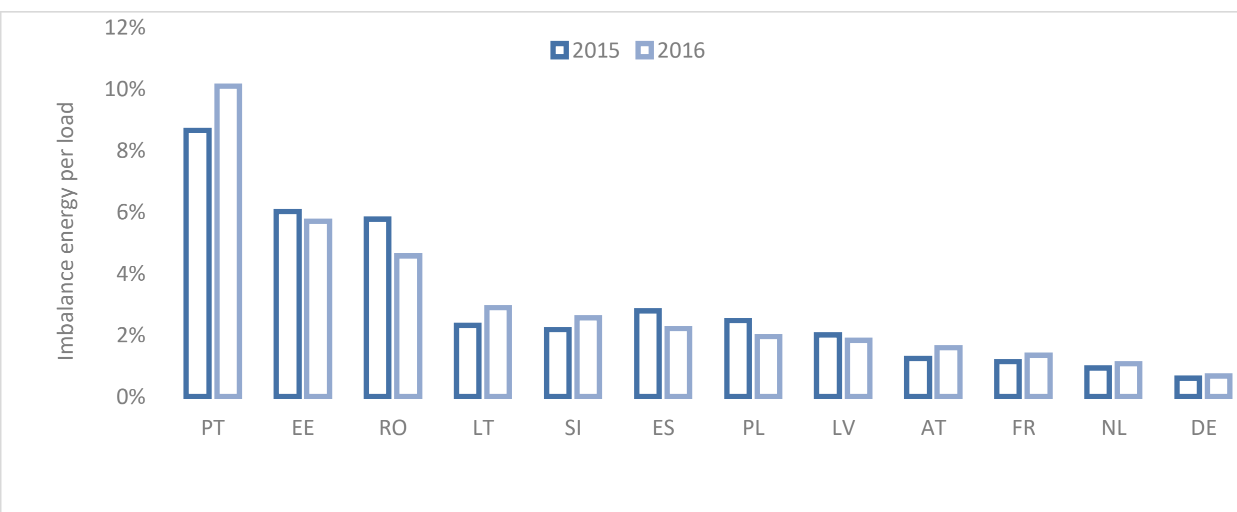

Figure 2: European comparison of absolute imbalances per load for 2015 and 2016 own calculation based on [1], [17], [18], [25]

2. INCENTIVIZE SHORT-TERM FLEXIBILITY RESOURCES IN ELECTRICITY BALANCING GROUPS AND IMPLEMENTATION OF ELECTRICITY BALANCING GUIDELINE

2.1. Central (via SO) or decentralized (via BRPs) allocation of short-term electricity flexibility resources

A decentralized allocation of short-term electricity flexibility of BRPs via the imbalance mechanism might reduce the control area imbalance in a cost efficient way. Short-term electricity flexibility might be integrated in balancing markets (central) via energy bids of BSPs. Central allocation would not take into account electricity flexibility sources which might become available after GCT. The decentralized allocation might be more efficient as local BRPs have the ability for short term forecasts and to react more swiftly. If there are schedule accuracy obligations short-term flexibility capacities of BRPs might only be used to balance own BRP. While the "Winter Package of the European Union" [20] proposes balance responsibility for everyone (also for vRES-E), the market design for central or decentralized allocation of flexibility depends on the structure and size of BRPs and control areas [2].

Table 3: Short-term electricity flexibility resources.

Schedule accuracy / balance obligations central allocation via SO (balancing market)	**No explicit schedule accuracy / no balance obligations / decentralized allocation via BRP (imbalance mechanism) and partly via SO (balancing market)**
• BRPs are only able to use the short-term flexibility capacities to balance own BRP • Central allocation of BSP capacities via SO (e.g. prequalification)	• BRPs are able to use own short-term flexibility capacities to balance own balancing group and minimize overall system imbalances via imbalance mechanism • Central allocation of BSP capacities via SO

2.2. Implementation of electricity balancing guideline (EB GL)

Even though effects of market integration measures of EB GL are not fully assessable yet, some estimations have been made. EB GL requires a harmonization of imbalance mechanisms and balancing markets [2]. However, some adjustments and additional obligations might remain at the specific control areas according to their diversified structure.

One problem after implementation of EB GL might be that the requirements to apply marginal pricing (pay-as-cleared) and common merit-order lists (cMOL) will lead to increased price risks. However, it depends on details of implementation, which will be developed over the next years. A cMOL is a merit order list, which combines bids of BSPs of different control areas.

According to EB GL [2], BRPs have to pay at least the price for activation of balancing energy within the ISP depending on the direction of the control area imbalance (imbalance price).Usually, imbalance mechanisms propose a higher payment for major deviations of BRPs and lower payment/income, if they are decreasing system imbalance or have minor imbalances. As the balancing guideline forces marginal pricing, high imbalance prices might occur. High system imbalances of other control areas within the same uncongested area might, due to the common marginal price, affect the imbalance price of BRPs in control areas without or relatively low system imbalances (own assumptions based on [2]).

Another issue is that congestions between control areas can cause high costs, because not every bid of cMOL can be exchanged. In such situations, especially trading BRPs, having deviations at periods with high overall marginal prices might have to pay more than they can pay (e.g. no assets). A further aspect to consider is the price risk, which would occur, if the marginal price is determined by the highest deviation within an ISP, even though the netted BRPs imbalance of the respective ISP is zero or relatively low. If there are balancing activations of the TSO in both directions within the ISP and the imbalances are hardly over zero, the prices for the imbalances in these periods might be very high, although the net sum is low.

The details of implementation are currently not clear, as they have to be developed in the next years. Therefore, mentioned effects may or may not occur, depending on the implementation design. In summary, there are many effects and interdependencies which have to be kept in mind for the future imbalance energy price formula. The design of imbalance mechanism is influenced by, and can only be seen in connection with, the relating electricity system of the respective control area.

2.3. Imbalance pricing

Although, electricity systems are different in Europe a harmonization of the main parts of the imbalance price mechanism have to be implemented as required by the EB GL [2]. Currently, there are different imbalance mechanisms applied within control areas in Europe [12]. The imbalance energy charges are currently not covering the costs for balancing energy and balancing capacity procurement and the share differs across European countries [26].
Importantly, the BRPs have strong incentives to optimize the short-term forecast errors to decrease imbalances to the maximal possible extent. Reducing arbitrage between intra-day and imbalance mechanisms is possible, by setting the intra-day price as basis [12]. Other additional national imbalance price components might be implemented, however obligations of EB GL have to be fulfilled. According to EB GL, the imbalance price should be the minimum/maximum of the marginal price of activated balancing energy (aFRR, mFRR and RR) of the respective ISP in the related direction [2].

EB GL will lead to market integration for balancing and imbalance mechanisms. Inter alia according to literature, future imbalance mechanisms might take into account following elements [12], [22]. Mentioned elements for imbalance mechanisms are not complete, not in order of importance and have to be further discussed:

- No market barriers for new market entrants
- Incentive for BRPs to reduce their imbalances additionally reducing system imbalances
- Avoidance of free-riders covering their consumers with imbalance energy
- Avoid fusion of balance responsible parties (e.g. subgroups of one BRP)
- Avoid arbitrage with intra-day markets
- Avoid arbitrage of balance service providers (BSP) on balancing activation with imbalances
- Imbalances should be published close to real-time for BRPs
- Imbalance prices or indicative prices should be communicated close to real-time to BRPs
- Efficient allocation of balancing cost

A major risk of imbalance pricing after implementation of EB GL is that imbalance prices and associated incentives will be directly influenced by effects in the common Merit-Order-List of balancing markets.

2.4. Different Merit-Order-Lists for balancing (pay-as-bid and marginal pricing)

The cMOL will combine bids of BSPs of different control areas and lead to one marginal price within an uncongested area. As there will be congestions within Europe, the joint balancing market will split into several uncongested areas leading to different marginal prices for different uncongested areas at the same time. Periods with congestions could be associated with high risk of high costs, since less bids are exchangeable. In the worst case all borders of a control area are congested and thus only national bids are available [2]. Especially, at time periods with high bids this effect is critical because this might lead to high imbalance prices. The cMOL should allocate the bids and might lead to marginal prices near marginal costs, which might be lower or higher than the marginal costs for the national level. The marginal balancing energy price will be determined by the supply of bids and demand for activation from several control areas. After implementation of EB GL it is assumed that BSP bids have a risk mark-up slightly above the marginal costs of the power plants. In a state without congestions, the marginal price within an uncongested area will be that of marginal pricing cMOL. Less activated energy and prices close to marginal costs for every BSP in Europe might lead to lower overall costs but price risks at periods with high overall deviations and/or congestions. These effects will also result in different local incentives for BRPs. Future harmonization of incentives of imbalance pricing schemes might mitigate these effects [2].

2.5. Merit-Order-List Model "Marginal price"

In order to the various effects of implementation of EB GL [2], a modeling of marginal price, instead of pay-as-bid (current scheme in AT), was calculated for Austria for the year 2015 with the pay-as-bid Merit-Order-List and MOL assuming perfect competition [27]. Modeling of marginal price is a theoretical approach as the price for activated balancing energy after EB GL will be affected by bids in the cMOL and marginal pricing (e.g. bidders would apply different bidding strategies and the bids would look different). However, it is an adequate method to indicate price risks of marginal pricing. Bids with marginal pricing MOL should converge to marginal costs of the BSPs according to theory [28]. Sometimes cMOL will partly split up (e.g. congestions) and national bids of the control area might determine the price. After market split, the competition (number of market participants) changes. Electricity wholesale markets and balancing markets are prone to market power in case of less market liquidity. There might happen situations where market participants speculate for splitting of cMOL (e.g. under congestions) and benefit from few periods with very high marginal balancing prices. The input data are "pay-as-bid Merit-Order-Lists" [29], "modeled perfect competition Merit-Order-Lists" [27] and activation time series for aFRR and mFRR for Austria for the year 2015 [29].

MOL-Model 1 (hypothetical)
MOL-Model 1 represents the pay-as-bid MOL with marginal pricing instead of pay-as-bid. As bidding behavior may change, the results are hypothetical.
The MOLs for pay-as-bid in 2015 (35,040 quarter hour periods) have 30 different products. There are 6 products for aFRR (08_20+/-, 20_08+/- and weekend+/-) and 24 products for mFRR (00_04+/-, 04_08+/-, 08_12+/-, 12_16+/-, 16_20+/-, 20_00+/-, WE_00_04+/-, WE_04_08+/-, WE_08_12+/-, WE_12_16+/-, WE_16_20+/-, WE_20_00+/-). For every product and week there is a single Merit-Order-List in the model (1,590 Merit-Order-Lists). The process of determining the marginal price is based on a step-function and cumulative sum of bids for every quarter hour. There are quarter hours with activations in both directions at the same time. The time resolution of the activation assumed for this model is one quarter hour based on average demand values, although balancing activation peaks might be much higher within the quarter hour. The model was created with the scientific computing language R [19].

MOL-Model 2 (theoretical)
MOL-Model 2 represents the theoretical MOL with modeled marginal costs of BSP [27]. The perfect competition MOL has four products (SRE+, SRE-, TRE+, TRE-), and 212 Merit-Order-Lists. In order to approximate the marginal pricing MOL, Merit-Order-Lists from another model were chosen [27]. This model combines data from three different optimization models, namely, a day-ahead spot market model, a week-ahead/day-ahead capacity procurement model and an activation model. The main assumptions of the models are prices assuming perfect competition in the period 09/2014 – 09/2015 for the Austrian balancing market [27].

MOL-real
To see the differences associated with the pricing mechanisms, the real weighted balancing prices (pay-as-bid pricing) are added.
In order to calculate the marginal price for every quarter hour for positive and negative aFRR and mFRR activation, the MOLs were splitted according to their products. Then a cumulative sum was calculated to reproduce a MOL. The model linked the activated energy with according MOL, which has to be applied for a given period and returned the marginal price. There were 35,040 iterations (35,040 quarter hours) per aFRR+, aFRR-, mFRR+ and mFRR-activation.

Figure 3 and Figure 4 indicate the modeled and real prices, respectively, for the year 2015. The marginal costs calculated show costs that are more than doubled. At the end of the period (Figure 3) a decrease of negative marginal prices can be seen. The price peaks are partly on an equal level, which indicates same bids in the MOL. The prices are extremely sensitive to activation of balancing energy, sometimes over 2000 €/MWh. Following figures indicate the possible price risks of marginal pricing instead of pay-as-bid during split of cMOL and high activation. However, after implementation of EB GL, average prices might be much lower according to cMOL and prices may be close to marginal costs. The negative aFRR prices for positive aFRR in Figure 5 resulted from negative values in the modeled Merit-Order-List assuming marginal costs. Figure 6 shows that marginal prices for mFRR are slightly above pay-as-bid prices in Figure 7. Some peaks of real average balancing prices happened due to settlement reasons. Flat Merit-Order-Lists and less activation are seen as reasons for relatively lower marginal prices for mFRR compared to aFRR. The balancing prices with marginal costs for mFRR with Merit-Order-List assuming perfect competition in Figure 8 are relatively low compared to Figure 6 and Figure 7.
Figure 9 and Figure 10 describe a sorted density function for the modeled balancing energy prices and real balancing prices for aFRR and mFRR for AT for the year 2015. It is indicated that marginal prices might lead to very high balancing prices for several periods within the year but hypothetical.

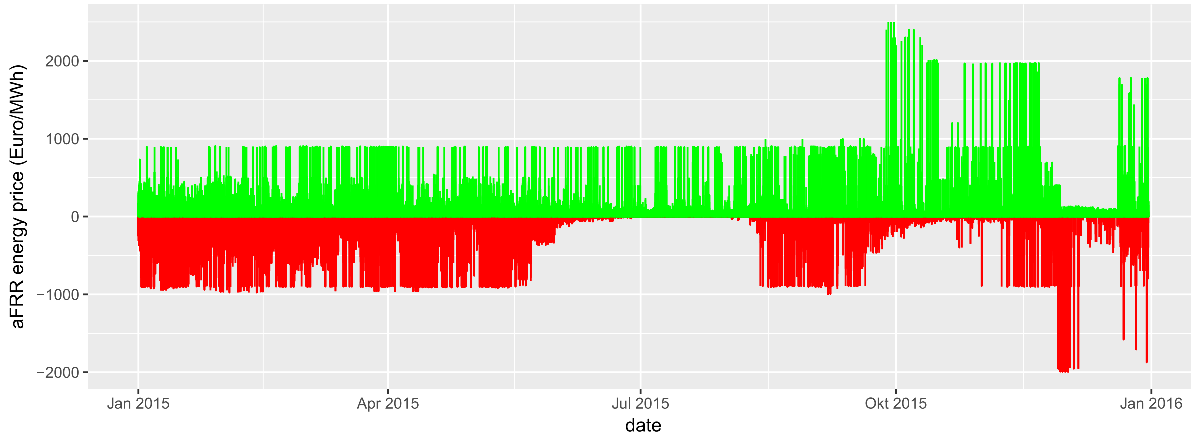

Figure 3: Modeling of marginal prices for aFRR for AT 2015 (MOL-Model 1) (hypothetical) [19], [29].

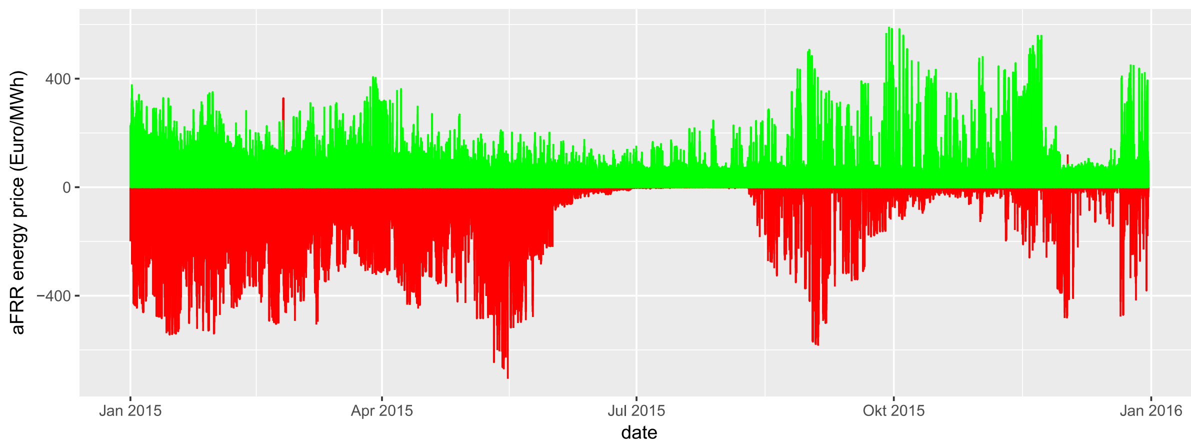

Figure 4: Real weighted average balancing prices for aFRR with pay-as-bid pricing and pay-as-bid Merit-Order-List for AT 2015 [19], [29].

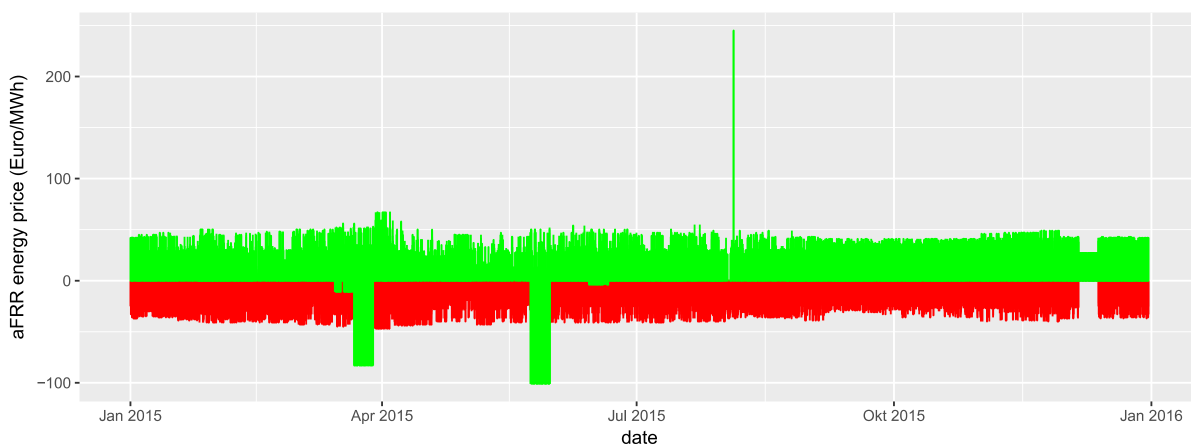

Figure 5: Modeling of marginal prices for aFRR with perfect competition Merit-Order-List for AT 2015 (MOL-Model 2) (theoretical) [19], [27].

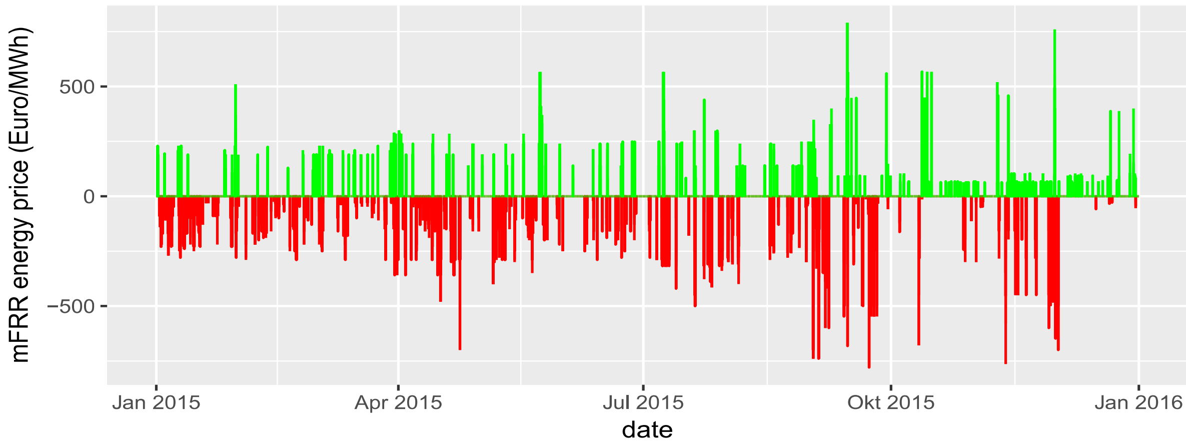

Figure 6: Modeling of marginal prices for mFRR for AT 2015 (MOL-Model 1) (hypothetical) [19], [29].

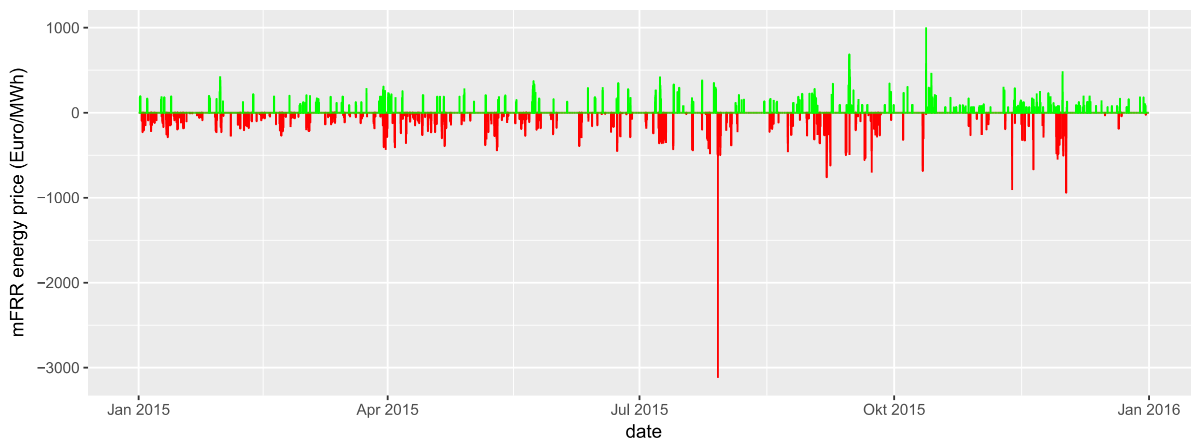

Figure 7: Real weighted average balancing prices for mFRR with pay-as-bid pricing and pay-as-bid Merit-Order-List for AT 2015 [19], [29].

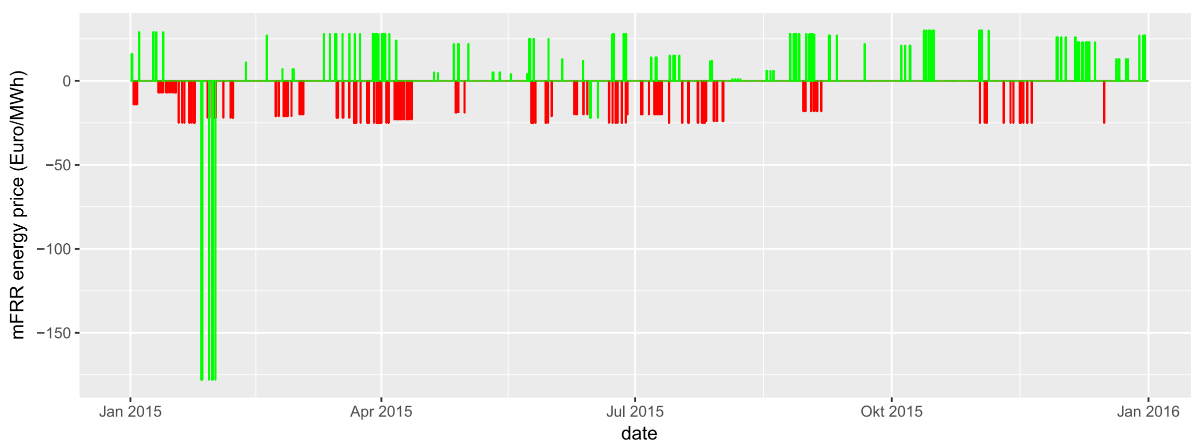

Figure 8: Modeling of marginal prices for mFRR with perfect competition Merit-Order-List for AT 2015 (MOL-Model 2) [19], [27] (theoretical).

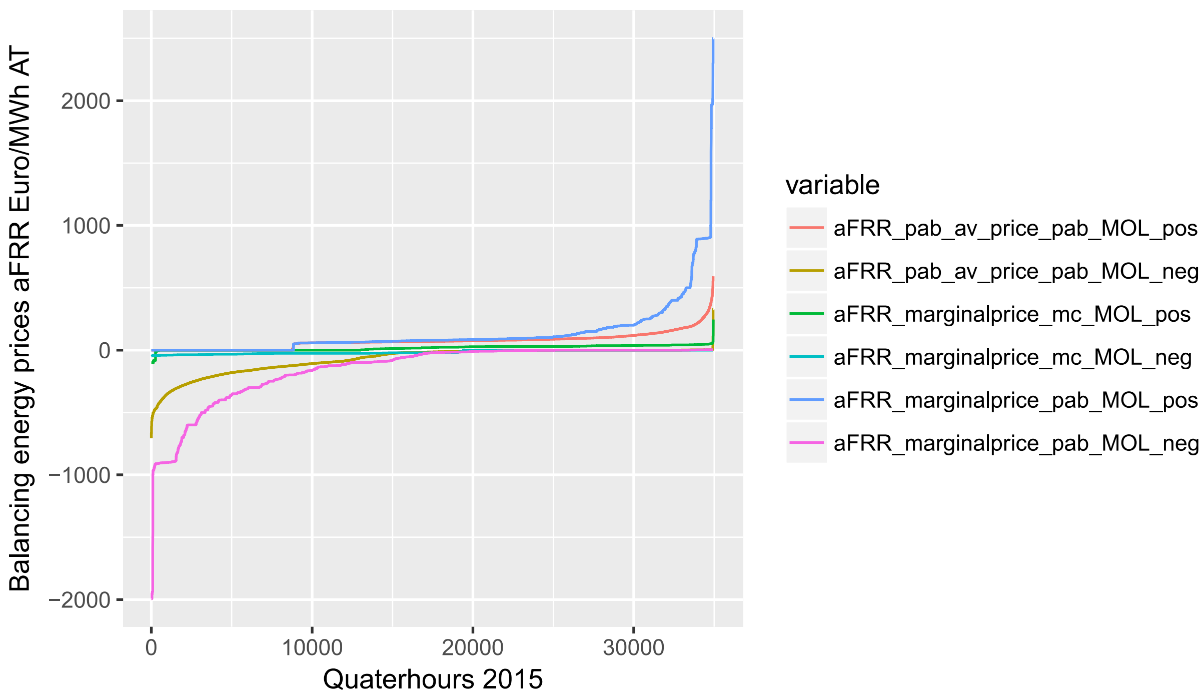

Figure 9: Modeled aFRR balancing energy prices with marginal pricing for pay-as-bid Merit-Order-List (MOL-Model 1), marginal cost under perfect competition MOL (MOL-Model 2) and real balancing prices in €/MWh for AT [19], [27], [29].

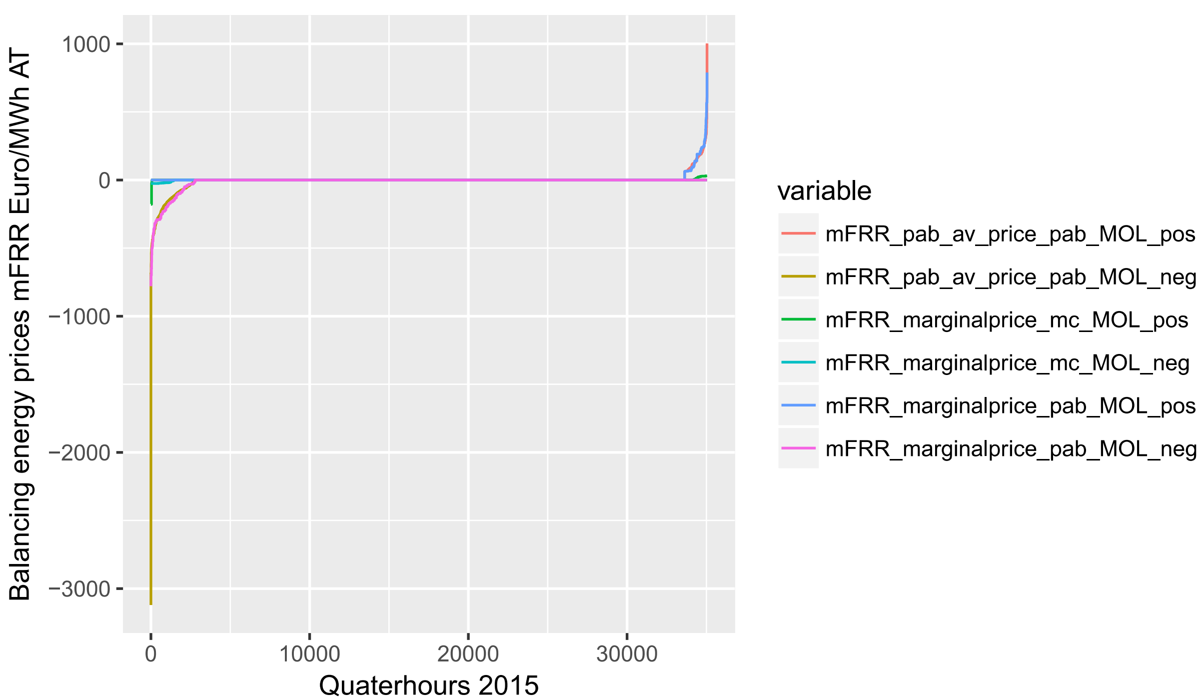

Figure 10: Modeled mFRR balancing energy prices with marginal pricing for pay-as-bid Merit-Order-List (MOL-Model 1), marginal cost under perfect competition MOL (MOL-Model 2) and real balancing prices in €/MWh for AT [19], [27], [29].

3. CONCLUSIONS

The implementation of electricity balancing guideline will lead to market integration for balancing markets and a harmonization of the main features of imbalance price mechanism. Nevertheless, electricity systems in Europe are widely different resulting from historical development. The design of imbalance mechanisms is influenced by, and can only be seen in connection with, the relating electricity system of the respective control area. Before harmonization has not yet been reached, some elements of imbalance price mechanisms should remain national.

Either BRPs are able to counterbalance the system to reduce control area imbalances or obligations for BRPs to fulfil their schedules are implemented. However, no general recommendation can be made, which imbalance mechanism is the best.

Marginal pricing is theoretical reducing overall costs, but in practice it might raise probabilities for extreme values of balancing prices and imbalance prices for several periods (e.g. during congestions). Modeled marginal prices assuming perfect competition might not occur in practice due to risk mark-ups of BSPs. Nevertheless, average balancing prices and costs might decrease according to competition and market integration. However, balancing markets have to be well observed and a stepwise implementation of marginal pricing affecting imbalance prices might be advantageous (for countries with no marginal pricing). Possibilities for quick mitigation measures in unpleasant situations (e.g. high costs) should be foreseen. Nevertheless, high prices might be the correct market signal for scarcity.

A well connected European electricity system is the basis to decrease congestion risks and the risks for high balancing prices. One problem is the temporary disintegration of integrated markets to local markets (e.g. split of cMOL, unexchangeable bids because of congestions), which has the risk to lead to balancing price and imbalance price peaks. For this reason, it might be better to reserve cross-border capacities for balancing in a structured way after observing market behavior. On the one hand, this will lead to low balancing and imbalance prices and less price peaks. On the other hand, not every cross-border capacity reserved for balancing might be effectively used as only some bids get activated (activation in real time), while for the intraday market bids will be effectively delivered (if used by the market). Therefore, an optimum should be found between reservation of cross-border capacities for intraday and for balancing markets.

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