Smart Balancing – Matching market rules with system requirements for cost-efficient power balancing

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Abstract

Ongoing negotiations about future European energy markets stagnate due to disagreements about power balancing. Dutch and Belgian system operators count on real-time transparency allowing Smart Balancing: All market participants are incentivized to balance generation and consumption of the control area. German system operators pursue a different strategy relying on prequalified reserves.

The introduced Smart Balancing indicator measures market performance by evaluating the demand and costs of balancing power. The analysis shows that Smart Balancing is a cost-efficient tool for coping with fluctuation between power generation and consumption. Evidence suggests that the German strategy is undermined and under-cover Smart Balancing is applied. On the other hand, misplaced incentives intensified the German "June events" with an imbalance of at least 8 GW. The observed cases lead to urgent policy implications.

Changes in timing and pricing schemes are required in the first place. Transparency and real-time information could potentially (with the Dutch performance) reduce the activation of balancing energy by 180 GWh per year (savings of 20 mio. €) in Germany.

Highlights

- Power system requirements and market performance indicator
- Transparency and real-time information are key for cost-efficient power balancing
- Passive balancing is applied in Germany, but current market rules are inconsistent
- June events in Germany were intensified by misplaced incentives of current marked design
- Policy implications and future European market approach

1. Introduction

The European electricity system developed from independent systems of supply and demand to national balancing areas, finally connected to an international grid. The power system was physically integrated for the purpose of enhanced reliability. International trade was facilitated for the purpose of economic benefits, limited by the capacity of cross-border interconnections. The objective of this work is to analyse aspects of harmonisation and integration of balancing markets. It is subject to both reliability and economic benefits.

Abbreviations
Frequency Containment Reserves and system inertia (FCR^+)
Frequency Restauration Reserves (FRR)
Imbalance Settlement Period (ISP)
Electricity Balancing Guideline" (EBGL)
International Grid Control Cooperation (IGCC)

How to design the common future European market rules? Policy implications and market approaches can be derived from data analysis and case studies. Goal is to identify the most reliable and cost-efficient power balancing approach, especially in terms of real-time market interaction.

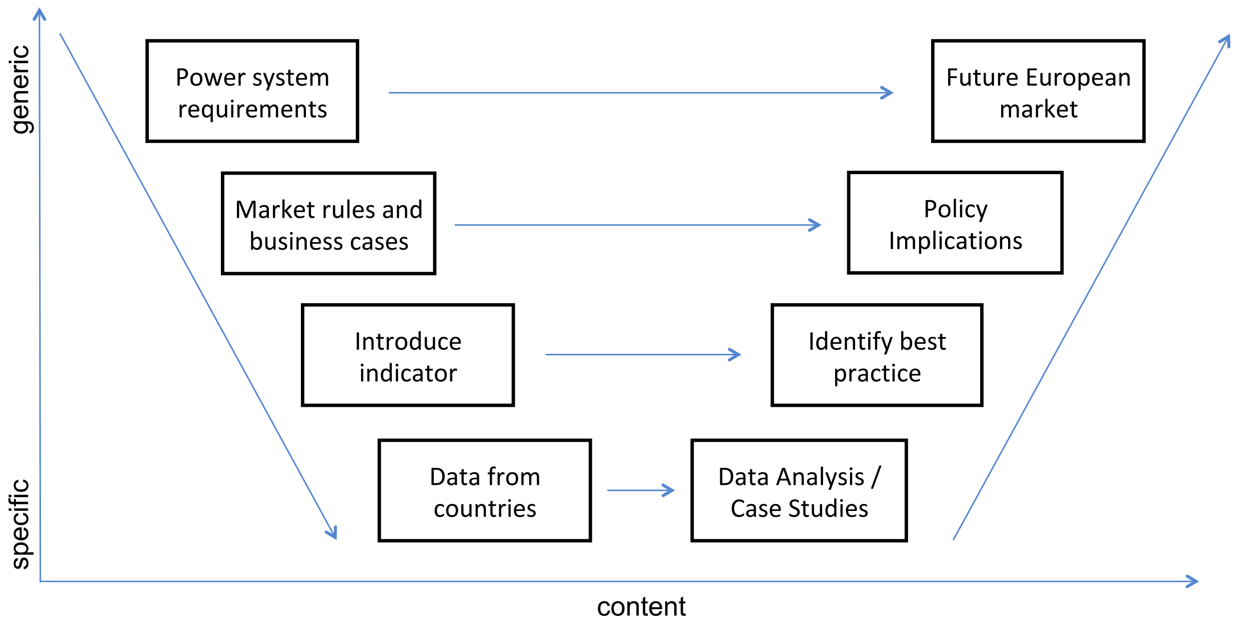


Figure 1: Structure of article between generic and specific content

Figure 1 shows the structure of the article. An overview about physical constrains (power system requirements) and resulting system services (market rules and business cases) for a reliable electricity supply is given in section 2. Section 3 introduces the Smart Balancing indicator for national power balancing mechanisms. It measures market performance by evaluating the demand and costs of balancing energy. Section 4.1 presents three case studies of (i) the introduction of real-time price incentives in Belgium, (ii) under-cover balancing and (iii) critical situations ("June events") in Germany. A detailed description of data from the Netherlands, Belgium and Germany is available in a co-published data article, which is outlined in section 4.2.

Section 5 discusses the results and evaluates different market approaches. The case studies help identifying misleading incentives. The Smart Balancing indicator identifies "best practice" design parameter and estimates potential economic benefits. Section 6 concludes the benchmark market rules and derives policy implications. Finally, a market approach for the future European energy market is presented.

2. Power system requirements and markets

This section outlines physical constrains for a reliable electricity supply and resulting power system services. Furthermore, existing market rules are outlined.

2.1. Physical constrains and system services for a reliable electricity supply

Figure 2 illustrates the physical constrains for a reliable electricity supply which are frequency stability, voltage stability, black-out events and grid capacity. These constrains are crucial and must be addressed by fail-safe measures. They impact the system in diverse manners and require interventions on different stages of coordination, as illustrated in the vertical axis.

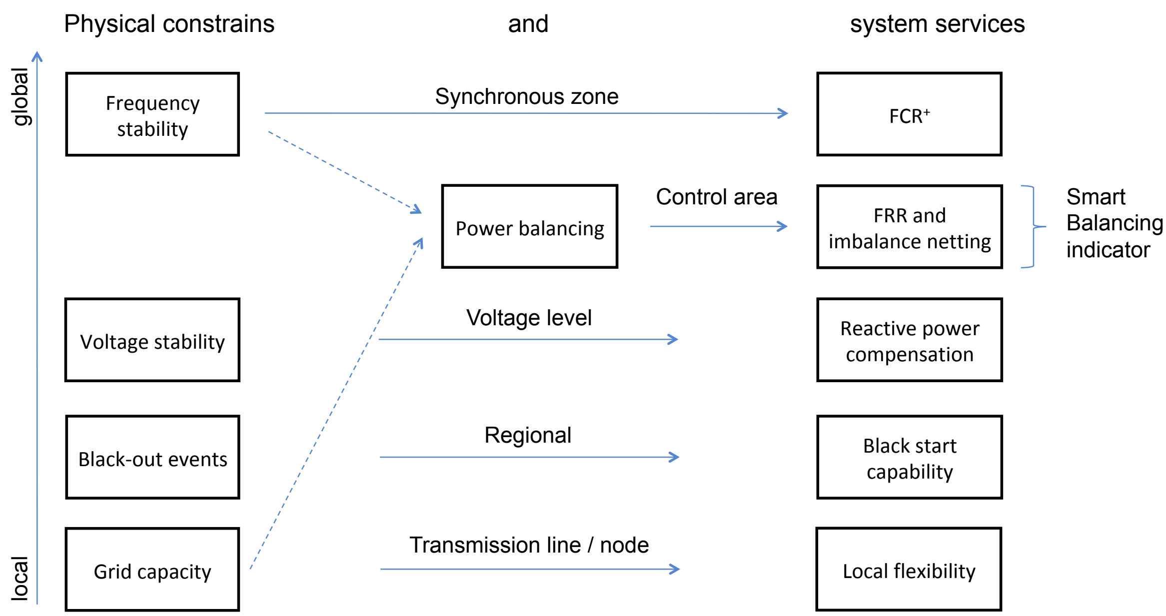


Figure 2: Physical constrains and resulting system services for a reliable electricity supply

A The frequency is the physical quantity which defines a synchronous zone. Any energy exchange impacts the global frequency, which is an indicator for the balance between all generation and consumption. A high deviation from the set-point frequency causes malfunctions of connected loads and generation units and must be avoided. In addition to the frequency itself, also a high change of rate of frequency (df/dt) must be obtained within limits. It is addressed by Frequency Containment Reserves (3 GW in central Europe) and system inertia (FCR^+).

B The voltage is the physical quantity which differs regionally and defines a voltage level. Voltage is transformed to minimise transition losses. Required system services keep the absolute voltage stable, provide reactive power compensation and realise damping of low-order harmonics.

C Black-out events can be caused by a variety of technical issues in the power system, which anyhow lead to a chain reaction of security mechanisms. Black-out events can occur either in a region, in a balancing area or in the whole synchronous zone. Independent from the causing issue, a region needs assets with black start capability and must be able to synchronise with neighbouring regions to get back to synchronous operation.

D The grid capacity is the most local constrain. Before the maximum power flow in a transmission line is exceeded, local flexibility with high sensitivity on that local point of the grid needs to be activated. Either curtailment or some sort of emergency pricing (traffic light allows nodal pricing) and leads to higher local power demand. Both measures relive the transmission line.

Power balancing is not a physical constrain, but a set of national system services. The legal aspects of markets developed with the technology and level of integration on national levels. The future European market design is partly directed by the "Electricity Balancing Guideline" (EBGL) as part of the EU winter package (ENTSO-E, 2017). Details are still subject to discussions (Röben, 2018). Regardless the details, power balancing assets have and will in future:

1. Support frequency stability of the synchronous zone.
2. Are limited by the voltage level of grid interconnection.
3. Play a major role when reactivating the power system after black-out.
4. Limit unscheduled power flows between countries.

Thus, power balancing within control areas interacts with physical constrains. An achievement are European agreements on imbalance netting. They help avoiding unnecessary counter-activation of Frequency Restauration Reserves (FRR) in neighbouring countries. The International Grid Control Cooperation (IGCC) saves costs by allowing unscheduled power flows. This practice requires available cross-border capacity.

2.2. Current market rules in the Netherlands, Belgium and Germany

Figure 3 illustrates current market rules on a timeline which represent the opportunities for market participants. The upper boxes are "energy-only" markets, which are the main tool to coordinate generation and consumption of electrical power. Buy and Sell orders for energy products are placed "over the counter" and at day-ahead markets. The preliminary day-ahead schedule with 15-minute resolution must be submitted to the system operator until 2.30 pm (D-1). Afterwards, continuous trade is possible at intraday markets. The schedule can be adjusted until 15 minutes before real-time (M-15). Even after-day trade is possible within a control area. The schedule can be adjusted ex post until 10 am of the next day (D+1). (Bundesnetzagentur, 2011)

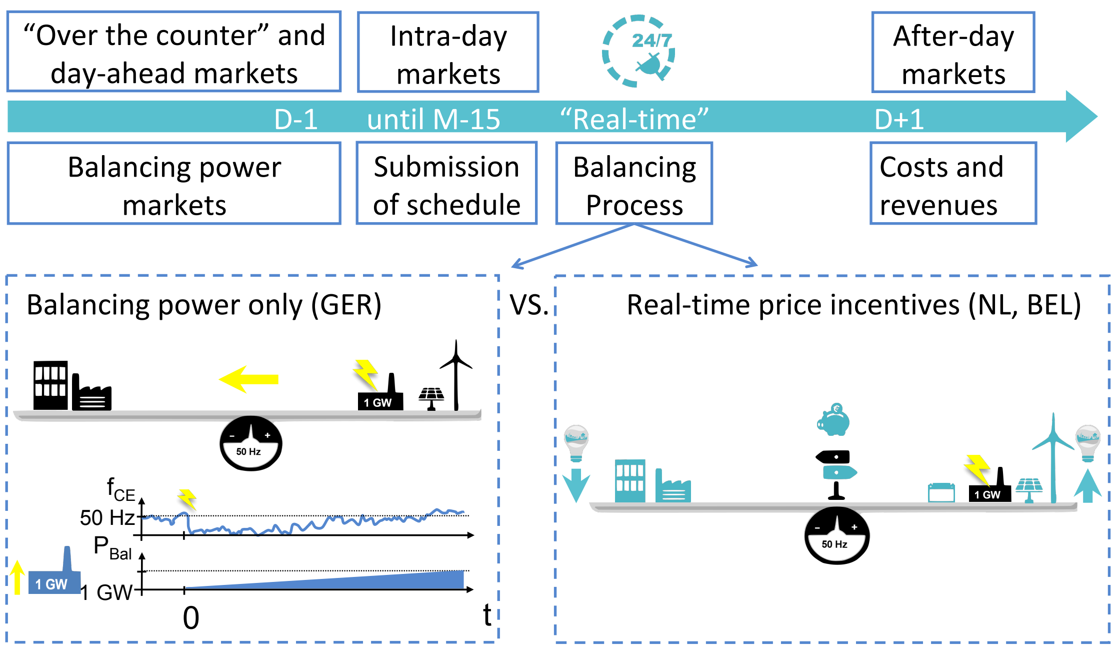


Figure 3: Market rules in Germany (GER) vs. the Netherlands (NL) and Belgium (BEL)

First limitation of "energy-only" markets is the resolution of energy products. This simplification does not cover individual consumption and generation patterns (ramps) in "Real-time". The resolution, or Imbalance Settlement Period (ISP), is 15 minutes. This issue is addressed by balancing power. Prequalified market participants offer their flexibility on day-ahead balancing markets. The bids from these balancing markets form merit order lists, which are published day-ahead. Germany (GER): All real-time deviations between generation and consumption are compensated by the four system operators who activate balancing power accordingly. For all other market participants, it is mandatory to stick to the final schedule. There is no transparency about real-time energy scarcity and no (public) value for flexibility. The Netherlands and Belgium (NL, BEL): Publish real-time energy scarcity and price information on a homepage[1,2]. See (Röben and de Haan, 2019) for more details on different market design parameter.

[1] https://www.tennet.org/english/operational_management/System_data_relating_implementation/system_balance_information/balancedeltaIGCC.aspx

[2] https://www.elia.be/en/grid-data/balancing/imbalance-prices-1-min

Neglected limitation: The cupper plate assumption applies when trading at "energy-only" markets and balancing generation and consumption with balancing power. Limitations in national grid capacity are subject to secondary downstream measures (curtailment, redispatch, traffic light).

3. Case studies and Smart Balancing indicator

Three case studies demonstrate the functionality of current market rules. (i) The introduction of real-time price information in Belgium end of August 2019. (ii) Under-cover Smart Balancing in Germany. (iii) Four days with critical situations in Germany ("June events").

The Smart Balancing indicator is introduced to compare the performance of national power balancing in a data-based way. It requires a definition of Smart Balancing, which was derived with the target: A reliable and cost-efficient electricity supply.

Definition: Smart Balancing avoids the activation of balancing energy by market participants who create system supporting schedule deviations. Smart Balancing is incentivized by a single (symmetric) imbalance price in combination with public real-time information. It must not lead to overcompensation.

This definition and the Smart Balancing indicator are developed to measure and expand the idea of "passive balancing", described by Nobel (Nobel, 2016), Hirth and Ziegenhagen (Hirth and Ziegenhagen, 2015) or Brijs et al. (Brijs et al., 2017). Data from the Netherlands, Belgium and Germany are considered.

Figure 4 illustrates the data required to calculate the Smart Balancing indicator. 1. Activation of FRR within the control block is the most obvious data set derived directly from the definition of Smart Balancing. 2. The imbalance netting contribution avoids counter-activation of FRR in neighbouring control blocks. 3. The schedule deviations of market participants, which led to the FRR activation in the first place.

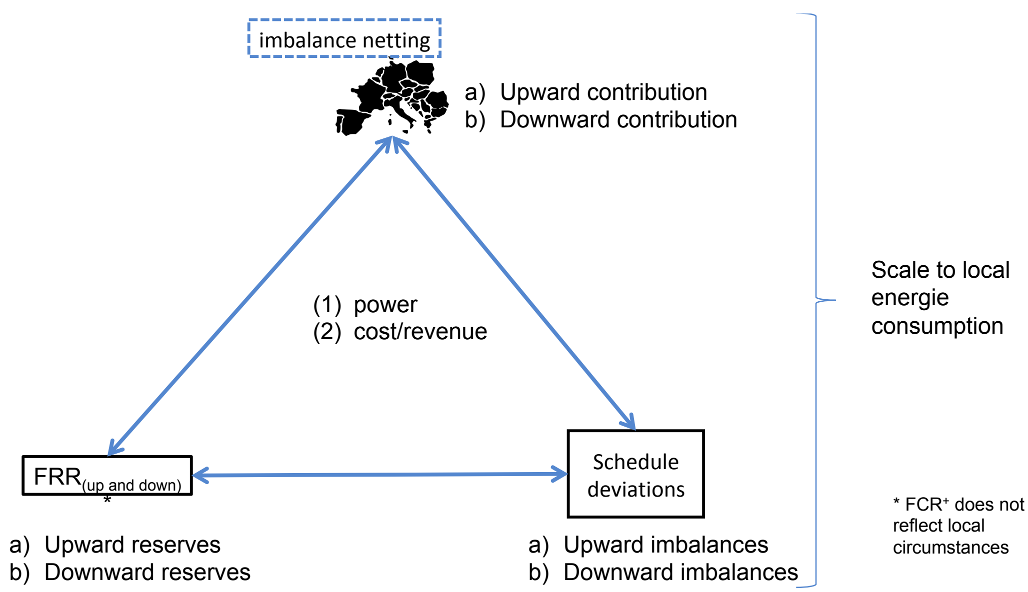


Figure 4: Smart Balancing indicator

The three datasets include a) upward and b) downward values of its (1) power and (2) price components. This results in 6 cost/revenue time series. The mean value and the standard deviation identify different power balancing and cost/revenue patterns. The overall balancing energy and costs are scaled to the local annual energy consumption for comparison and benchmark forming. Potential financial benefits can be estimated.

4. Data

This data section presents three case studies and data for the performance evaluation of power balancing with the Smart Balancing indicator.

4.1. Three case studies

Three case studies of Smart Balancing show how market rules influence the balancing process. (i) The introduction of real-time price information in Belgium end of August 2019. (ii) Under-cover Smart Balancing in Germany. (iii) Four days with critical situations in Germany ("June events").

4.1.1. Implications of market change in Belgium

On the Elia website it was only launched at the end of August 2019. The real-time imbalance price is published in a one minute resolution with a few minutes delay. The amount of activated reserves was already published before 2019. (https://www.elia.be/en/grid-data/balancing/imbalance-prices-1-min)

The mean of the absolute imbalance was reduced by 5.4 MW and fewer balancing reserves were activated after the introduction, as shown in Table 1. The average imbalance price was reduced by 5.3 €/MWh.

Table 1: Average imbalance, FRR activation and costs (ENTSO-E Transparency Platform, 2019)

Mean power values	**01.01. to 31.08.2019**	**01.09.2019 to 15.11.2019**
BEL_Imablance	119.2 MW	113.8 MW
BEL_activated_aFRR_up	50.5 MW	50.2 MW
BEL_activated_aFRR_down	56.1 MW	54.6 MW
BEL_activated_mFRR_up	11.7 MW	9.9 MW
BEL_activated_mFRR_down	9.2 MW	9.0 MW
BEL_FRR_up_activated	62.2 MW	60.1 MW
BEL_imbalance_price	40.39 €/MWh	35.09 €/MWh

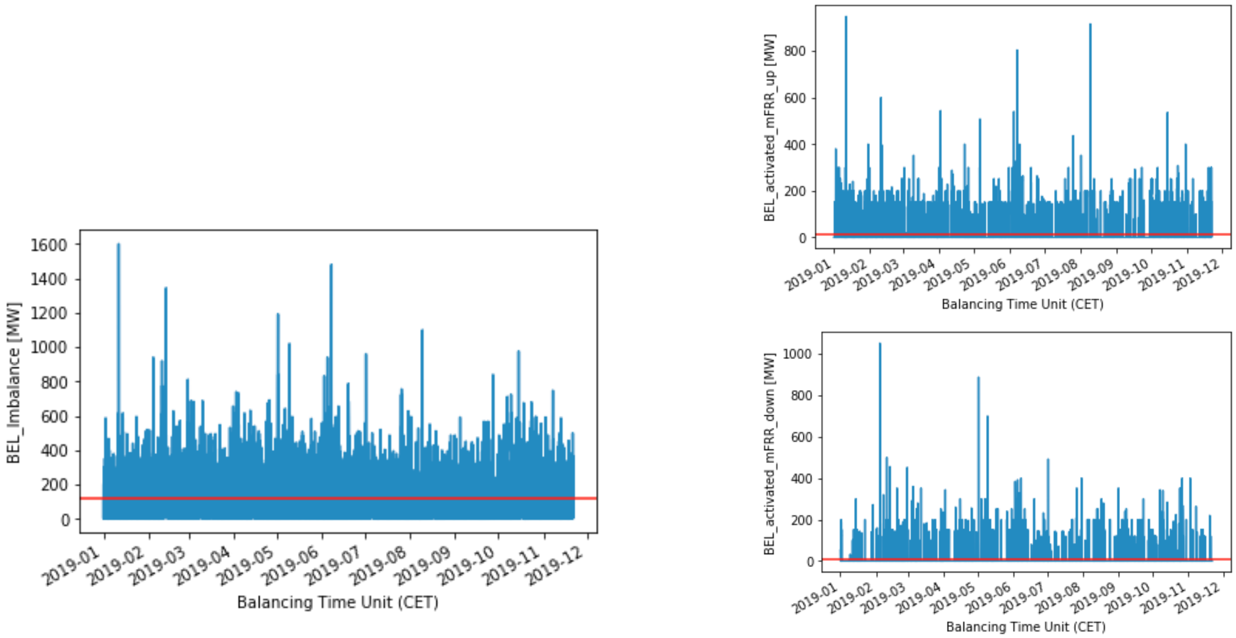


Figure 5: Imbalance and mFRR activation in Belgium in 2019, introduction of real-time price signal at the end of August 2019 (ENTSO-E Transparency Platform, 2019)

Figure 5 shows the absolute imbalance (blue: 15-minute average, red: 1-year average) of the Belgian control block in 2019. 14 settlement periods had an imbalance of more than 1 GW, all of them before the introduction of the real-time publication of the imbalance price end of August. The peaks and the amount of activated FRR were also reduced.

4.1.2. Under-cover Smart Balancing in Germany

This subsection aims to identify under-cover Smart Balancing in Germany. Events suggest, that market participants react to the activation of mFRR with system supporting behaviour. The median and distribution of (left) the imbalance in Germany and (right) the imbalance delta to the last ISP help identifying a pattern.

Figure 6 shows 933 ISPs in 2017 with an imbalance of over 1 GW. There are 449 ISPs with mFRR activation and 544 ISPs without mFRR activation.

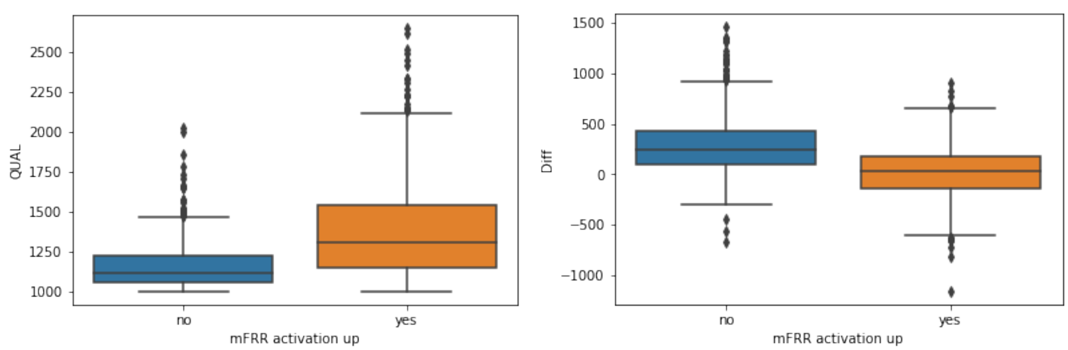


Figure 6: Analysis mFRR upwards activation. ISP with imbalance over 1 GW. Imbalance delta to last ISP (ENTSO-E Transparency Platform, 2019)

Figure 7 shows 847 ISPs with an imbalance of over 1 GW and under 1.5 GW. There are 320 with mFRR activation and 527 without mFRR activation.

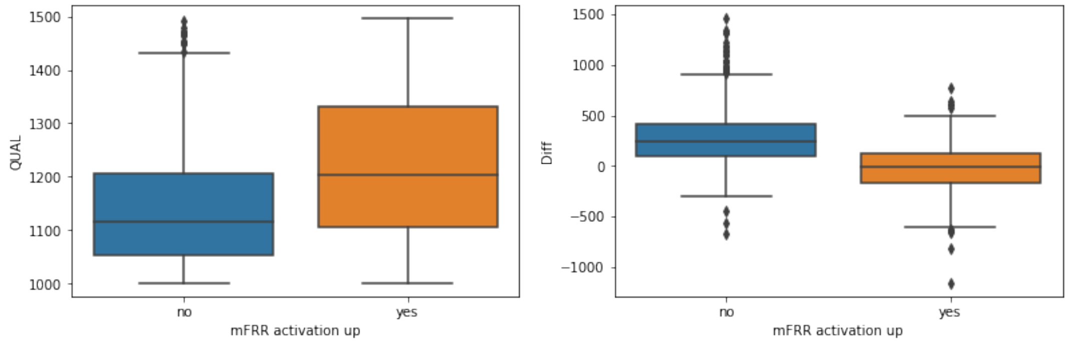


Figure 7: Analysis mFRR upwards activation. ISP with imbalance over 1 GW and under 1.5 GW. Imbalance delta to last ISP (ENTSO-E Transparency Platform, 2019)

Figure 8 shows 484 ISPs in 2017 with an imbalance of under -1 GW. There are 229 ISPs with mFRR activation and 255 ISPs without mFRR activation.

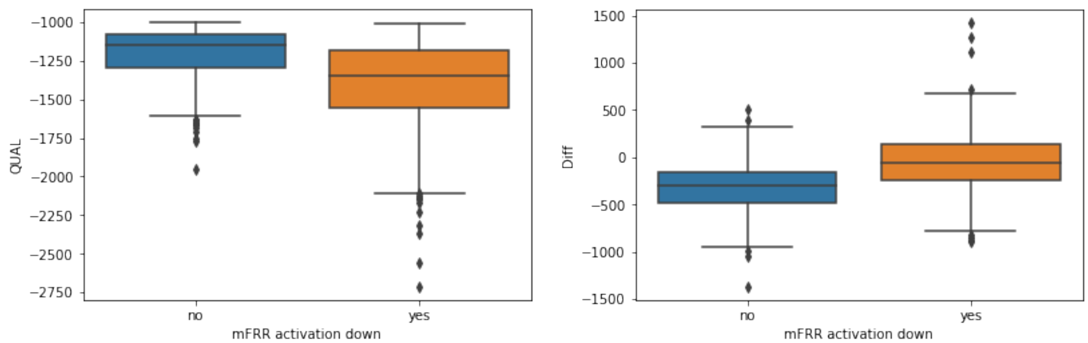


Figure 8: Analysis mFRR downwards activation. ISP with imbalance under -1 GW. Imbalance delta to last ISP (ENTSO-E Transparency Platform, 2019)

Figure 9 shows 393 ISPs in 2017 with an imbalance of under -1 GW and over -1.5 GW. There are 162 ISPs with mFRR activation and 231 ISPs without mFRR activation.

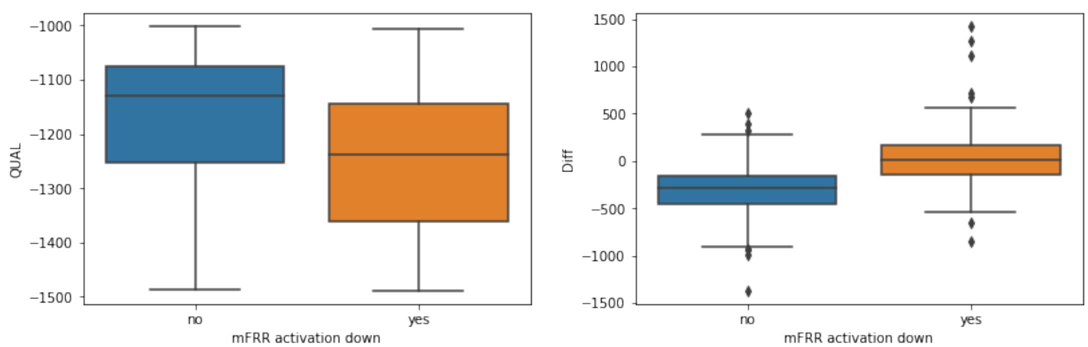


Figure 9:Analysis mFRR downwards activation. ISP with imbalance under -1 GW and over -1.5 GW. Imbalance delta to last ISP (ENTSO-E Transparency Platform, 2019)

The difference to the last ISP tends to be more system supportive in case of mFRR activation in all four considered comparisons.

4.1.3. Case study of critical situations "June events" in Germany

Four days with severe situations took place in Germany in June 2019. The activated reserves in Germany during the first and the second of these "June events" (06.06.2019, 12.06.2019, 25.06.2019 and 29.06.2019) are presented in the following figures. They illustrate the sum of (automatic and manual activated) FRR and additional emergency reserves (Zusatzm.) The "June events" are particularly especial not only because of activated reserves of over 8 GW (12.06.2019), but also because the penalty for schedule deviations (which is the imbalance price) was lower than the energy price. The EPEX high and, during the peak of the imbalance events, even the EPEX weighted average price exceeded the imbalance price.

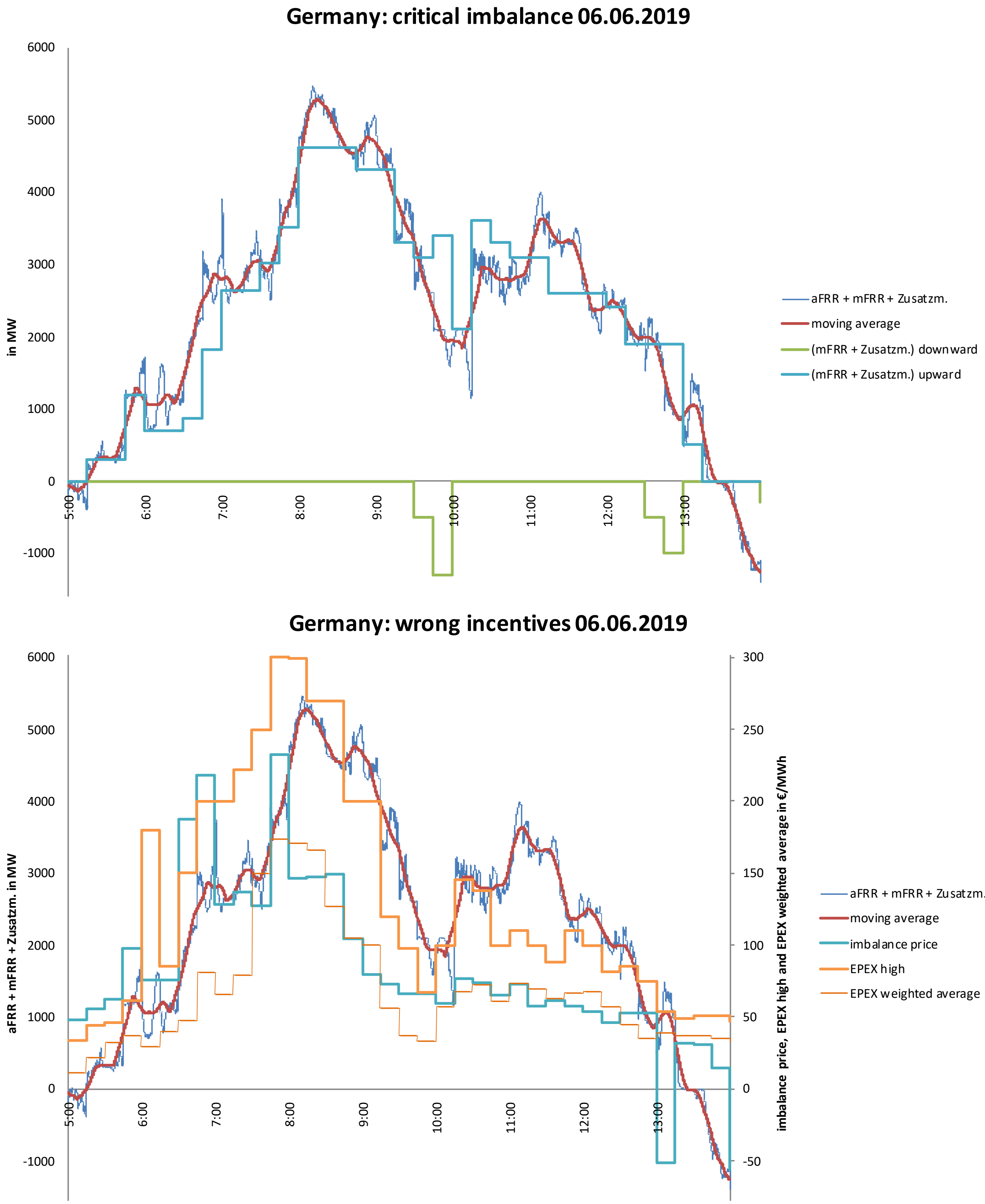
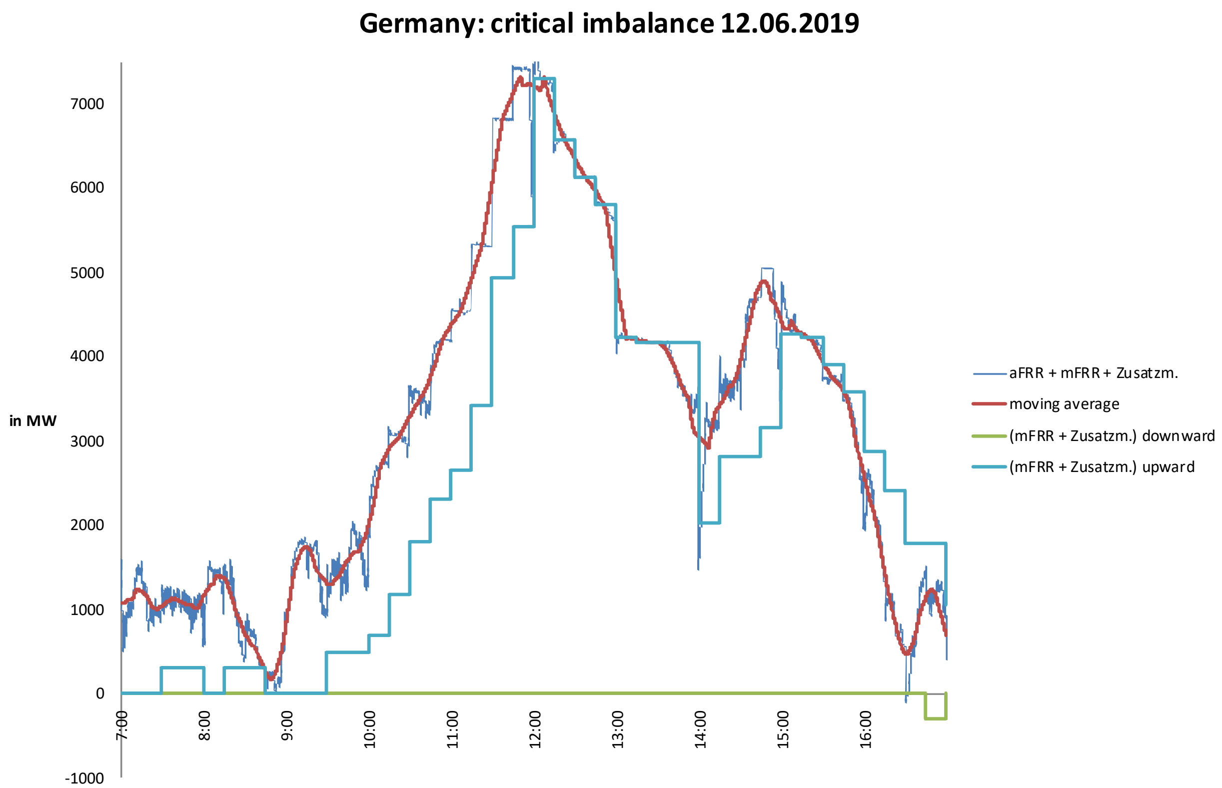


Figure 10: Critical imbalance correlation with imbalance price and EPEX intraday market price in Germany, 06. June 2019 (www.regelleistung.net and www.epexspot.com)

Figure 10 illustrates all activated reserves in Germany, the imbalance price, the EPEX weighted average and the EPEX high at the 06. June 2019 between 5 am and 2 pm.



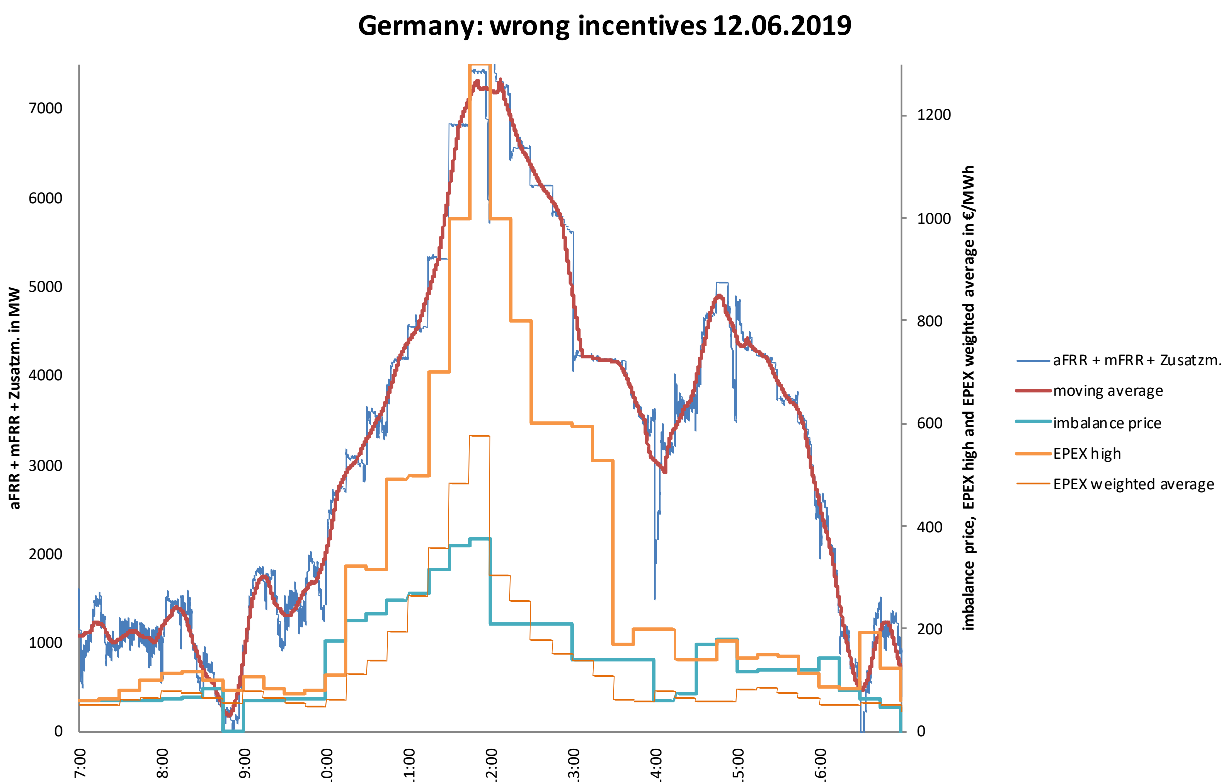


Figure 11: Critical imbalance correlation with imbalance price and EPEX intraday market price in Germany, 12. June 2019(www.regelleistung.net and www.epexspot.com)

Figure 11 illustrates all activated reserves in Germany, the imbalance price, the EPEX weighted average and the EPEX high at the 12. June 2019 between 7 am and 5 pm.

4.2.Data analysis

The Smart Balancing indicator is applied to historic data of the Netherlands, Belgium and Germany. Table 2 summarizes FRR and IGCC performance over the year 2017. The published data about imbalance does not include separate values for upward and downward imbalance. Therefore, cash and energy flows based on schedule imbalances cannot be evaluated. A detailed presentation of the available data is provided in a co-published data article (see section 8).

Table 2: Smart Balancing indicator - scaled FRR and IGCC demand and costs in 2017 (ENTSO-E Transparency Platform and www.regelleistung.net)

Smart Balancing indicator - 2017 data	**Netherlands (NL)**	**Belgium (BEL)**	**Germany (DE)**
Local energy consumption	115 400 GWh μ = 13 173.5 MW	84 800 GWh μ = 9 680.4 MW	538 700 GWh μ = 61 495.4 MW
$FRR_{(up\ and\ down)}$	512 GWh 15,7 mio. € 30.7 €/MWh	639 GWh 24.79 mio. € 38.8 €/MWh	2 428 GWh 90.35 mio. € 37.2 €/MWh
Scaled $FRR_{(up\ and\ down)}$	**0.44 %** **136 €/GWh cons.**	0,75 % 292 €/GWh cons.	**0,45 %** **168 €/GWh cons.**
$IGCC_{(up\ and\ down)}$	632 GWh 3.68 mio. € 5.8 €/MWh	427 GWh 4.89 mio. € 11.5 €/MWh	1 056 GWh 29.12 mio. € 27.6 €/MWh
Scaled $IGCC_{(up\ and\ down)}$	**0.55 %** **31 €/GWh cons.**	0.50 % 58 €/GWh cons.	**0.20 %** **54 €/GWh cons.**

5. Results and Discussion

The Smart Balancing indicator shows that the Netherlands have been performing best when it comes to cost-efficient power balancing. Savings of 29.6 mio. € (17.2 mio. € reduction of cost for FRR and 12.4 mio. € for IGCC) in Germany could be possible assuming that Germany can achieve the same power balancing performance. In theory, the four interconnected German control areas could aim for a better performance with Smart Balancing due to scaling-effects. Belgium requires higher volumes of scaled FRR than the Netherlands and Germany, which makes it less comparable. The scaled IGCC contribution in Belgium is only 0.05 % smaller than the Dutch contribution, but the scaled costs are nearly double. The Belgium performance shows that the missing imbalance price limited Smart Balancing in Belgium, even if the imbalance volume was already published.

Introduction of a public imbalance price in Belgium end of August 2019 shows that no unexpected market (over-) reactions took place. The mean imbalance of the control area was reduced by 5.4 MW after the introduction. The imbalance exceeded 1 GW in 14 settlement periods in 2019 of which all happened to be before the introduction. The Belgian case suggest that the practice of publishing not only the imbalance, but also the imbalance price is the more efficient approach of incentivising system supporting behaviour of market participants.

Influence of mFRR activation on the system imbalance in Germany emphasizes that market participants undermine the German legislation and apply under-cover Smart Balancing. The correlation is an indication of how sensible market participants react to strong price information, even if the information is derived from secondary sources and uncertain. This practice carries the risk of overreaction and an imbalance to the opposite direction, because market participants get no official information or any other kind of feedback on their behaviour.

The “June events” in Germany illustrate a misplaced incentive for market participants. The intraday market price exceeded the imbalance price. Therefore, to correct forecast errors and buy the energy back was more expansive than not delivering and paying the imbalance price. Even worse: Short sales of energy were profitable. The maximum imbalance price could be estimated by market participants, because the merit order list for balancing reserves is published day-ahead. Incentivising short sales must be avoided to guarantee reliability.

The “June events” require rethinking the design parameter of current market rules. Reliable flexibility must be available at short term intraday markets, whenever wrong scheduling occurs. This can lead to high prices. How to guarantee the imbalance price is higher? The European legislation mandates the answer: “Balancing energy gate closure times shall: (a) be as close as possible to real-time; (b) not be before the intraday cross-zonal gate closure time; (c) ensure sufficient time for the necessary balancing process.” (EBGL, Article 24.2) With the energy bids at balancing markets being submitted after the intraday market, the imbalance price will increase over the market price in case of a (short) system imbalance. Short sales are not incentivized.

These findings go along with the hypothesis that real-time information about energy scarcity and the imbalance price are key for cost-efficient power balancing. Findings in previous research come to similar results. Hirth and Ziegenhagen (2015, p. 1048) state: “Fostering passive balancing could be an alternative (indeed, a very good substitute) to the introduction of energy- only balancing markets.” Nobel (2016, p.109) argues: “Provision of balancing energy by the system operator is a result, and not the objective of power balancing. This choice allows, invites, and basically incentivizes active participation and competition between imbalance and balancing energy.” Brijs et al. (2017, p. 49) conclude: “as passive balancing can serve a valuable social purpose and improve the valorization of flexibility, incentivizing design changes should be considered for the French and German balancing markets.”

6. Conclusion and Policy Implications

The three considered balancing markets represent two different design strategies, especially in terms of transparency to incentivize efficient Smart Balancing. The transparent approach is found in the Netherlands and Belgium. Publication of data on current imbalance volumes and prices close to real-time is visible online to the general public. Any market participant is encouraged to act in favour of system stability. Schedule deviations are allowed, and Smart Balancing by market participants is incentivised by the public imbalance price.

The German balancing market design does not include official incentives for market participants other than keeping to their submitted schedule. Information on imbalance volumes and prices is only published ex post. The German strategy is to minimise imbalances by promoting good scheduling (accurate load and generation prediction) and to compensate any imbalances by the activation of reserve capacity. Evidence of under-cover Smart Balancing and the “June” events (imbalance of over 8 GW) in Germany indicate that the German strategy is undermined. The performance indicator of the Netherlands implies that transparency about imbalance pricing is key for cost-efficient power balancing.

The provided case studies and performance indicator lead to the following major conclusions:

- Best-practice in the Netherlands. No policy implication.
- Introduction of real-time transparency about imbalance price in Belgium improved reliability and cost-efficiency of power balancing immediately. No policy implication.
- Current market rules lead to misplaced incentives in Germany (e.g. during the "June events"). Policy implications for Germany.
- Current market rules incentivise under-cover Smart Balancing, but lacking transparency on imbalance can lead to over-reactions of market participants. Policy implication.

The German power balancing strategy should therefore converge towards an approach with real-time transparency about the current imbalance and imbalance price. Allowing Smart Balancing could potentially (with the Dutch balancing performance) reduce the activation of balancing energy by 180 GWh per year (savings of 20 mio. €) in Germany.

Figure 12 shows the timeline of opportunities and information in the proposed European market, which is derived from the conclusions and policy implications. The following steps are recommended for national policy makers to apply this approach. It goes along with the European legislation (ENTSO-E, 2017) and allows Smart Balancing:

1. Publication of imbalance, imbalance price and imbalance netting close to real-time
2. Gate Closure Time of balancing markets close to start of ISP
3. Final schedule / end of intraday market before Gate Closure Time of balancing market

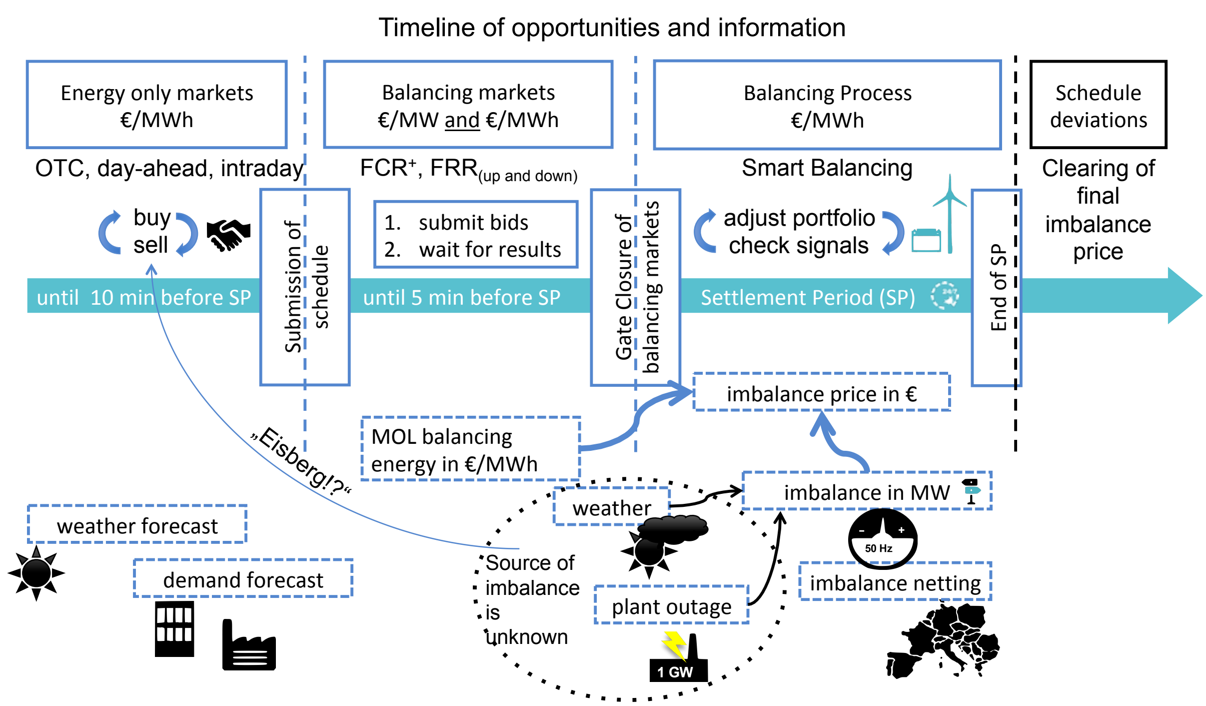


Figure 12: Future European market

The misplaced incentives during the "June events" can be avoided by these changes of timing and pricing schemes. The intraday trade and submission of the final schedules take place before the Gate Closure of balancing markets. The submitted bids for the Merit Order List (MOL) of FRR upward will lead to an imbalance price which always exceed the intraday market price in case of a short control area. Therefore, to correct forecast errors at the intraday market is beneficial compared to paying the imbalance price. Short sales do not lead to profit.

The hypotheses that trading until 10 minutes before and bids at balancing markets until five minutes before the ISP ensure sufficient time for the balancing process needs to be proven. An intraday cross-zonal gate closure time of 30 minutes and bids at balancing markets until 25 minutes before the ISP is recommended for the first implementation. Also secondary downstream measures for coping with limited grid capacity need sufficient time.

An ISP of 15 minutes is currently the common energy product resolution in Europe, harmonized by the EBGL (article 53). In future, changing to a shorter ISP of e.g. 1 to 5 minutes would be beneficial as it reduces the limitation of "energy-only-markets" in terms of individual consumption and generation patterns. An ISP of the smallest period possible will limit the energy vs. power conflict. Furthermore, shorter resolution of energy products will incentivize digitalisation, automatization and pooling of flexible technologies (demand and generation side). This would accelerate the development of virtual power plants.

The presented evidence, policy implications and future European market leave questions open for future research. Even though the practicability on a national level could be shown, further elaboration on how Smart Balancing can be organized in harmonized European markets with cross-zonal activation of FRR (via optimisation function) is required. Modelling different market design parameter with a focus on worst-case scenarios and balancing performance would help identifying interrelations with other balancing mechanisms.

From the perspective of market participants, further research on business cases and marketing strategies for flexibility is demanded. Asset owner face changing legislation and growing opportunities, but also more competition in the future European balancing markets.

7. Acknowledgements

I would like to thank … for providing help with proof reading the article.

8. Data availability

The considered power and price time series were obtained from the ENTSO-E Transparency Platform (https://transparency.entsoe.eu/) and the common homepage of the four German system operators (www.regelleistung.net). The resulting cost time series were calculated.

The intraday energy prices during the "June events" were obtained from the homepage of epexspot (www.epexspot.com).

(To be clarified! Considered research data can be obtained at the following repository:
Can I provide my data frame on Mandeley Data with time series from ENTSO-E Transparency and regelleistung.net ? If not, can I upload at least the (calculated) costs?
If YES -> The research data are subject of a co-submitted data article, which elaborates on the data in great detail.)

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