Indicators to measure intraday electricity market efficiency in 18 selected Member States of the European Union

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***Abstract*—With increasing volatile wind and solar energy generation, the importance regarding designs of intraday and balancing energy markets ensuring efficient allocation of energy supply is growing. Typically yearly traded volumes and prices of intraday power exchanges and imbalances are used to analyse the market performance. This study introduces two indicators to measure efficiency in intraday electricity markets. The efficiency is measured during hours of high deviation of actual and forecasted residual load. The results of the analysis show non-complementarity of activated balancing energy to forecast deviations, thus pointing to an inefficient market. As the power plant generation mix cannot sufficiently explain the intraday market inefficiency, further research regarding imbalance regulations and incentives as well as forecast information deferral and OTC trading practice is needed.**

***Index Terms*— forecast deviation, intraday market, inefficiency**

I. Introduction

The integration of renewable energies in the existing power system is currently a major challenge. This challenge is the result of increasing renewable energy shares in the electricity system aimed at decarbonizing energy supply in the European Union (EU) and Member States (MS). Volatile renewable energies (*vRE*), especially technologies converting wind and solar radiation, are crucial for such sustainable energy provision. To tremendously reduce greenhouse emissions, it is not only necessary to not replace the existing fossil power generation units with sustainable technology, but to install expand capacities beyond to provide clean energy for mobility and heat applications as well as industrial processes.

The fluctuating production of electrical energy from *vRE* plants and the location-dependent resource availability of decentralized locations as well as their comparatively small size challenges the historically evolved electricity system characterised by central and dispatchable power plants. To ensure energy supply security and system stability as well as avoiding grid bottlenecks, the availability of flexibility options and their efficient utilisation becomes increasingly important.

The availability of flexibility is most crucial during hours, in which the deviation of the actual and forecasted (day ahead) residual load (ΔRL) is highest. In this paper, based on the approach used for assessing flexibility in the context of the Eur'ObservER Report[1], we define such hours as critical hours (h_c^+). [1]

In this analysis, we investigate how efficiently the electricity market delivers "flexibility" in these critical hours. When doing so, we focus on critical hours with a positive deviation. In these hours, the actual residual energy demand is higher than forecasted, hence the market is short on energy and ramp-up capacity is needed. In order to deliver sufficient ramp-up capacity at reasonable costs, i.e. to meet the objective of the EU Energy Union[2], an efficient performance of the market, i.e. a functioning market clearing mechanism providing this flexibility at least cost is required.

In this study, two indicators measuring the efficiency of flexibility provision between day-ahead and actual, physical delivery are developed. It is assumed that intraday electricity markets work efficient when balancing needs are low, i.e. are close to zero. [2] Based on this assumption and the derived indicators, the market efficiency for providing flexibility in the EU MS is assessed and evaluated. In addition, we discuss some possible reasons for low efficiencies.

In the remainder of this paper, first the motivation of developing enhanced indicators measuring the market efficiency for flexibility will be explained. Next, the methodology for the determination of these indicators and the utilized data will be introduced. Afterwards, the results of the approach will be depicted and discussed. Subsequently, possible reasons for differences between MS regarding the indicators will be assessed, i.e. the share of *vRE* as well as flexible and inflexible power plants of the MS. Finally, the

[1] See: https://www.isi.fraunhofer.de/en/competence-center/energiepolitik-energiemaerkte/projekte/eu-res-monitoring.html#tabpanel-3

[2] Sustainable, affordable, secure, competitive energy

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conclusions of this study will be discussed considering findings from previous research and further research needs listed.

II. Motivation for enhanced flexibility indicators

Studies assessing flexibility of the power system so far mostly focus on the physical availability of flexibility options (compare among others [3, 4]) or the assessment of market rules, market liquidity or other regulatory provisions (compare among others [2, 5–9]). As explained above, however, in times when flexibility needs are high but flexibility capacity is scarce, it needs to be allocated in an efficient and effective way.

Above, critical hours h_c^+ with the need of flexibility provision were explained. In such hours, when ΔRL is high, the provision of flexibility means that capacity is ramped up during the day, reacting to new information about electricity demand and generation from *vRE*. Thus, intraday trading enables short-term distribution of non-expected deviations. Ideally, the balancing market is then used to cover a relatively small remaining difference between actual and forecasted (i.e. traded) demand and supply. If intraday markets work efficiently, the sum of intraday trading (including im-/exports) for any certain hour should equal ΔRL of this hour. [2]

As shown among others by [10] based on the example of Germany, a higher intraday power exchange volume, slender temporal resolution, shorter time period between gate closure and physical delivery as well as extended trading times to 24/7, decrease the need for reserve power. Based on this interrelation between intraday exchange trading and balancing needs, we use the actual balancing power in a certain hour as a key parameter for the efficiency of the intraday power market of the MS. Further, we define the intraday market as all trading being done (stock exchange-based and over-the-counter (OTC)) after gate-closure of the day-ahead power exchange. Even though temporal inaccuracies between power exchange trading times and day-ahead forecasts of *vRE* exist, the focus is put on the short-term trading features.

Figure 1 and Figure 2 show actual stock exchange-based intraday trading, and the activation of balancing energy for the 50 highest critical hours h_c^+ of France in 2017, respectively. Both figures give a first impression that market efficiency for providing flexibility is not very high in critical hours h_c^+.

Figure 1 shows the absolute deviation between day-ahead forecasted residual load and actual load, as well as the volume and relative share of this deviation traded in the intraday market. It can be seen, that the volume of the intraday power exchange in France does not contribute significantly to compensate the forecast errors. The highest shares of at the intraday exchange traded volumes in relation to the absolute deviation of actual and forecasted volume can be found with 19% in the 50th critical hour h_c^+ and 16% in the 16th and 49th critical hour h_c^+. Consequently, the rest of deviation not being traded at the intraday exchange has to be compensated via OTC intraday market or with activation of reserve energy.

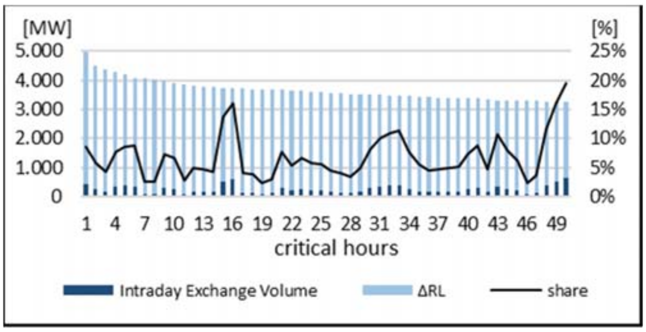

Figure 1. Intraday exchange volume, ΔRL and the share of indraday exchange trade of ΔRL in France 2017 (source: own assessment with data for ΔRL [11] and intraday volume [12])

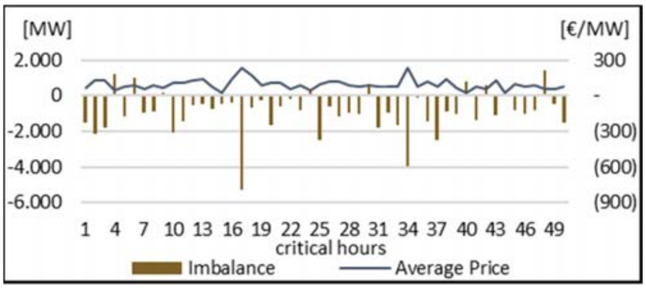

Figure 2. Positive and negative balancing energy and correlating imbalance costs trade in France 2017 (source: own assessment with data from [11])

To illustrate the performance of reserve power to balance ΔRL, the imbalance volumes of the highest 50 critical hours h_c^+ are depicted for France as a specific example in Figure 2. The figure shows first that a higher need for activation of reserves is correlated with higher imbalance prices, which is not surprising. Second, it displays, that the vast majority of imbalance volumes are negative during the 50 most critical hours h_c^+. This effect is non-complementary to the need of positive ramp-up energy to compensate ΔRL. Not only the negative sign of the imbalance, but also the volume emphasises a possible distortion of expected flexibility needs. For example, the absolute value of hour 2 is almost half of the absolute ΔRL when comparing it with the related value from Figure 1. The results of the balancing markets in the critical hours h_c^+ are very counterintuitive and give an indication that at least in France in the most critical hours h_c^+ in 2017, intraday markets did not work as expected. The need for negative balancing in hours with a high demand for ramp-up capacities could even be called a paradox.

In the following, we will first test whether the observed paradoxical need for negative balancing energy in critical hours h_c^+ and thus existing intraday market inefficiencies are a broader phenomenon in the EU energy markets or only prevail in the French market. In order to do this, two indicators for intraday market efficiency are developed and analysed. Afterwards, the observed results are analysed regarding some possible reasons such as the plant mix of a specific country.

III. METHODOLOGY

To assess the efficiency of intraday market flexibility provision, two indicators are developed and explained in the following. In addition, we briefly outline the methodology applied for identifying critical hours h_c^+ and checking for potential relations between intraday market behaviour and selected parameters characterising the power system.

A. Identification of critical hours

A critical hour h_c is calculated according to [1] as one hour of a specific year with a high deviation of the actual residual load (RL_a) from forecasted residual load (RL_f) (day ahead of physical delivery). The residual load itself is defined as the difference between the demanded energy (L) and the generated energy from Wind and Photovoltaics (vRE) in hour h with f and a indicating either forecasted or actual values:

$$RL(h)_f = L(h)_f - vRE(h)_f \quad \text{(I)}$$

$$RL(h)_a = L(h)_a - vRE(h)_f \quad \text{(II)}$$

The deviation between residual load forecast and actual residual load ΔRL is determined as followed:

$$\Delta RL(h) = RL(h)_a - RL(h)_f \quad \text{(III)}$$

The value of ΔRL can be both, positive or negative, stating either undersupply or oversupply of energy. When $\Delta RL(h) > 0$ the energy system is short on energy and either extra electrical energy needs to be allocated/generated or load has to be reduced. These hours are defined as h^+. Analogically, in hours with $\Delta RL(t) < 0$ more energy is available than demanded i.e. the power system is long. In these hours defined as h^- either reduction of power generation is needed or an increase of load is necessary. Every hour h^+ and h^- receives a position in the order of positive and negative critical hours, decreasing with lower ΔRL. As short term ramp up power is considered the more challenging flexibility condition, this study will focus on critical hours of h_c^+, with high ΔRL and power shortage.

B. The efficiency measurement approach of energy intraday markets

Considering the need of balancing power as the key criterion for efficiency in the intraday market, the efficiency indicators are based on the imbalance values of the highest thousand critical hours.

As stated above an ideal system, intraday trading, both exchange-based and OTC should reduce the deviations during physical delivery and thus lead to a lower need for balancing energy[3]. Hence, the efficiency is measured regarding the activated reserves in times of energy shortage, i.e. in critical hours. This approach is also motivated by [13] expecting to reduce imbalances through intraday market mechanisms.

Thus, the activated balancing reserve volume is considered as an appropriate key parameter to measure efficiency of the intraday market. Regarding the imbalances during the critical hours h_c^+, two indicators are calculated. One indicator depicts a volume independent view: on the hours of activated negative reserve power in the top thousand critical hours h_c^+. This measurement enables a perspective on the frequency of overcompensation of ΔRL. The indicator for negative reserve share during the high hours h_c^+ in which up-flexibility is needed, depicts the ratio of critical hours with negative reserve energy of the 1000 highest critical hours h_c^+ where up-flexibility is needed (NIS).

$$NIS := \frac{number\ of\ h_c^+\ with\ negative\ imbalances}{1000} \quad \text{(IV)}$$
$$,for\ all\ h_c^+ = \{1, \ldots, 1000\}$$

Because the share of hours with negative reserve power activation during the top thousand critical hours h_c^+ do not contain any information about the volume of activated reserve power, an additional measurement is needed. Therefore, a second indicator is calculated: the median of the imbalance shares (MSI). The imbalance shares indicate for each critical hour the absolute values of imbalances (negative and positive) in relation to the positive ΔRL. The share is used because only the absolute volume would not provide an adequate basis for a comparison between the MS, since the total energy demand and vRE generation varies significantly within the MS. Thus, the hourly share takes the volume of imbalance as nominator and positive ΔRL as denominator.

$$MSI := Median\ of\ \frac{absolute\ value\ of\ imbalance\ (h_c^+)}{\Delta RL\ (h_c^+)} \quad \text{(V)}$$
$$,for\ all\ h_c^+ = \{1, \ldots, 1000\}$$

This indicator depicts the average magnitude of the distortion between energy supply and demand, i.e. it shows how much the need for ramping up and the actual activation of reserves diverges. It is a measure for the extent of inefficiency in the intraday market.

Following this approach, countries with low shares exhibit efficient intraday market performance, while high shares define inadequate intraday mechanism.

C. Definition of inflexable and flexible generation capacities

As agility varies with technology and utilized energy type among power plants, it is assumed that inflexible (e.g. nuclear and lignite) and flexible (e.g. gas and hydro) power plants contribute differently to intermittent ramp-up, especially when fast reactions are needed. The indicators will be analysed considering the power plant mix of the selected MS especially regarding the share of vRE generation.

In order to enhance the assessment of intraday market efficiency, flexible generation potential of the MS is also taken into consideration. The generation share (GS) of vRE as well as the share of flexible and inflexible power plants of the total energy generation in 2017 are computed for the selected MS. The GS is calculated with the nominator containing the cumulated power generation of yearly produced energy from specific power plant types *i* that display a limited flexibility and

[3] Assuming that balancing market compensates for unforeseen load, technical and system problems, and the intraday market for vRE

the denominator containing the total energy generation of one year for each MS:

$$GS = \frac{\sum_{i=1}^{n} energy\ generation\ of\ plant\ type\ i}{total\ energy\ generation} \quad \text{(VI)}$$

The vRE plants encompass solar and wind power plants. Flexible power plants are containing plant types of biomass, hydro and gas. The inflexible share displays the ratio of all nuclear, lignite, fossil hard coal and oil power plants generation to the overall energy production in 2017.

D. Data

The data for imbalance volumes and prices are taken from the imbalance power data provided by transparency platform from ENTSO-E in section imbalances [11]. Data source regarding the actual generation of all power plant types is also taken from the transparency platform of ENTSO-E from section generation [11]. The data providing the forecast of vRE can be found as well at transparency platform in section forecast [11]. Data for the intraday exchange for France is taken from the intraday exchange EPEX Spot [12]. Missing data in one specific hour led to exclusion of this hour in this investigation

IV. Results

In the following the results of the enhanced flexibility indicators are presented.

Fig. 3 depicts the share of hours with negative imbalance (NIS) of the highest 1000 critical hours h_c^+ for the selected MS.

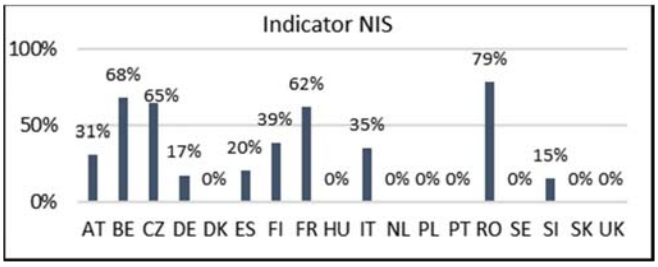

Figure 3. Indicator NIS - Negative imbalance share during the highest 1000 critical hours (source: own assessment with data from [11])

It gives evidence, that in 10 member states, the NIS is larger than zero. This means, that despite the need for up-flexibility (ramp-up of power plants) the intraday volume failed to appropriately supply electricity during the top thousand critical hours h_c^+. Thus, the activation of reserve energy was not complementary to the need of flexibility but reacted to the overshooting of the intraday market. In Belgium, Czech Republic, France and Romania the share is even above 50%, meaning that in more than half of the top thousand critical hours h_c^+ the energy supply of the reserve market was opposite to the estimated need for ramp-up power.

Fig. 4 shows the results of the second efficiency indicator. It illustrates that in Poland and Portugal the total balancing volume (negative and positive) was even significantly above the residual load deviation, while in Spain, Romania and Sweden activated balancing reserves almost reached the level of the ΔRL. These results are puzzling as they point to an extreme lack of reaction of the intraday market, i.e. an undershooting mobilisation of ramping-up capacities, which has to be corrected by the balancing market.

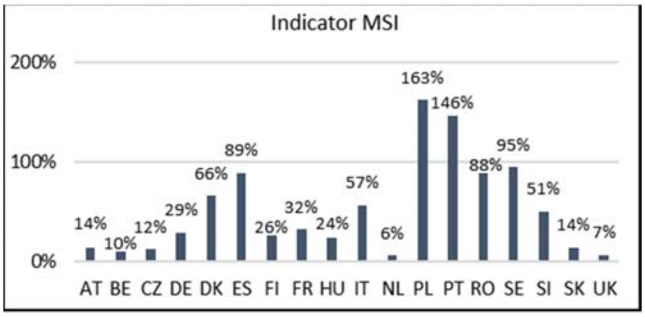

Figure 4. Indicator 2 - Median share of imbalance and ΔRL during the highest 1000 critical hours h_c^+ (source: own assessment with data from [11])

There are several possible explanations for such paradoxical market behaviour. A first assumption is that in countries with a less flexible generation fleet, flexibility is lower and thus more balancing power needs to be activated. To explore this a bit more, Fig. 5 shows shares of vRE, flexible and inflexible power plant generation of the total energy generation for each MS in 2017.

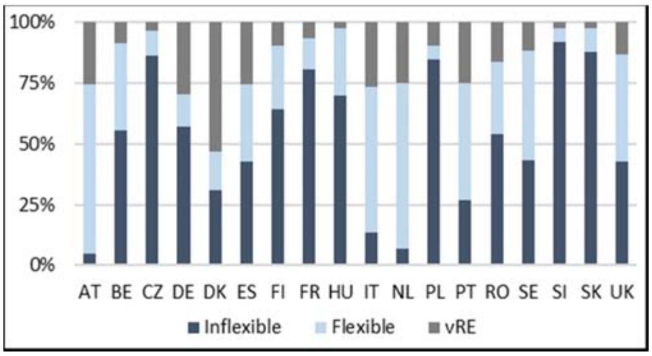

Figure 5. Share of inflexible, flexible and vRE energy generation for selected MS in 2017 (source: own assement with data from [11])

Comparing the shares in Fig. 5 with the two efficiency indicators NIS and MSI, provide no answer. The reasons explaining the balancing paradox of the NIS and the wide spread of MSI (6% to 163%) seem to be far more complex. Hence, a simple approach with the GS explaining this paradox in the MS seems not feasible.

Denmark, with the highest share of vRE generation, does not show any negative imbalance quantities, but quite high MSI volumes during the highest critical hour scope. Germany, with the second highest vRE share shows lower MSI than Denmark but a negative reserve share of 17%, meaning that in 17% of the top 1000 critical hours, the intraday market is overshooting. But even though the two MS are characterised by high vRE shares, their indicators show opposing results.

In contrast, the Netherlands and Austria show a similar pattern of generation type shares and also both depict small MSI. However, the Netherlands do not display a NIS value above zero, while Austria shows a considerably high NIS (31%)

in the investigated critical hours h_c^+. Besides, the United Kingdom, with similar results of NIS and MSI than the Netherlands, depicts significantly higher shares of inflexible power plants.

The hypothesis that large-scale inflexible power plant capacities might lead to imprecise ramp-up power seems reasonable. But considering the GS of vRE, flexible and inflexible power plants in Fig. 5, it can be seen, that not all of the afore mentioned countries with pattern of high inflexible power GS exhibit such a reserve paradox.

Transparency and full information is a precondition for the functioning of markets in economics. Therefore, a delayed exchange of information within the intraday market, i.e. between the OTC and stock exchanges, or cross-border flows could be another possible reason for the failure of market clearing in the intraday market. In addition, the design and regulations of intraday markets differ from country to country; some are rather flexible, allowing for very short-term trade and gate closure times while others offer only large time spans and early gate closure times and thus limit the efficiency of the intraday markets. Finally, regulations regarding the balancing market such as available capacities, coordination of reserves, scheduling resolution, incentives of the balancing responsible party etc., might also play a role for the inappropriate activations.

V. Conclusion

The developed approach of the intraday market efficiency measurement enables further insights in the intraday energy allocation. The results of the year 2017 give evidence, that current intraday market mechanism in many MS do not lead to an efficient energy distribution. It is shown, that activation of negative balancing power during the highest thousand critical hours h_c^+ was non- complementary to the shortage of energy demand in 10 out of the 18 investigated MS. Further, activated reserve power in the highest critical hours h_c^+ is relatively high compared to ΔRL in some MS, with high variations between 6-163 % among all analysed countries. No correlation can be observed between the generation shares of inflexible, flexible and vRE power plants and the measured intraday market efficiency. Evaluating the intraday exchange and reserve market results in France in 2017 prove that the majority of trading is done OTC.

This paper has identified the need for assessing the efficiency of intraday trading to enable the provision of flexibility beyond assessing market rules, liquidity and pricing. It shows that a large number of intraday markets do not contribute to effective flexibility provision. Further research is necessary to detect the reasons for these observations. Possible explanations include different imbalance price regulations and varying incentives for avoiding imbalances as well as available imports or exports, intraday market rules, bilateral long-term contracts (PPAs), missing information regarding forecast updates and practise of OTC trading.

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