Analysing Market Movements from Day-Ahead- to Intraday-Market to Improve Capacity Validation Processes

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Abstract:

To facilitate electricity markets, Regional Coordination Centres determine available cross-zonal capacities between bidding zones. This is done in line with the relevant regulations including the minimum capacity requirements. Transmission System Operators have the right to validate these cross-zonal capacities, which requires a forecast of most likely power exchanges for upcoming markets. In Europe, the increasingly fluctuating power flows from Renewable Energy Sources make forecasting power exchanges more challenging. Therefore, in this paper, we initialise an analysis of patterns in cross-zonal Intraday-market trading, depending on the Day-Ahead-market results. For the neighbouring bidding zones Germany/Luxembourg and Austria, we identify and discuss first patterns. Knowing such patterns could improve Intraday capacity validation processes.

Keywords: European Electricity Market, Capacity Calculation, Capacity Validation, Electricity System Operations, Transmission System Operator, Power Exchange Patterns

1 Motivation and Central Research Question

In order to achieve the goals of the European internal market for electricity – e.g., efficiency gains, more cross border trades, and contribution to security of supply – the provision of safe cross-zonal capacities between bidding zones is a key factor [1]. Especially in the current energy crisis in Europe, a good cooperation across borders, in terms of enabling power exchanges, is crucial. Thereby, calculated cross-zonal capacities reflect the "[…] *capability of the interconnected system to accommodate energy transfer between bidding zones*;" [1, p. 15]. The calculated cross-zonal capacity limits the cross-zonal power exchange.

Electrical energy can be traded on several markets, beginning with the forward market, followed by the Day-Ahead-, and Intraday-market. In order to facilitate electricity markets while also ensuring system security, Regional Coordination Centres (RCCs) determine available cross-zonal transfer capacities between bidding zones on a regular basis. This capacity calculation is done in line with all relevant regulations. One of these regulations is the EU Regulation 2019/943 ("CEP"), which defines a minimum value for cross-zonal capacities [1]. This minimum value might increase the level of needed remedial actions in order to keep the electricity system within its operational limits. As Transmission System Operators (TSOs) have the responsibility to ensure the security of the electricity system, TSOs have the right to validate these capacities. TSOs can perform this validation in different ways.

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In a mathematical perspective the capacities can be interpreted as hyperplanes in a multidimensional room. The combination of hyperplanes creates a solution space. This solution space represents all admissible combinations of power exchanges. One approach to validate cross-zonal capacities, is to prove that points within the solution space are safe. In this context, safe means, that the electricity system remains within its operational security limits even if the application of remedial actions is required.

In this paper, we focus on short-term capacity validation, i.e., we consider the Day-Ahead- and the Intraday-market. Validating the solution space with a closed optimisation seems possible, but to our knowledge no further research has been done in this field so far. Currently it is only possible to check several discrete points or certain market directions in this solution space. Hence, to reduce the number of points/market directions to be checked a forecast of most likely power exchanges is needed. However, forecasting power exchanges is steadily becoming more complex. Among others, especially Europe observes increasingly fluctuating electricity generation from Renewable Energy Sources (RES) [2, 3]. As RES generally have low fuel costs, a high electricity generation from RES tends to reduce the wholesale price [4]. Market coupling allows to increase the socio economic welfare in Europe [5]. For this purpose, the bids of market parties can be matched anywhere in the single Day-Ahead coupling-area. In combination with fluctuating electricity generation from RES, this can lead to volatile power flows between bidding zones. As a consequence, the complexity of forecasting likely power exchanges increases.

Therefore, to forecast most likely power exchanges between bidding zones, given increasingly fluctuating power flows, we ask the following research question: Are there patterns in cross-zonal Intraday power exchanges, depending on the results of the Day-Ahead-market? In order to start analyses and discussions on this topic, we first investigate the traded energy between bidding zones on the Day-Ahead-market. Depending on these results, we analyse the traded energy on the Intraday-market and derive first patterns. Knowing such patterns could foster forecasting most likely power exchanges and, therefore, improve short-term, i.e., Intraday, capacity validation processes.

2 Methodological Approach

In general, the objective of validating cross-zonal capacities – before they are given to the markets – is to ensure that the determined capacities do not allow for power flows which violate operational security limits [6]. As already mentioned, in this paper we focus on the validation of short-term capacities, i.e., the capacities for the Intraday-market. Ideally one would validate all possible power exchanges in the solution space, i.e. all combinations of power exchange directions and magnitudes of trading activities on the Intraday-market. The process of capacity calculation including validation, however, only has limited time. For capacity validation, we perform a series of (n-1) load-flow calculations combined with an optimization of remedial actions including redispatching of conventional and renewable electricity generation units. Even with a significant increase in computational performance, we can only analyse a part of the solution space, considering the bidding zones in the Core-region (Core-region refers to one capacity calculation region in Europe). Against this background, looking for patterns that help to reduce the number of power exchange combinations that need to be checked seems worthwhile.

Therefore, we analyse the nominated cross-zonal power exchange schedules within the Core-region on the Day-Ahead- as well as on the Intraday-market. In this paper, we refer to this as the market movement from Day-Ahead- to Intraday-market. The aim is to find patterns in this market movement that help us to identify most likely power exchanges.

For nominated cross-zonal power exchange schedules, we use scheduled commercial exchanges, i.e., the power traded per hour between neighbouring bidding zones. This data is published on the ENTSO-E transparency platform and accessible via an API [7, 8]. This data consists of Day-Ahead as well as Total scheduled commercial exchanges. Day-Ahead scheduled commercial exchanges represent aggregated schedules for all previous time horizons including the results of the Day-Ahead-market [7]. In addition to Day-Ahead scheduled commercial exchanges, Total scheduled commercial exchanges also include the aggregated schedules from the Intraday-market. This data basis allows us to determine the Intraday scheduled commercial exchanges by subtracting Total and Day-Ahead scheduled commercial exchanges. In this context, it is important to consider both directions for the respective border since there might be scheduled commercial exchanges in both market directions during the same hour.

After the Day-Ahead market coupling process currently the so-called “left-over” capacities, i.e., the Intraday Available Transfer Capacities (ATC), are determined [9]. For the Core-region, this data is published via the JAO Publication Tool [10]. These “left-over” capacities need to be validated.

In addition to scheduled commercial exchanges and Intraday ATCs, we also consider wholesale prices as a potential indication for market movement. Therefore, we examine Day-Ahead-prices for each bidding zone as well as the difference in Day-Ahead-prices between two neighbouring bidding zones. Such price differences imply an economic incentive for cross-border energy trading. Data for Day-Ahead-prices is also published on the ENTSO-E transparency platform and accessible via an API [8, 11].

As stated above, this paper aims to initialise analyses and discussions about the increasingly important topic of cross-zonal power exchanges and corresponding patterns. To generate first insight in such patterns, we investigate the Day-Ahead scheduled commercial exchanges resulting from the Day-Ahead-market (that need to respect the Day-Ahead-capacities). Based on these results, we examine in which market direction and to which magnitude power was traded on the Intraday-market, i.e., the market movement from Day-Ahead- to Intraday-market, between two bidding zones. In this regard, we analyse the market movement in both, absolute and in relative means. For the relative analysis, we take the Intraday ATC into account. With regard to Day-Ahead-prices, we determine the price difference between two neighbouring bidding zones. For illustrating and interpretating the results, we use descriptive statistics like scatterplots, frequency distributions, and heatmaps.

3 Results

In this paper, we conduct our analyses for one bidding zone border in the Core-region, namely for Germany/Luxembourg and Austria. For the purpose of generating first insights, we focus on the year 2022. However, it is possible to extend our methodology and evaluations to other borders that follow a similar market design as well as to a larger time interval. In the following

subsection 3.1, we describe our conducted analyses. Then, in subsection 3.2 we interpret our results and discuss the identified patterns.

3.1 Description of Results

In the first step, we use scatter plots to visualise the market movement from Day-Ahead- to Intraday-market between Germany/Luxembourg and Austria. Figure 1 illustrates how to interpret this scatterplot for the market movement. The diagram represents the perspective for the “exporting” bidding zone, here Germany/Luxembourg. The x-axis depicts Day-Ahead scheduled commercial exchanges. Positive values represent the exporting direction of power, i.e., in our case, export from Germany/Luxembourg to Austria. The y-axis depicts Intraday scheduled commercial exchanges. Again, positive values represent the exporting direction of power. Each hour in the analysed time interval is represented by a data point that contains the Day-Ahead and Intraday scheduled commercial exchanges. Figure 1 comprises the four resulting combinations of im- and export seen from the perspective of the exporting bidding zone. In order to get the perspective of the corresponding importing bidding zone, here Austria, one needs to switch the export and import direction. Note that you need to combine the Day-Ahead and the Intraday values to determine the resulting direction of the power exchange. For instance, an exporting direction on the Day-Ahead-Market and an importing direction on the Intraday-Market can lead to a power exchange in exporting or in importing direction.

The x-axis has the unit MW. For our analyses of absolute trading on the Intraday-Market, the y-axis also has the unit MW. For our investigation of relative Intraday-Market movements, related to the available Intraday ATC, the unit is percent.

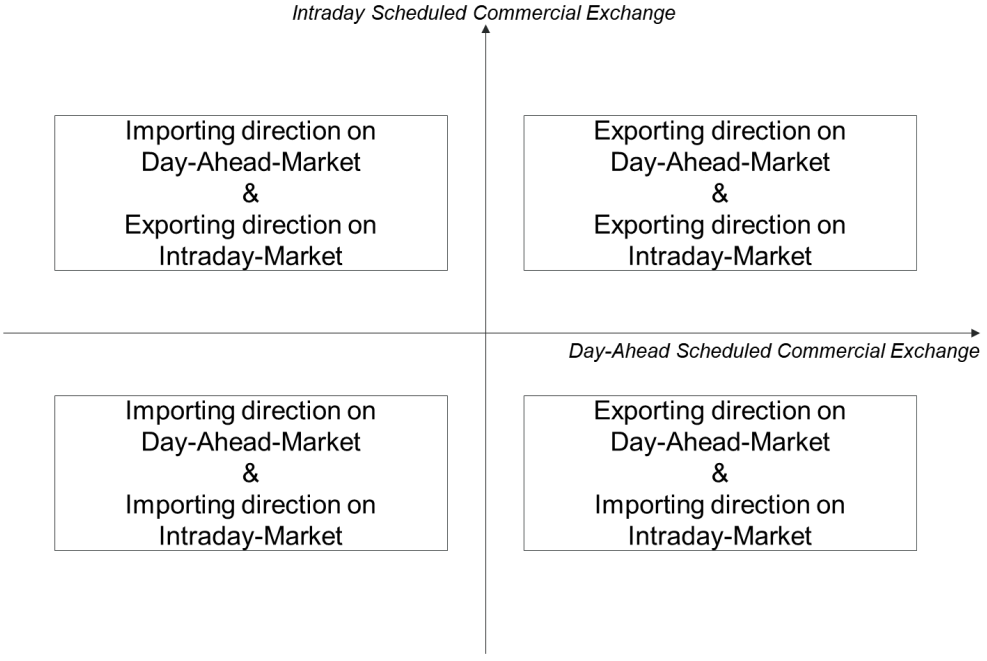

Figure 1: Interpretation of the absolute and relative market movement scatter plot.

Figure 2 illustrates the absolute and relative market movement for Germany/Luxembourg and Austria from 01st January to 31st December 2022. Note that the relative market movement

starts at 09th June 2022 as the Intraday ATC data is available since the start of the flow-based capacity calculation in the Core-region [12].

The scatterplot for absolute market movement in the upper left reveals that in our considered time interval, most of the time, Germany/Luxembourg exported power to Austria on the Day-Ahead market. However, you also need to consider the volumes on the Intraday-market, since Intraday trading can lead to reversal of the flow. For instance, assume a scheduled commercial exchange of 1 000 MW on the Day-Ahead market. Then, a scheduled commercial exchange of more than -1 000 MW on the Intraday-market would result in an export situation from Austria to Germany/Luxembourg. In other words, in the second and fourth quadrants, the angle half-lines (also included in Figure 2) provide information on whether trading on the Intraday-market is large enough to reverse the power flow.

The scatterplot for relative market movements in the upper right indicates to what extent the Intraday trading exploited the available capacity, i.e., the Intraday ATC. Note that in the case the left-over capacity of the Day-Ahead market is zero, it is not possible to trade more power on the Intraday-market in this specific direction. In this case, the data points in the scatterplot are set to a value of 100 % on the y-axis to represent the utilisation in this direction. Also, if the Intraday ATC is greater than zero and the Intraday scheduled commercial exchanges sum up to the Intraday ATC, the data points exhibit 100 % on the y-axis.

In addition to the scatter plots, the frequency plots illustrate the distribution of the data points included in the scatter plots. More precisely, the frequency distribution plots provide information about where and how many data points are located for the absolute (bottom left of Figure 2) as well as for the relative market movement (bottom right of Figure 2).

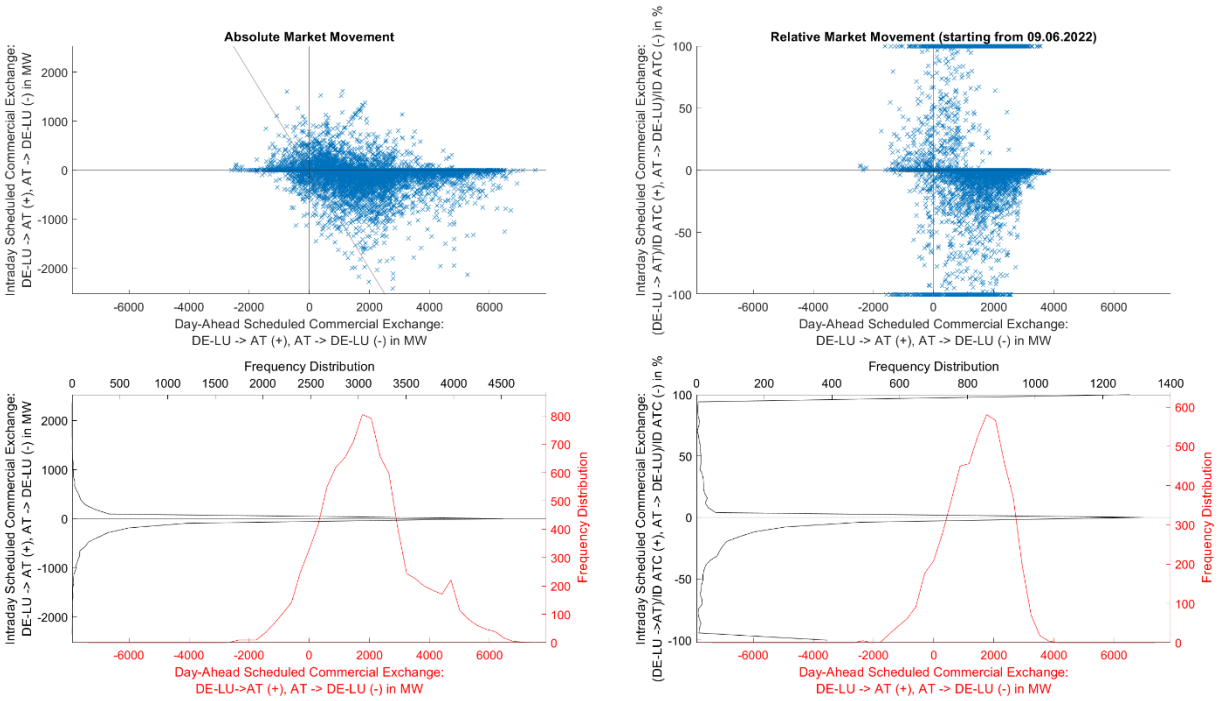

Figure 2: Absolute and relative market movement for Germany/Luxembourg and Austria.

Figure 3 contains three heatmaps which illustrate the price difference on the Day-Ahead-market between Germany/Luxembourg and Austria, the Day-Ahead Scheduled Commercial

Exchange, and the Intraday Scheduled Commercial Exchange over the course of the year 2022.

The first heatmap depicts the price difference that is calculated as Day-Ahead price in Austria minus Day-Ahead price in Germany/Luxembourg. Therefore, positive values of the price difference are equal to situations when the Day-Ahead price in Austria is greater than in Germany/Luxembourg and vice versa. Note that price differences greater/less than +-50 €/MWh are capped in order to better visualise smaller price differences. On the x-axis, each column represents a day. Each row on the y-axis represents one hour of the day.

The second heatmap illustrates the Day-Ahead scheduled commercial exchanges. The y-axis contains the same values as the x-axis of the upper left scatter plot in Figure 2. Analogues, the third heatmap represents the Intraday scheduled commercial exchanges. It's y-axis contains the same values as the y-axis of the upper left scatter plot in Figure 2. Note that in the third heatmap the values of scheduled commercial exchanges greater/less than +-250 MWh are capped in order to better visualise smaller values. The illustration of Day-Ahead and Intraday scheduled commercial exchanges as heatmaps allows to derive daily and seasonal patterns.

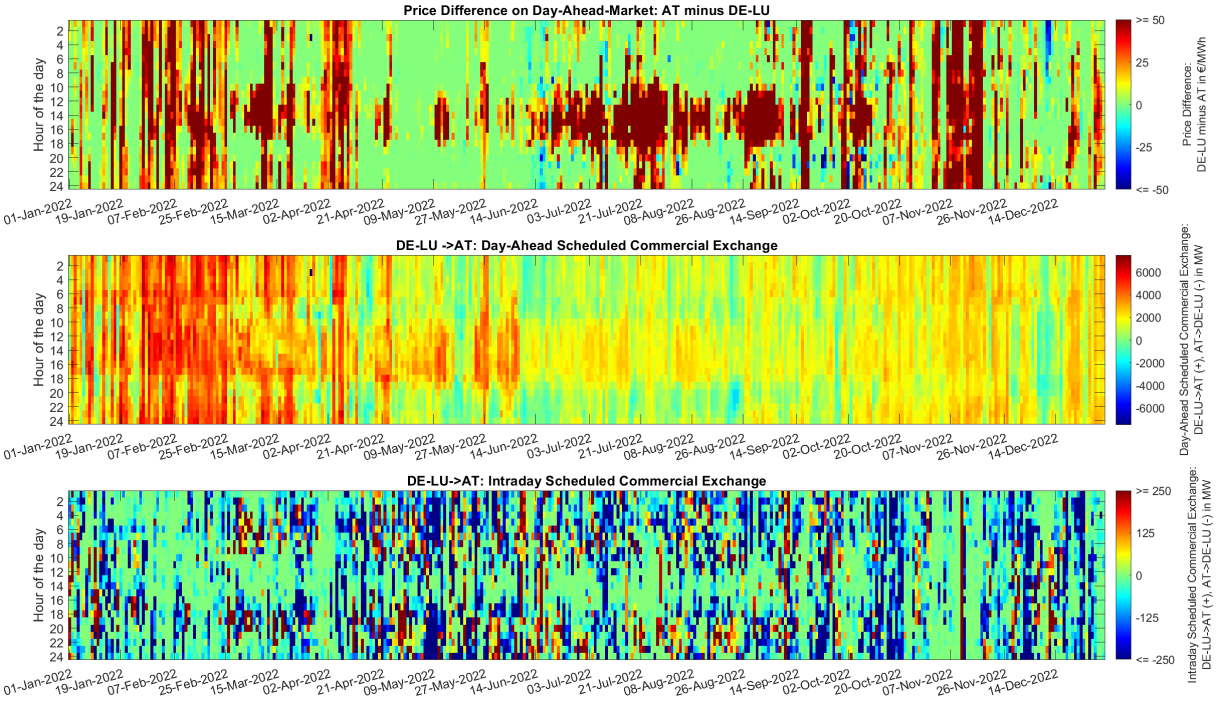

Figure 3: Difference in Day-Ahead prices, scheduled commercial exchanges on the Day-Ahead-market, scheduled commercial exchanges on the Intraday-market for Germany/Luxembourg and Austria over the course of the year.

3.2 Interpretation of Results

In this subsection, we now interpretate the results of our conducted analyses. Interpretating the scatterplots and frequency distributions in Figure 2 allows us to observe the following patterns:

- The scatterplot illustrating the absolute market movements reveals that the primary trading direction on the Day-Ahead-market is from Germany/Luxembourg to Austria.

- The frequency distribution plots reveal that there are a lot of hours with no movement on the Intraday-market. However, when electrical energy was traded on the Intraday-market, we can observe that the higher the exchange on the Day-Ahead-market is, the more likely it is that the Intraday-market "moved back", i.e., electrical energy was traded in the opposite direction.
- One reason why electrical energy was traded in the opposite direction on the Intraday-market can be deduced from the scatterplot as well as the frequency distribution for relative market movement. There are many data points with 100 % utilisation of the available capacity. Recall that data points are also set to 100 % when the Intraday ATC is zero – that means that the only possibility to trade electrical energy on the Intraday-market is in the opposite direction.

Interpretating the heatmaps in Figure 3 allows us to observe the following patterns:

- Generally, the heatmaps contain seasonal and daily patterns which might be – among others – caused by seasonal and daily dependencies of electricity generation by RES. The heatmap for price differences illustrates that especially during February and March, during midday in the summer, and in November the Day-Ahead prices in Germany/Luxembourg were lower than in Austria.
- Such price differences reflect an economic incentive to trade energy between these bidding zones. Hence, in the heatmap for Day-Ahead scheduled commercial exchange a certain correlation of exports from Germany/Luxembourg to Austria is visible in times of higher price differences between these two bidding zones.
- The heatmap for Intraday scheduled commercial exchanges, however, does not reveal any obvious seasonal or daily patterns.

4 Conclusion, Limitations, and Further Research

In order to ensure security of supply, Transmission System Operators have the right to validate cross-zonal capacities. In this context, knowledge about trading volumes as well as trading directions is worthwhile to efficiently validate these capacities. Therefore, in this paper, we started to generate first insights into patterns of short-term market movements, i.e., the scheduled commercial exchanges on the Day-Ahead- and Intraday-market. Using only most likely market movements in capacity validation avoids that capacities are reduced due to very unlikely, respectively unrealistic exchanges. Hence, this article contributes to foster the efficient usage of electricity grid capacities and, therefore, the power exchange between bidding zones in times of increasing shares of fluctuating Renewable Energy Sources in the European internal market for electricity.

Recall that this paper intends to generate first insights into patterns of market movement from Day-Ahead- to Intraday-market. Against this background, this paper has some limitations. For instance, besides scheduled commercial exchanges, we only consider Day-Ahead-prices and corresponding differences between bidding zones in our analyses. Moreover, we focus on the year 2022 which might have unique results due to European energy crisis. Therefore, patterns we identified might change in the future. Also, we analysed only on border, namely the border of the bidding zones Germany/Luxembourg and Austria. It is also important to take into account that the relevant Transmission System Operators can perform redispatch across this border. This might have an impact on the patterns of the Intraday-market.

Considering the limitations of this paper, further research could take more input data – e.g., the mentioned circumstance like share of Renewable Energy Sources, temperatures, or the

residual load – into account. When using more input data, it is also worthwhile to examine methods that allow a fast processing of the corresponding data, since there is only a short period of available time in system operations. Using more sophisticated methods like approaches from machine learning could allow to gain additional insights into patterns in the market movement from Day-Ahead- to Intraday-market. Overall, further research in this field can contribute to improve the capacity calculation and validation in order to facilitate the European internal market for electricity while ensuring operational security.

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