IMPACT ASSESSMENT OF THE ORDER TYPES MIX IN THE GREEK DAY-AHEAD ELECTRICITY MARKET

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Abstract

The Greek Day-Ahead Electricity Market facilitates a diverse array of order types and offers participants a plethora of choices. While Block Orders are theoretically supported, their accessibility is confined to a subset of market participants so as to ensure the Market Clearing Price formation and the technical feasibility of the resulting Market Schedules. This paper presents a quantitative analysis of the implications of lifting the currently applicable restrictions on the availability of Block Orders in the Greek Day-Ahead Electricity Market, based on past historical data. Clustering techniques are used to convert anonymized past Hourly Hybrid Orders into plausible Block Orders. A market clearing simulator is then used to derive the outcome of the market given the created plausible Block Orders. Simulations are conducted under Coupling and Isolated conditions for three indicative weeks in 2022 and while exploring various scenarios for the specifications of the new Block Orders and the categories of participants who could use them. Assessment metrics encompass Marginal Clearing Price (MCP) statistics, instances of Paradoxically Rejected Block Orders, and Lost Opportunity Cost, shedding light on whether restrictions should be upheld or mitigated

1. Introduction

1.1. Background

The Day-Ahead Market (DAM), operated by the Hellenic Energy Exchange (HEnEx), is a main pillar of the Greek wholesale electricity market. Since December 2020, the Greek DAM is an integral part of the Pan-European Day-Ahead electricity market under the Single Day-Ahead Coupling (SDAC) framework [1]. Accordingly, the Greek DAM supports in principle the full range of SDAC products decided by the European Union Agency for the Cooperation of Energy Regulators (ACER), including (simpler) Hourly Hybrid Orders as well as (more complex) Regular Block Orders, Linked Block Orders and Exclusive Groups of Block Orders [2]. While all such products are supported in principle, their availability is restricted to a sub-group of the Greek DAM participants so as to ensure Market Clearing Price (MCP) formation and technical feasibility of the Market Schedules (MS). More specifically, acting on the recommendation of HEnEx, decision 661/2021 of the Greek Regulatory Authority for Energy, Waste & Water (RAEWW) temporarily restricts the availability of Block Orders only to Power Producers and only for the Thermal Production Units which they operate [3]. The decision was taken on the basis of a quantitative analysis of the effects of the aforementioned different products on the clearing of the non-coupled Day-Ahead Scheduling (DAS) market and the validity of decision 661/2021 should be extended or terminated on the basis of an updated analysis of the new, coupled Day-Ahead Market (DAM).

1.2. Related literature

An assessment of the collective impact of all presently accessible EUPHEMIA market products on the economic and operational performance of the Greek interconnected power system has been presented in [4]. As described in the specification document of EUPHEMIA [5], all the currently available Block Order types in the European Power Exchanges are identified by uniform and fixed minimum acceptance ratio and price offer for the whole duration of the submitted block order. A new approach where all these aspects can be converted into dynamic ones, leading to improvements in key Block Order characteristics and eventually introducing new block-based market products was proposed [6]. The new products aim at enhancing the flexibility of market participants towards the robust and efficient management of their resources. The effects of the size, type, and number of Block Orders on the Day-Ahead auctions organized by power exchanges, and more specifically on the total computational time and the likelihood of Paradoxically Rejected Block Orders was investigated in [7]. The conclusions of this study argue against imposing constraints on block sizes as well as limitations on the quantity of Block Orders that a participant may submit within a given day.

1.3. Paper contributions

This paper presents a novel methodology for the quantitative analysis of the implications of lifting the currently applicable restrictions on the availability of Block Orders in the Greek DAM. The methodology leverages anonymous data on past submitted Hourly Hybrid Orders to create alternative plausible market clearing instances for hypothetical situations wherein the DAM participants would have access to alternative products and specifically Block Orders. The conversion of Hourly Hybrid Orders into plausible Block Orders relies on clustering techniques. Using this as a basis, different scenarios are examined regarding the specifications of the new Block Orders and the categories of participants who could potentially use them. A market clearing simulator is used to simulate such scenarios, under Coupling and Isolated conditions for three indicative weeks in 2022. To evaluate the results, indicators related to Marginal Clearing Price (MCP) statistics, Paradoxically Rejected Block Orders (PRBs), and Lost Opportunity Cost (LOC) were studied, and their impact on the relationships between MCP and various DAM metrics are considered. Finally, we discuss the conclusions drawn from the study regarding the extended use of Block Orders, and the specifications that should be met to minimize their impact on DAM metrics.

2. Problem Description

As already mentioned, in the Greek DAM the availability of Block Orders is limited to Power Producers and only for the Thermal Production Units which they operate. The overarching question that we seek to address in this paper is whether lifting such restrictions severely affects the functioning of the market.

Let us formally define as HO a set of historical anonymized orders submitted in the Greek DAM over a set of past Delivery Days (DD) $d = 1, \dots, D$ and Market Time Units (MTU) $t = 1, \dots, T$. Along with this set, we also have access to the following historical results:

- $MCP_t(HO)$: The market clearing price for any Market Time Unit t within the set of past delivery days $d = 1, \dots, D$.
- $NL_t(HO)$: The net load. It is computed for each MTU t, as the summation of priority price taking buy/sell order quantities, non-dispatchable load/supply portfolio order quantities and order quantities submitted by traders from non-coupled interconnectors.
- $\rho_{NL}(HO)$: The Pearson correlation between $NL_t(HO)$ and $MCP_t(HO)$ over the set of past delivery days $d = 1, \dots, D$.
- $PRB_{DD}(HO)$: The total number of Paradoxically Rejected Block Orders during the set of past delivery days $d = 1, \dots, D$.
- $LOC_t(HO)$: The Lost Opportunity Cost [8] of PRBs defined as the product of the quantity that was paradoxically rejected times the difference between the order price and the order-quantity-weighted MCP at each MTU over a set T.
- $LOC_{DD}(HO)$: The summation of the $LOC_t(HO)$ over the market time units $t = 1, \dots, T$ within the set of past delivery days $d = 1, \dots, D$.

Notice that we explicitly denote all these metrics as functions of the historical order set HO. Indeed, the values of these metrics result from the submission of set HO in the Greek DAM. In other words, had the market participants submitted any alternative order set AO in the past, the values of these metrics could differ. We posit that the difference in these metrics over alternative plausible order sets, reflecting relaxed Block Order restrictions, quantifies the effect of lifting such restrictions in the Greek DAM. On this basis, we seek to:

(i) generate plausible alternative order sets for a historical period under study, assuming relaxed Block order restrictions and
(ii) evaluate the change in the aforementioned metrics by simulating the Greek DAM counterfactual clearing.

3. Methodology

3.1. Formation of Plausible Alternative Order Sets

The formation of plausible alternative order sets reflecting relaxed Block Order restrictions for the historical period under study is performed by converting historical submitted Hourly Hybrid Orders into Block Orders. As a first step, Hourly Hybrid Orders are converted into simple Block Orders by exploiting the k-means clustering technique [9]. Additional complex relationships between Block Orders (e.g., exclusive block relationships, linked block relationships etc.) are added on top of the converted simple Block Orders in a second step.

3.1.1. Conversion of Hourly Hybrid Orders into Simple Block Orders: As a pre-processing step, each Hourly Hybrid Order is divided into sub-sections according to the price levels at which it operates. In case an order consists of linear (monotonic) segments, the new price is defined as the average price of the price levels of that specific segment, and the quantity is defined as the difference in the corresponding quantities of the segment of the bid (Delta-Quantity). Eventually, for each MTU, each bid is decomposed into Price - Delta-Quantity pairs, which generate surplus identical to that of the original bid. These pairs, in combination with the MTU to which they have been submitted, constitute the parameters that the k-means algorithm will utilize to cluster the orders.

The next step is to input the processed historical Hourly Hybrid Order data into the k-means clustering algorithm. To do so, it is necessary to define the features based on which similar orders should be clustered together and the relative weights of these features. The features selected to represent the orders in our approach are: (i) the Price, (ii) the Delta-Quantity and (iii) the MTUs wherein the Price, Delta-Quantity Pair appears. Further, in order to best represent the technical characteristics of Power Production Units (e.g., flexibility) very large weight is assigned to the MTU feature which relates to time continuity. A large weight is assigned to the Price feature and low weight is assigned to the Delta-Quantity feature. The resulting weighted triplets of MTU/Price/Delta-Quantity are the inputs of the clustering algorithm, which determines the optimal clusters to represent the historical order set. These optimal clusters are used to define the plausible Block Orders that will replace the historical Hourly Hybrid Orders for the counterfactual market clearing. More specifically, a distinct Block Order is formed by collecting the data of the points belonging to the same optimal cluster. As a final optional step, if a created Block Order includes zero production for a single MTU, it is broken down into multiple uninterrupted Block Orders.

3.1.2. Formation of Linked Block Orders: Linked Block Orders are created by establishing connections on top of converted Simple Block Orders. Two alternative types of connections were considered:

- Between orders of the same buy/sell "side": Once the converted Simple Block Orders are formed, for each unit or portfolio and for each MTU, the Block Order with the lowest price is selected and designated as the "Parent" Block Order. Segments of the same MTU with higher prices are defined as "Children" Block Orders of the aforementioned "Parent" Block Order.
- Between orders of opposite "sides": Connection between the formatted buy Simple Block Order ("Children") and the sell Block Orders with the lowest price ("Parent") for the corresponding unit/portfolio are created.

3.1.3. Exclusive Block Orders: For each converted Simple Block Order two distinct orders with differentiated prices are created. The first one is cheaper than the converted Simple - Block Order and the second one is more expensive, by the same predetermined percentage of 2%. The two new Block Orders that are created in this way are submitted together with the initial Block Order from which they were generated as an Exclusive Group of Block Orders.

3.2. Market Clearing Simulator

Given any Plausible Alternative Order Set, we compute the metrics introduced in Section 2 by relying on an in-house simulator for the Day-Ahead Market clearing. The simulator exploits the efficient MIP reformulation for the European-style Day-Ahead electricity market clearing problem introduced by Madani and Van Vyve in [10] with appropriate extensions to account for Linked Block Orders and Exclusive Block Orders. Our implementation of the resulting MILP problem was developed in Julia [11] using the JuMP modelling language [12]. We solved all instances of the MILP problem with the CPLEX solver [13].

4. Results

4.1. Scenarios and simulations

We consider three *study periods* corresponding to a week in each of the months January, March and July of 2022.

In order to systematically define plausible alternative order sets, we first introduce 8 so-called *scenarios.* A scenario specifies which types of market participants have additional access to Block Orders as well as which additional types of orders they could use. In the simplest scenario 1, owners of flexible low-carbon units with energy constraints and production/consumption capabilities can submit Simple Block Orders.

In scenarios 2 through 8, the types of market participants that would be able to use Block Orders as well as the complexity of the available Block Order types are gradually expanded. More specifically, scenario 2 introduces the option of Linked Block orders to the same group of market participants as in scenario 1. In this scenario, connections are established between Block Orders of opposite buy/sell sides. In scenario 3, Simple Block Orders are also available to owners of flexible, low-carbon, energy-constrained assets. In scenario 4 Linked Block Orders are created for the same-side orders from these market participants while in scenario 5 Exclusive Block Orders are created for them. Scenario 6 includes Simple Block Orders from the aforementioned groups of market participants as well as from energy traders. Scenario 7 additionally includes Simple Block Orders from load aggregators. Finally, the most extreme scenario 8 allows Block Orders from all market participants. For validation purposes, we also reproduce the base case wherein the original anonymized order books are submitted to our market clearing simulator.

For any scenario, we performed 5 alternative *simulations* by modifying the parameters shown in Table 1. In addition to parameters related to the hypothetical Block Orders, we study the Greek Bidding Zone both in coupled and isolated conditions. Figure 1 summarizes the number of block orders in each considered scenario as per the parameters of simulation 1. Unless otherwise specified, for the sake of conciseness, we will henceforth report detailed results from this simulation and the January 2022 study period only. Similar results and observations have been extracted from all other simulations and across all three study periods.

Table 1 Simulation Parameters

Simulations	**Block Orders Parameters**		**Coupled**
	Average duration *(MTU)*	**MAR *(%)***	
Simulation 1	10.6	100	YES
Simulation 2	10.6	0	YES
Simulation 3	Single Block Order	100	YES
Simulation 4	10.6	100	NO
Simulation 5	Single Block Order	100	NO

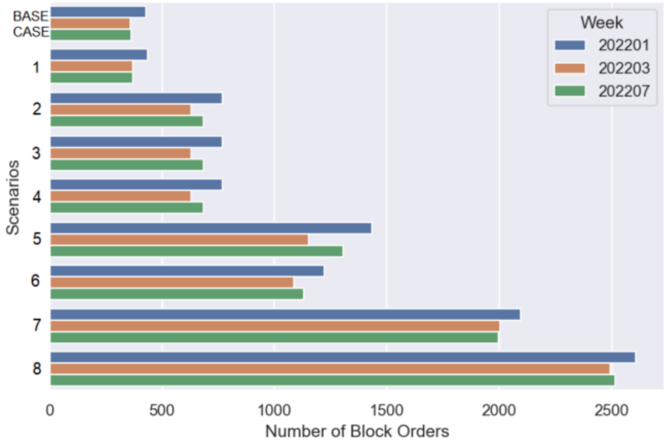

Figure 1 Number of Block Orders for Simulation 1

4.2. Effect of Additional Block Orders on the Market Clearing Price Statistics

We found that the gradual increase in the number and complexity of Block Orders has a minimal effect on the average value and standard deviation of the Market Clearing Price. In other words, in the simulated conditions, these metrics are not dependent on the availability of Block Orders to the market participants. Indicatively, the average MCP for the considered week in January 2022 is in the order of 226 €/MWh across all scenarios. The respective standard deviation is in the order of 34 €/MWh, with the variation among scenarios not exceeding 3%.

The correlation coefficient (ρ_{NL}) between MCP and NL is also of interest. It can be considered as indicative of the relationship between the market outcome and system conditions. For the considered week of January 2022, a very small and gradual decrease in the correlation between the two metrics is observed, resulting in scenario 8 having a correlation coefficient of $\rho_{NL} = 0.821$ compared to $\rho_{NL} = 0.840$ in the base case. Regardless of the number of Block Orders, the correlation remains very strong between the two metrics. Table 2 presents in detail the average MCP and its correlation to the net load for the considered study period (January 2022 week).

Table 2 Market Clearing Statistics for Simulation 1

Scenario	**MCP *(€/MWh)***	$\boldsymbol{\rho_{NL}}$
Base case	226,65	0,840
1	227,07	0,836
2	226,71	0,841
3	226,69	0,841
4	226,71	0,840
5	226,69	0,839
6	227,61	0,822
7	227,72	0,821
8	227,73	0,821

4.3. Paradoxical Rejections and Lost Opportunity Costs

The two metrics that exhibit the greatest diversity among the study scenarios are: a) the number of $PRBs$, and b) the LOC. The increase in the number of Block Orders, alongside a decrease in Hourly Hybrid Orders, results in a rise in the number of Block Orders that, while in-the-money, are rejected by the market clearing algorithm. A characteristic example is scenario 5, where the large number of Block Orders generated, combined with relatively small deviations among the prices of orders within the same family, leads to some of these orders being paradoxically rejected. Similar behaviour is observed for the LOC metric, where the total quantity of Block Orders plays a significant role, rather than just the number of $PRBs$. Substantial increases in the number of Paradoxically Rejected Block Orders do not necessarily entail significant changes in the LOC. For instance, in scenarios 6, 7, and 8, where $PRBs$ are approximately 30-100% more than in base case, the LOC exhibits an increase of no more than 10-40% (approximately). Figure 2 illustrates the comparison of Lost Opportunity Costs over the considered scenarios and study periods.

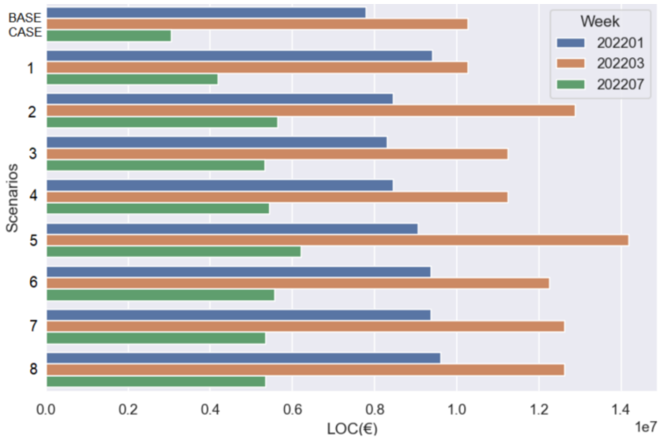

Figure 2 Lost Opportunity Costs for Simulation 1

4.4. Net Position Variability and Market Coupling Effects

In most cases, we observed that the energy that remained uncleared due to the creation of Block Orders was covered by imports/exports through coupled interconnections. In other words, the import/export component of the Greek Bidding Zone Net Position adjusted to the newly created Block Orders in a way that maintained a smooth hourly Market Clearing Price profile. To illustrate this Figure 3, plots the average Net Position of the Greek Bidding Zone while Figure 4 plots the average MCP. The greater variability of the Net Position over the considered scenarios is visually apparent by examination of these two figures. Our detailed numerical results confirm that indeed the NP shows greater variability than the MCP in the considered situations.

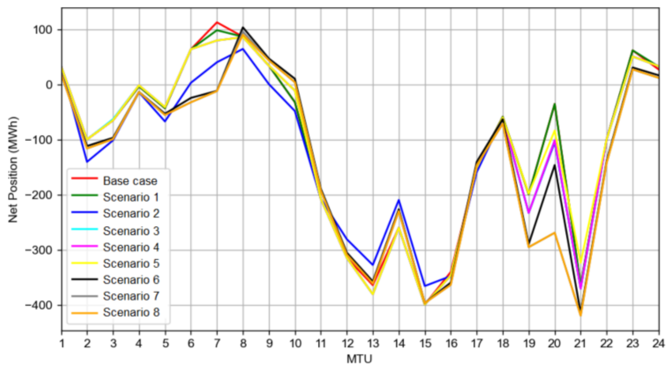

Figure 3 Greek Biding Zone Net Position for Simulation 1

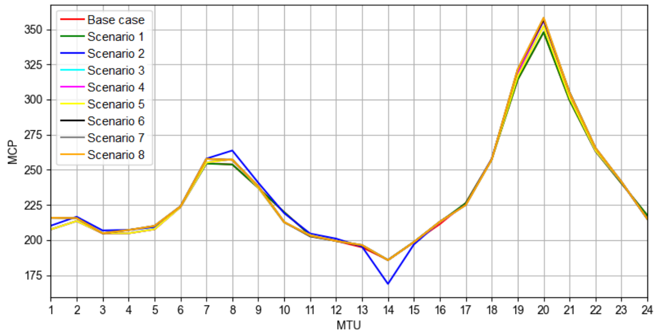

Figure 4 Greek Bidding Zone MCP for Simulation 1

The significance of interconnections and their impact on the MCP formation can be understood by observing the results of Simulation 4, where the Greek Bidding Zone is isolated. Examining the boxplots in Figure 5 (isolated conditions) and Figure 6 (coupled), two significant observations can be made. The first observation pertains to the increase in the size of the boxes, particularly in scenarios 6, 7, and 8, indicating a substantial rise in the variance of the 50% of resulting MCPs. The second observation is related to the appearance of extreme MCP values in the outliers, indicating a challenging price formation under the certain conditions.

4.5. Effect of Block Order Duration & Minimum Acceptance Ratio

To assess the impact of the duration of Block Orders, an extreme case was created. More specifically, in Simulation 3 only one (#1) Block Order was used for each asset/portfolio. The most notable observation pertains to the LOC, which escalates to very high levels for cases involving extensive use of Block Orders.

The MAR of Block Orders shows a limited influence on both the Clearing Price and its variance. Nonetheless, it does result in a marginal rise in the number of PRBs and the total LOC. This effect becomes apparent when comparing Simulations 1 and 2. Specifically, in the baseline scenario, the number of PRBs for the January 2022 week is 21 Block Orders. In Simulation 1, for the 8th scenario, this number increases to 30, while in the corresponding scenario of Simulation 2, it rises to 29. A similar trend is observed in the LOC, whose value appears to decrease by 5-10% in Simulation 2.

In the worst-case scenario, where only one (#1) Block Order is submitted and Greek Bidding Zone is resolved in isolation (Simulation 5), the correlation between MCP and NL decreases significantly. More specifically, for a week in July 2022, ρ_{NL} for the base scenario was calculated to be 0.840, while for scenario 8, it decreased to 0.332 (weak correlation).

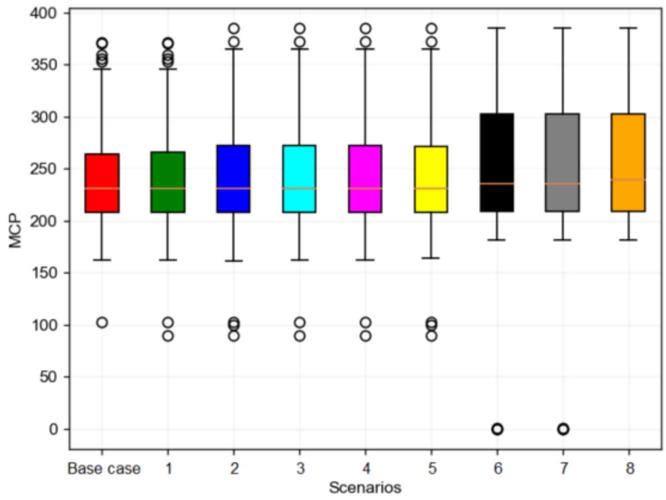

Figure 5 Market Clearing Price results for Simulation 4

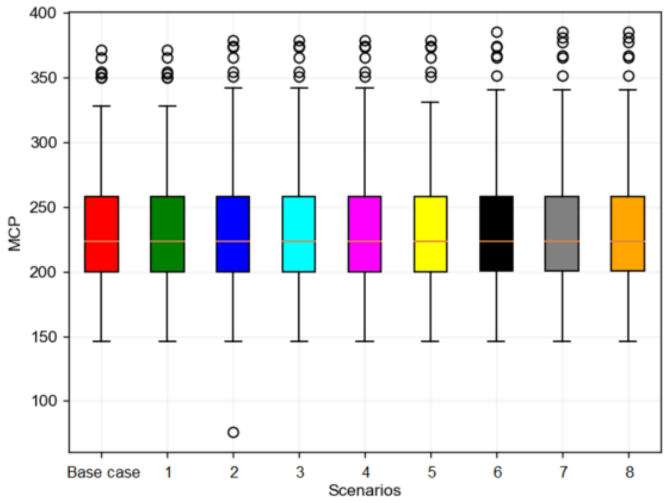

Figure 6 Market Clearing Price results for Simulation 1

5. Conclusions

This paper studied the effects of a potential change in the types of Block Orders available to the Greek DAM participants. The main conclusion of this study is that lifting the currently applicable restrictions should not have a considerable effect on the MCP formation.

First of all, the coupling of the Greek Bidding Zone enables the effective handling of any inconsistencies in the feasible space, which pose challenges to the mechanism determining the MCP due to the extensive use of Block Orders. This is the primary reason why the increase in Block Orders does not cause significant changes in the most critical metrics such as the average market clearing price, its standard deviation, and its correlation to the net load.

The duration of Block Orders is a crucial parameter, as long-duration Block Orders lead to a rapid increase of LCO.

From all the simulations conducted, it became clear that their maximum duration should be significantly shorter than 24 MTUs/Block Order. For instance, based on the results of Simulation 1, a maximum duration of around 11 MTUs could be considered without causing significant changes in market sizes.

Lastly, given the aforementioned two points, MAR plays a minor role in shaping MCP and LCO. Specifically, as can be easily observed, MAR $= 0\%$ minimizes LCO, while in the case of MAR $= 100\%$ the increase in LCO is less than 10%. Therefore, the absence of a limit on the MAR would not have a significant negative impact on the MCP and overall social welfare.

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