SDAC measures in cases of short supply

Curtailment management, Second auction, and Peak Load Capacity in SDAC

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1 Executive Summary

The main purpose of this paper is to disseminate and facilitate the understanding of price calculation processes in the Single Day-Ahead Coupling among stakeholders and the wider public.

Price calculation process is not necessarily able to satisfy supply and demand in all Market Time Units (MTUs) due to lack of offered resources (supply/demand) to the market. To avoid extreme prices, in this situation, there are different methodologies established in the relevant bidding zones (BZs). These methodologies are regulated nationally. In this document, the focus is on the high/maximum prices processes, however, some of the methodologies are also applicable in case of minimum prices.
In Single Day-Ahead Coupling (SDAC), we use three kinds of mitigation processes: 2nd auction, Peak Load Capacity, and curtailment management.

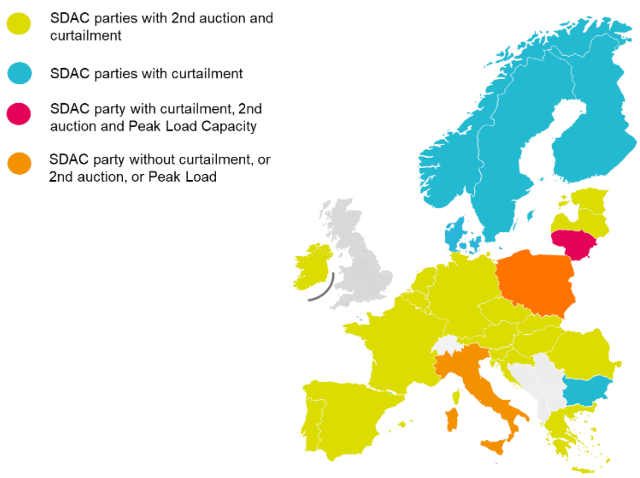
2nd auction is triggered when a threshold price is reached. This threshold is lower than the maximum price to improve supply or lower demand in the market and also help the market find a balance for a reasonable price. Currently, the price threshold limit is set to €2,400 in most countries where 2nd auction is applied. When triggered, NEMOs Order Books (OBKs) are (re-)opened, and market parties are able to update their orders, then a new SDAC calculation is run. In case the price is still above thresholds, the new calculated results are still valid.

In very few countries, TSOs have reserved capacity from the market that can be utilized when the maximum price is reached. This is called **Peak Load Capacity**. In this procedure, peak load capacity order is included in the calculation, and a new SDAC calculation is performed . In case the price is still above thresholds, the new calculated results are still valid. Currently, this mitigation procedure is used only in Lithuania.

If no mitigation actions are provided when maximum price is reached, if needed, **curtailment procedure could be applied** to reach equilibrium point of the order curves (which means that some price taking demand orders will be rejected). This is also applicable in cases where the mitigation actions (2nd auction or peak load reserves) are initially used.

In the EUPHEMIA [1] algorithm, curtailment management has several steps: curtailment minimization, curtailment sharing and curtailment mitigation. These are described in more detail in the next chapters. **Curtailment sharing is applied almost in all SDAC countries except in Poland and Italy, where curtailment is not applied due the nature of the order types (Merit orders) and Slovenia, where establishment of curtailment sharing is in progress.**

Mitigation methodologies' different steps are explained in this document. The curtailment management description is accompanied with several concrete examples. The last section of this document addresses the question of price limits in EUPHEMIA.



The map above shows regions/countries where the different mitigation processes are available.
Curtailment is used in all SDAC regions except Italy and Poland. Second auction is established in the green regions (Slovenia is in progress to take curtailment sharing available). Peak Load Capacity is only used in Lithuania. In Italy and in Poland no mitigation procedure is applied.

[1] EUPHEMIA is the algorithm that has been developed to enable Day-Ahead European Market Coupling. EUPHEMIA matches energy demand and supply for all the periods of a single day at once while taking into account the market and network constraints. Public description of EUPHEMIA is here.

2 Principles of 2nd Auction and Peak Load Capacity

2nd Auction is run in case price threshold is reached at least in one hour in one of the bidding zones (BZ) where 2nd auction can be applied. In this case all OBKs in those BZs are re-opened. Also other bidding zones can open their OBKs, but this is not mandatory. In case threshold is reached in one of BZs in the Core region, then all Core region OBKs are opened at least.

In case order curves have an intersection point at the maximum price in Lithuania bidding zone at least in one hour, then Peak Load capacity order is activated together with the re-opening of OBKs. Peak load capacity order is activated for all 24 hours with same volume and price. A new calculation is performed including peak load capacity order in Lithuania and modified OBKs from the BZs where a 2nd auction was performed.

3 Curtailment Management

When intersection points of curve orders are not met in a BZ, despite the mitigation actions utilized earlier, algorithm outputs maximum price and some price taking demand orders can be curtailed. Principle of curtailment in Euphemia is minimization. Which means curtailment volume is minimized and shared proportionally by all price taking orders in the curtailed BZ. As an outcome, in case of maximum price in a BZ, total curtailment volume is shared by affected market participants in that BZ on pro rata based.

Price taking orders (curve orders) are always prioritized over the non-curve orders (e.g block orders) in case of curtailment.

3.1 Definition of price taking orders

Price taking orders are orders defined at the maximum price of a bidding zone, their rules of acceptance are different from other hourly orders when the maximum price is reached, and depend on the corresponding curtailment policy of the bidding zone[2], characterized by the values of the parameters ShareCurtailment_Pmin and ShareCurtailment_Pmax:

- 0 (i.e. ”keep”): a price-taking order can only be curtailed (i.e. partially accepted) if the bidding zone itself is curtailed; it cannot be curtailed more than it would be if the bidding zone was isolated. (This option is only used by Italian bidding zones and Slovenia, including zones for explicit nominations)

- 1 (i.e. ”share”): when the bidding zone is in curtailment at maximum price, the supply orders on this bidding zone are shared with orders from other markets which are also in curtailment at maximum price and share their curtailment.

[2] Current curtailment policy in place in SDAC is a joint decision made by all NEMOs in the beginning of PCR based on extensive testing.

3.2 Curtailment Minimization

The first step aims at minimizing the curtailment of the price-taking limit orders, i.e. minimizing the rejected quantity of price-taking orders. More precisely, Euphemia enforces local matching of price-taking hourly orders with hourly orders from the opposite sense in the same bidding zone as a counterpart.

Hence, whenever curtailment of price-taking orders can be avoided locally on an hourly basis – i.e. the curves cross each other – then it is also avoided in the final results. This can be interpreted as an additional constraint setting a lower bound on the accepted price-taking quantity and is referred to as the LOCAL_MATCHING constraint. It is active in the master problem, i.e. prior to the price- and volume- coupling problems, but as an additional constraint to the welfare maximization problem.

3.3 Curtailment Sharing and Mitigation

In case several BZs are needed to be curtailed at the same market time unit, then (if chosen) curtailment sharing is applied in order to equalize the curtailment ratios between BZs that are to be curtailed. To allow curtailment sharing function to operate, BZs need to be configured to allow curtailment sharing. If curtailment sharing is not allowed, then curtailment is done on BZ in the welfare maximizing function. This means that BZ will not get any support from the other BZ to lower their curtailment ratio, where curtailment sharing is allowed. When curtailment sharing is allowed, then curtailment sharing is attached to the volume problem step together with welfare maximization.

For ATC lines, curtailment sharing and solving curtailment in the volume problem is feasible as in the ATC network welfare maximization forces flow always from the non-curtailed BZ to the curtailed BZ. However, this is not necessarily applicable in the Flow-based (FB) network. In the FB network, flow between BZs depends on how to maximize the capacity use in the FB network in order to maximize welfare and this can lead to the situation that one BZ in the FB region is curtailed. This is called "flow factor competition" and is prevented by adding a penalty term to the welfare optimization function. When the penalty factor is large enough, it will minimize non-accepted price taking quantity in all markets over the welfare and try to harmonize curtailment ratios across the curtailed markets.

Curtailment sharing is allowed in all BZs where curve orders available, in the areas where merit orders are used, curtailment sharing is not used as curtailment cannot be performed in the similar way as with linear curves orders.

3.3.1 Details of the curtailment sharing

When parameter for local matching constraint is set to zero (ShareCurtailment_Pxxx=0), i.e. not to share curtailment, the accepted volume of supply bids must at least be equal to the minimum of the price-taking volume and the total matching quantity available within a bidding zone (i.e. supply for demand). In case markets share their curtailment (ShareCurtailment_Pxxx=1), then local matching is not enforced for them.

In the local matching, $LocalVolume$, is the largest quantity of hourly supply at maximum price that can be matched locally at that period. In other words, it's the minimum of the supply of hourly orders at maximum price at period t in bidding zone m and the total hourly demand in bidding zone m and period t.

Relying solely on the local matching constraint is not sufficient to fully satisfy the requirements of Euphemia regarding the acceptance of price-taking orders. The additional curtailment rules are treated as a post processing of the solution, in two separate indeterminacy problems:

- Curtailment minimization: minimization of the curtailment for all curtailed markets.
- Curtailment sharing: harmonization of the curtailment ratios to the extent possible (according to the network constraints), for all the bidding zones willing to share their curtailment.

These two problems are solved if there is at least one market in curtailment for at least one period (i.e. the market price the maximum allowed price).

When sharing curtailment, it could happen that price-taking orders are not fully matched even though there exist some quantity locally that can be matched, because this quantity is already used to match price-taking orders in another market. The objective function will then ensure the same curtailment ratios for all markets with curtailment sharing (homogenized).

The modelling of network constraints (ATC or FB) has no impact on the specification of the curtailment sharing sub-problem, it is only defined by the curtailment policy of the bidding zones.

Sharing or non-sharing does not impact the total sum of social welfare with an ATC network model, but it can impact the distribution of accepted volumes among bidding zones.

The reason is that Euphemia algorithm first maximizes social welfare. Once the optimal value of the social welfare objective has been found, as well as the corresponding prices for each market, only indeterminacies on the volumes matched in each of the markets can remain (several volumes can match the prices obtained when the price cap are reached). Euphemia then solves those indeterminacies through several sub-problems (including curtailment sharing if needed).

3.3.2 Details of curtailment mitigation

However, if the network constraint model is flow based, curtailment sharing may impact the calculated social welfare. The objective function of the master problem is to maximize welfare. For an ATC line this results in a situation where zones that are not in curtailment will export to zones that are in curtailment. However, under flow based this is not necessarily the case: if an exchange from zone A to zone B results in a higher usage of the capacity compared to an exchange A to C it is possible that is more beneficial to exchange from A to C, whereas market B is in curtailment. This is referred to as “flow factor competition”.

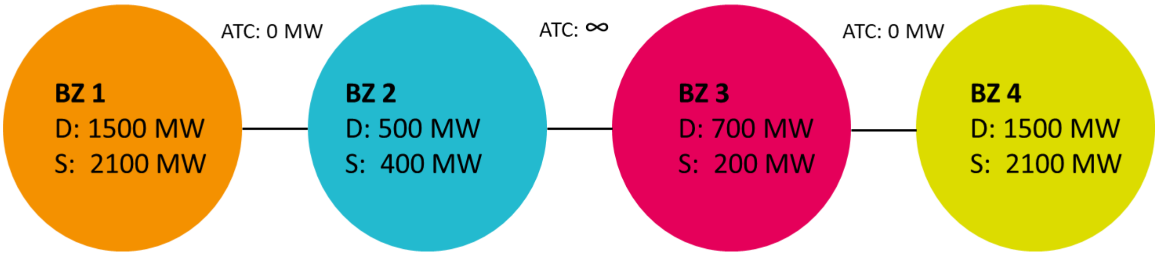
In order to prevent such cases on demand side (effectively treating curtailment outside of the welfare maximizing framework), the objective function (social welfare) can be penalized by a curtailment mitigation term (or penalty function) to enhance the algorithm’s handling of curtailment cases in flow based. The reason is that under flow based method, because of flow factor competition, it can occur that curtailed markets are not treated equally by the network. For example, when two curtailed markets are importing from a third one, the value of the PTDF coefficients can be such that one of the importing markets is preferred more and the flow to that market is maximized while the other market will be ignored and cannot have its curtailment mitigated in any way. The curtailment sharing therefore solves a dedicated volume problem, where all network constraints are enforced, but only the acceptance of the price-taking volume is considered in the objective function

4 Other constraints

Network constraints (ramping), losses, and external constraints are taken care of in the social welfare maximization problem. Curtailment management step is after that Euphemia has calculated the prices and net positions in such a way that social welfare is maximized while all these constraints are respected. Curtailment handling mechanism (sharing or local matching) solves volume indeterminacy withing the solution found in the first step.

5 Example cases

Curtailment sharing is illustrated with the simplified Cases 1 to 4 in the ATC network. In cases 1 to 3 with the assumed ATCs, in bidding zones 2 and 3 have a deficit of 50 %. In case 4 bidding zones 2 and 3 have a deficit 25%. Focus is on the situation with a deficit and a price at the maximum price limit.



Case 1, ATC1-2=0, ATC3-4=0

In this case, the deficit in BZ2 and BZ3 must be distributed between them.

ShareCurtailment_Pmax=0
Without sharing, each supplies its own demand. Curtailment in BZ2 equals 100/500 = 20.0% and in BZ3 500/700 = 71.4%.

ShareCurtailment_Pmax=1
With sharing, the curtailment shares are equalized to (in this case) 50%. This is obtained when cleared supply in BZ2 is 250 and in BZ3 350. There will be a flow of 150 from BZ2 to BZ3 of 150 MW.

The results are illustrated in the table below.

ATC 1-2=0, ATC 3-4=0
No sharing

Line	Flow
1->2	0
2->3	0
3->4	0

Zone	Price	Net Position
1	50	0
2	3000	0
3	3000	0
4	50	0

ATC 1-2=0, ATC 3-4=0
Sharing

Line	Flow
1->2	0
2->3	150
3->4	0

Zone	Price	Net Position
1	-500	0
2	3000	150
3	3000	-150
4	-500	0

Case 2, ATC1-2=300, ATC3-4=0

The reason for this example is to show how an asymmetry between BZ2 and BZ3 (one has imports, the other not) affects the result.

ShareCurtailment_Pmax=0
Zone 2: Matched demand=400, Total demand (at max price) = 500, curtailment ratio = 1 – (400/500) = 0.2
Zone 3: Matched demand=500, Total demand (at max price) = 700, curtailment ratio = 1 – (500/700) = 0.285714.

Without sharing, BZ 2 fully uses the import from its neighbour zone BZ 1, before exporting the surplus to BZ 3.

ShareCurtailment_Pmax=1
BZ 2: Matched demand=375, Total demand (at max price) = 500, curtailment ratio = 1 – (375/500) = 0.25
BZ 3: Matched demand=525, Total demand (at max price) = 700, curtailment ratio = 1 – (525/700) = 0.25
With sharing, the curtailment shares are equalized. This is obtained with a flow of 325 from BZ 2 to BZ 3.

In order to explain the flow of 300 MW, in case there is no curtailment sharing, from BZ 2 to BZ 3 one needs to keep in mind that:

- There is 400MW of supply in BZ 2, so Euphemia imposes local matching (both in the primal problem as well as the curtailment minimization problem):
  - Matched demand BZ 2 >= 400;
- In the curtailment minimization step, Euphemia allocates all the imports from 1 directly to BZ 3, since the curtailment in BZ 3 is worse than the BZ 2 one, as evidenced by the final outcome where BZ 2 has 20% curtailment, and BZ 3 28.6%. The LOCAL_MATCHING constraint is binding for BZ 2. But this constraint does not include any consideration for the imports from BZ 1. There is no rule that all imports into BZ 2 belong to BZ 2 and shall not be transferred.

ATC 1-2=300, ATC 3-4=0
No sharing

Line	Flow
1->2	300
2->3	300
3->4	0

Zone	Price	Net Position
1	50	300
2	3000	0
3	3000	-300
4	50	0

ATC 1-2=300, ATC 3-4=0
Sharing

Line	Flow
1->2	300
2->3	325
3->4	0

Zone	Price	Net Position
1	-500	300
2	3000	25
3	3000	-325
4	-500	0

Case 3, ATC1-2=0, ATC3-4=300

This example is similar to the previous one, but now BZ3 receives additional imports instead of BZ2.

ShareCurtailment_Pmax=0

Without sharing, BZ 3 fully uses the import from its neighbour zone BZ 4, before exporting the surplus to BZ 4. As these imports are insufficient to fully cover demand in BZ 3, there is no export to BZ 2. Curtailment in BZ 2 is 100/500 = 20% and in BZ 3 200/700 = 28.5%.

ShareCurtailment_Pmax=1

With sharing, the curtailment shares are equalized to 300/1200 = 25% as in Case 2. This is obtained with a flow of 25 from BZ 2 to BZ 3.

ATC 1-2=0, ATC 3-4=300
No sharing

Line	Flow
1->2	0
2->3	0
3->4	300

Zone	Price	Net Position
1	50	0
2	3000	0
3	3000	-300
4	50	300

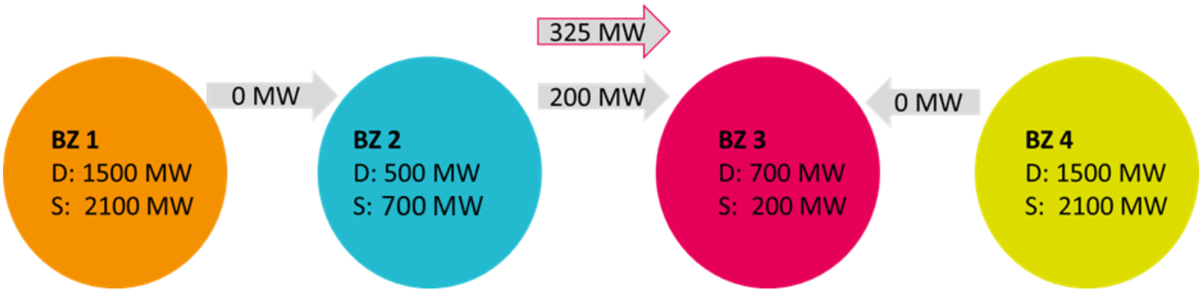
ATC 1-2=0, ATC 3-4=300
Sharing

Line	Flow
1->2	0
2->3	25
3->4	300

Zone	Price	Net Position
1	-500	0
2	3000	25
3	3000	-325
4	-500	300

Case 4, ATC1-2=0, ATC3-4=0 , ATC2-3=325

In this example there is surplus on BZ2 and deficit on BZ3, if areas are isolated.



ShareCurtailment_Pmax=0

Without sharing, BZ 2 will utilise supply in order to fulfil demand, no curtailment seen on BZ 2. BZ3 import remaining surplus from BZ2, but as the import is insufficient to fully cover demand in BZ 3, curtailment in BZ 3 is 400/700 = 42,9% %. This is obtained with a flow of 200 from BZ 2 to BZ 3.

ShareCurtailment_Pmax=1

BZ 2: Matched demand=375, Total demand (at max price) = 500, curtailment ratio = 1 – (375/500) = 0.25

BZ 3: Matched demand=525, Total demand (at max price) = 700, curtailment ratio = 1 – (525/700) = 0.25

With sharing, the curtailment shares are equalized. This is obtained with a flow of 325 from BZ 2 to BZ 3.

The results are illustrated in the table below.

ATC 1-2=0, ATC 3-4=0

No sharing

Line	Flow
1->2	0
2->3	200
3->4	0

Zone	Price	Net Position
1	50	0
2	3000	200
3	3000	-200
4	50	0

ATC 1-2=0, ATC 3-4=0

Sharing

Line	Flow
1->2	0
2->3	325
3->4	0

Zone	Price	Net Position
1	-500	0
2	3000	325
3	3000	-325
4	-500	0

Regarding the last part of the question, when one BZ is sharing but the other not, the result would be the following:

- If the surplus zone is sharing, the result is like sharing
- If the surplus zone is not sharing, the result is like no sharing

In this context, imports are treated as part of the local supply. Consequently, the result depends on the setting of ShareCurtailment_Pmax for the surplus zone.

6 Removal of Euphemia's Price Limits

There has been a question on the possibility to remove price limits from Euphemia and if not, are limits needed to get algorithm functioning. Below is an explanation where price limits are used in Euphemia and possibility to remove those. Explanation focuses only on the Euphemia's point of view, which means that there may exist reasons outside of Euphemia that may justify setting max (and min) prices.

There are reasons for Euphemia to impose price limits. Not having price limits would have consequences where properties that hold true under today's market design would no longer hold (see second bullet on price clipping). It will require further assessment to consider if these consequences are acceptable, or if further mitigations need to be sought:

- Euphemia will need a technical limit on the maximum price: if we allow demand orders at any price, and they would be offered for high prices, as an example . millions of euros per MWh, this would increase the total economic surplus 1,000 fold in this example case.. Since Euphemia uses a solver that does calculations with limited precision, the increase in economic surplus and keeping the relative precision of solutions the same to what we have today implies results would be 1,000 times less accurate.
    - Of course, the example above is an extreme, and likely the VoLL is less than millions of euros per MWh;
    - Since in today's design we do have max prices, we lack the experience to make conclusive statements on the effects. In the past there have been conducted some tests using max prices of 10,000 €/MWh, and Euphemia still managed those sessions. Those tests were done some years ago using historical (i.e. 60' MTU) order books. I.e. further assessment would be advisable before changes are introduced;
    - The consequences of lost precision could be:
        - Downstream rejection of results if expected precision is not met. This could ultimately result in decoupling;
        - Alternatively, mitigations are sought to deal with the reduced precision. More work would be required what could be done. It may include options that would impose further constraints on market participants E.g., increase the tick size of prices + volumes they enter. Continuing the example where precision loses three orders of magnitude, this could imply entering orders not in 1ct increments, but rather in 10 euro increments.
        - Clearly follow up work would be needed to quantify the expected loss of precision, and corresponding mitigations needed to combat this.
- Max/Min prices are also used to clip prices, as they are not necessarily defined by the highest buy or lowest sell order prices).
    - *Example 1*:
        - Assume the existing market design with uniform prices.
        - Consider a single market example with two hours:
        - Hour 1:
            - Sell: 100MWh@0€/MWh;
        - Hour 2:
            - Sell: 10,000MWh@0€/MWh;
        - A single fully curtailable block that covers both hours: buy 10,000MWh@4000€/MWh
        - The economic surplus maximizing solution is to activate both sell orders to meet as much of the demand from the block order. The block shall have equal volume in both hours. Since in hour 1 only 100MWh is available, also hour 2 will match 100MWh for the demand block. The price in hour 2 is set by the (marginal) sell order @0, i.e. $mcp_2 = 0$. Similarly, the marginal block order sets the average price to 4000, implying $mcp_1 = 8000$ (and $(mcp_1 + mcp_2) / 2 = 4000$).
        - I.e. the price in hour 1 is 8000, which is not the marginal price of any order.
        - Euphemia today would have clipped the price of hour 1 to 4000, and then concluded the block should not be accepted. This would have resulted in less economic surplus, but hourly prices consistent with the 4000 EUR max price
    - *Example 2a*

    - I In flow-based regions, there is competing access to remaining available margin (RAM) of PTDF constraints covering several bidding zones and called "flow-factor competition". Ultimately, an optimal equilibrium is found between the BZ imports/exports and the welfare generated within these areas. In some extreme situations, (min/)max prices allow to maintain a balance between BZs willing to import a few MWh consuming a large part of the RAM but for high incentive (=covering orders at very high prices) and BZs having less impact on RAM but generating fewer welfare. Removing a max price in this case would favour the former at the expense of the other involved BZs.;
    - In turn optimality conditions then impact prices and therefore markets may still clear above the price of the highest bid.
  - *Example 2b*
    - To mitigate some of the effects flow factor competition can have on aggravating curtailment situations, Euphemia implements a curtailment mitigation mechanism where the non-acceptance of PTOs is penalized in the objective function (see https://www.jao.eu/sites/default/files/2020-04/Annex%2016_20%20Adequacy%20Mitigation.pdf where this mechanism is called “adequacy mitigation”).
    - Since this mechanism singles out the PTOs to apply the correction, if we let go of min and max prices, this mitigation would no longer be available either.

Consequences

The above examples illustrate hourly (or MTU) prices still will not be set by bid prices, and that existing mitigation measures to exempt certain exchanges from flow factor competition no longer apply. This is a departure from the existing market design, and we would need to assess which of the designs has more desirable properties. In case properties from the existing design are deemed more desirable, a next step could be to look for mitigations that could “patch” those shortcomings.

7 Annex

7.1 Glossary

In the following text a series of concepts and acronyms are being used. This section contains a reference to all of them.

ATC	Available Transfer Capacity
BZ	Bidding Zone
FB	Flow Based
HMMCP	Harmonised Maximum and Minimum Clearing Price
MTU	Market Time Unit
NEMO	Nominated Electricity Market Operator
OBK	Order Book
PTDF	Power Transfer Distribution Factor
PTO	Price Taking Order
RAM	Remaining Available Margin
SDAC	Single Day-Ahead Coupling
TSO	Transmission System Operator
VoLL	Value of Lost Load