N-SIDE

WEBINAR

How do modern power market auctions work?

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With the current situation on the electricity markets like the Day-Ahead market, the need to understand how the prices are determined has never been as important. Getting a better understanding of it is critical for any energy professional.

As a provider of auction algorithms for multiple Power Exchanges and System Operators worldwide, N-SIDE has decided to open the box and to explain how power market auctions work.
In this second webinar of the trilogie, we have built on what was covered in the first episode and go more into practice: what are the inputs & outputs of a market clearing algorithm, such as the one used for the Single Day-Ahead Coupling of electricity markets in Europe?[1] How are electricity prices and volumes computed in practice? What are the main challenges in computing prices? How do we overcome them?

POLL #1

When did market coupling between France, Belgium, Netherlands, Germany, Luxembourg, and Austria (the so-called CWE region) go-live?

2006	**2010**	**2014**	2015

Answer: The correct answer is 2010. That year, the Day-ahead market in the CWE region (Central-Western Europe) became coupled using the COSMOS algorithm already developed by N-SIDE. In 2014, the CWE region became part of MRC (Multi-Regional Coupling), covering much of the European market, using the EUPHEMIA algorithm which was also developed by N-SIDE. In the same year, 4MMC (CZ-SK-HU-RO) became coupled using EUPHEMIA as well.

POLL #2

What was the average daily number of orders given to EUPHEMIA in 2021, after aggregating curves?

around 50.000	around 100.000	**around 250.000**	around 1.000.000

[1] The EUPHEMIA algorithm is the property of the Power Exchanges in the Price Coupling of Regions (PCR) project.

Answer: The average number is around 250.000 orders. This number considers aggregated bid/stepwise curves, which means that multiple hourly orders with matching bidding area, period, and price are represented by a single order. Such aggregation can reduce the number of orders significantly without changing the problem for the algorithm. As the time resolution in the Day-ahead market is set to change from 60 minutes to 15 minutes in 2025, the number of orders will also change. A 4-fold increase in time periods indicates that the number of orders will also change by a factor of 4. Hence, the average number of orders will be around 1,000,000 in 2025.

POLL #3 What is the maximum value of items fitting into the knapsack?

Item	Weight [kg]	Value [EUR]
a	1	5
b	2	4
c	7	10
d	10	12
e	13	15

Knapsack
Weight limit: 15 kg

20€ **21€** 22€ 23€

Answer: The correct answer is EUR 21, which can be achieved by selecting items a, b, and d. The total weight of these items is 1 kg + 2 kg + 10 kg = 13 kg, which respects the weight limit. The value is 5 € + 4 € + 12 € = 21 €.

No other combination of items respects the weight limit and has a larger value. Note that the problem is hard because no fractional items can be selected; otherwise, we could simply order items by €/kg for selecting them. Binary decisions as in the Knapsack problem are also a source of complexity in EUPHEMIA.

Three key takeaways

1 A modern market clearing algorithm can manage advanced order types and power grid constraints

Taking EUPHEMIA as an example, we discussed a few examples of advanced orders and network aspects considered by the algorithm to compute essential outputs. More precisely:

Inputs include:

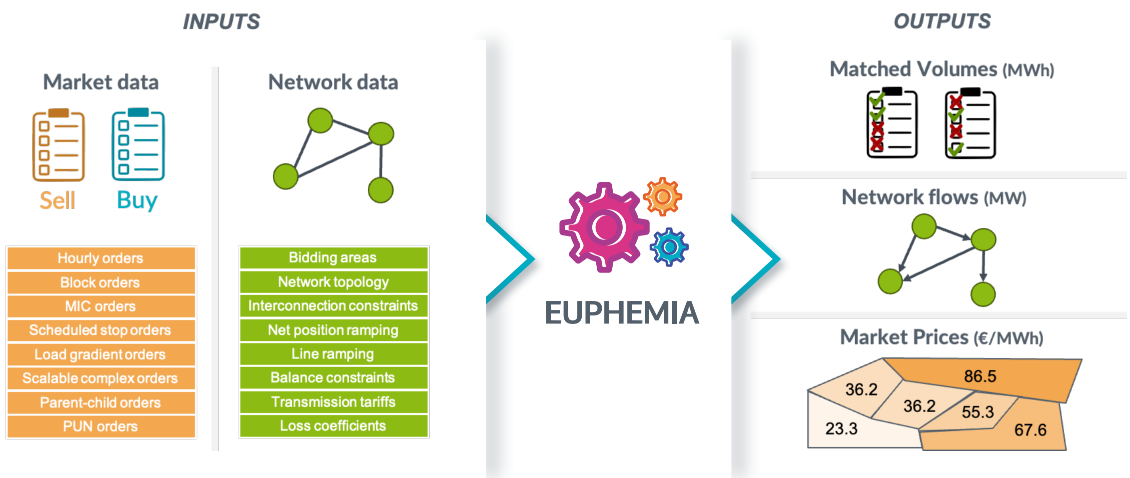
- complex orders allowing advanced trading strategies allowing asset owners to reveal some of their internal constraints
- an advanced network modelization including line limits, network effects, losses and other key information shared by system operators

Outputs include:

- Volume acceptance per order [MWh]
- Commercial network flows [MW]
- Market price per bidding zone [€/MWh]

Want to know more about network modelization? Have a look at this blog post addressing this topic in details.

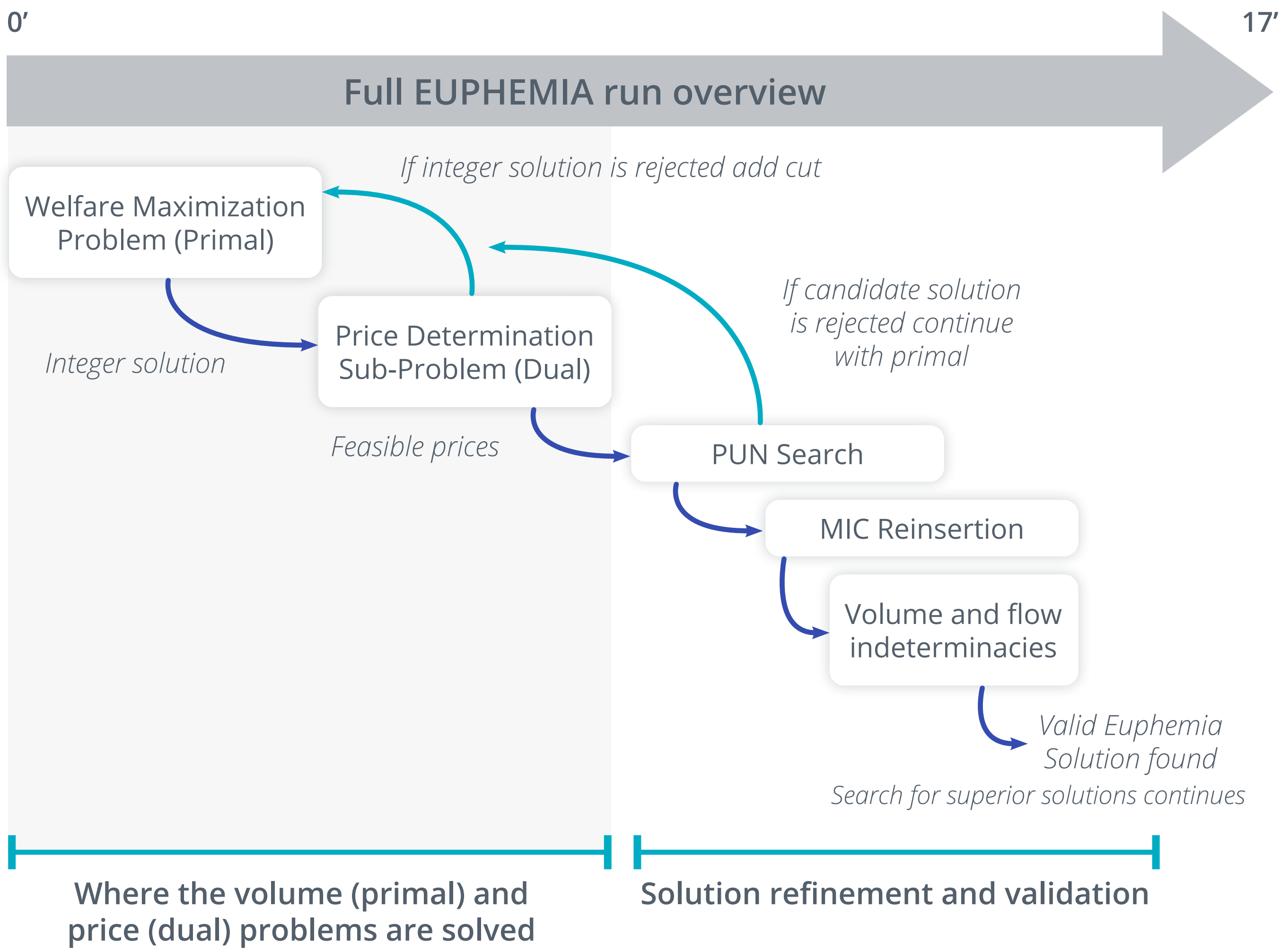
Taking EUPHEMIA in Europe as an example



2 In a modern market clearing algorithm, several optimization problems have to be solved in order to obtain the final outputs

The algorithm behind EUPHEMIA does not solve only one optimization problem, but several ones for different purposes:

- The primal problem provides the order acceptance ratios
- The related dual problem - reveals adequate prices for the same order acceptance ratios
- Then, many subproblems come into action to form a highly iterative process validating and refining the solution.

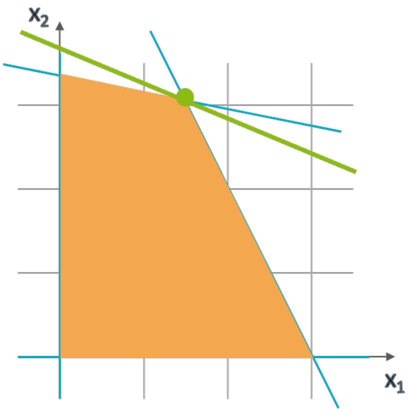


3 Computing market results is an algorithmic challenge on multiple dimensions

Clearing electricity markets can cause diverse challenges that can be mitigated with the right algorithm design:

- Complex order types such as block orders require the usage of binary decision variables. That is why EUPHEMIA is building on the branch-and-bound method often used for Mixed-Integer Linear Programs (MILP). EUPHEMIA also requires specific cuts, heuristics, and other advanced algorithmic approaches. (Cuts are constraints that can tighten the problem formulation or reject invalid solutions. Heuristics can be incorporated into the branch-and-bound method and help with finding new integer-feasible solutions.)
- When solving mathematical problems numerically, computers work with limited precision. This leads to small errors in the results which can cause numerical challenges in later subproblems of the algorithm. Such challenges can be overcome by the right mathematical model, algorithmic approach, and solver configuration.
- EUPHEMIA has only 17 minutes to find the final solution. Thanks to the tree-structure in the EUPHEMIA search, the workload can be shared by multiple machine cores or be distributed over multiple machines.

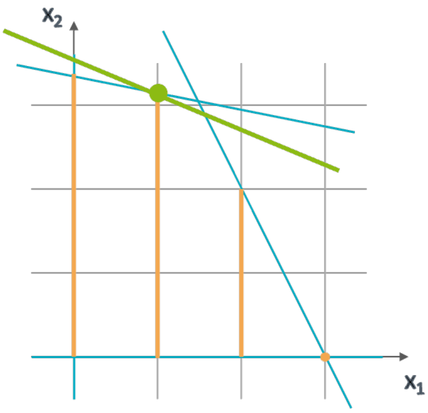
Algorithms used in market clearing



Linear Program (LP)
Constraints and Objective linear
$x_1, x_2 \geq 0$
⇒ feasible area is convex

Market clearing problems without complex order types requiring binary variables. All orders can be curtailed.

Use e.g. simplex or barrier algorithms

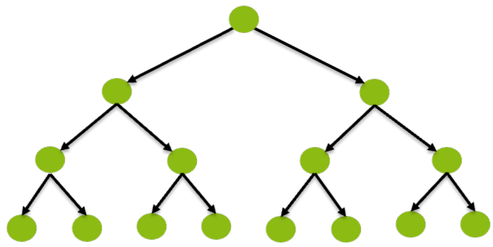


Mixed Integer Linear Program (MILP)
$x_1 \in \{0, 1, 2, 3, 4, \ldots\}$
$x_2 \geq 0$
⇒ feasible area is not convex

Market clearing problems with complex order types requiring binary variables (e.g., for block order acceptances).

Use e.g. branch and bound algorithm

Note: Euphemia's objective is in general quadratic due to interpolated orders.



Branch and Bound algorithm

Fundamental building block of Euphemia:

- Search for optimal solution uses a tree structure (can be used in parallelization).
- The root of the tree is a relaxation where all binary variables can take continuous values.
- Branching on binary variables if variables take fractional values.

Five questions answered by our experts

What is a level of details for the transmission network modelling in EUPHEMIA?

EUPHEMIA relies on a zonal network model: the network model consists only of restrictions on the cross-zonal flows and zonal net positions (which in practice can be used to restrict flows on intra-zonal network elements).

Is flow-based much more complicated in terms of complexity of the whole problem and needs much more calculation time in comparison to ATC?

Flow-based network models are more complex in terms of numbers of constraints. However, given the expressiveness of the PTDF model it is possible to allow certain flows which would have to be omitted in an ATC model. This extension of the region of feasible flows can lead to an increase in welfare.

How many constraints are there in EUPHEMIA?

Market clearing solutions developed by N-SIDE can handle hundreds of thousands to millions of variables and constraints. Given the size of the Day-ahead market today with around 250.000 orders as input (already aggregated orders) and the expected growth in the coming years it is key to rely on solutions that can handle this magnitude of variables and constraints.

Would you recommend a new power exchange to propose advanced orders such as block orders to its participants, considering all the challenges you have mentioned?

Block orders are a crucial element in energy markets as they help market participants to express their technical constraints in the auction.

Nevertheless, it is true that like other complex order types, they are modelled with binary variables making the energy market a combinatorial problem, which is more complex to solve.

The good news is that an advanced market clearing algorithm such as EUPHEMIA allows the presence of these advanced orders to benefit all actors, while limiting their computational challenges thanks to advanced mathematical methods.

Does EUPHEMIA have any market power monitoring/mitigation?

Power Markets are actively monitored in Europe, mainly by national regulators and ACER through the market monitoring and REMIT teams. You can find more info about how they work on ACER website

Focusing on EUPHEMIA, the biggest market power mitigation feature is the zonal pricing design, ensuring higher liquidity and competition within each bidding zone.

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