***ANALYZING THE EFFECTS OF EUROPEAN CO-OPTIMIZED DAY-AHEAD ENERGY AND RESERVE MARKET COUPLING***

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## Overview

Since the liberalization of the European electricity market beginning in the mid-90s, several products have been traded for different purposes in sequential markets, including energy and reserves from the day-ahead to several months ahead. In addition, the electricity market has been moving towards higher levels of regional integration. The Price Coupling of Regions–which now includes 23 countries–has pushed this goal to the forefront through the use of a single market coupling algorithm called EUPHEMIA for day-ahead energy markets.

In order to guarantee security of supply, Transmission System Operators (TSOs) purchase reserve capacities that can be activated in real-time to match supply and demand, a crucial requirement for maintaining a steady frequency and stable supply to the electricity consumers. Some of these reserves may be pooled between countries to decrease the total reserved capacity as has been done with Frequency Containment Reserves. Initiatives like TERRE or MARI aim at further integrating real-time balancing products. The cross-border integration of the procurement of these reserves is likely to augment the liquidity in these markets and improve the overall social welfare.

Traditional markets occur sequentially. While the specifities vary largely by region, in Europe, reserve products are generally tendered in advance. In these traditional sequential market designs, a market player must decide to offer its installed capacity on either the reserve market or the energy market. Since the player must decide prior to any knowledge of the market clearing price, this leads to the potential for a lost opportunity cost for that market player and a potential scarcity in one of the two markets. This can be remedied through a simultaneous co-optimized market coupling of energy and reserve products.

In this study, a co-optimized market design, that couples both energy and reserves on the day-ahead and taking into account cross-border exchanges, was developed. A formulation of hybrid energy/reserve bids is presented as well as a new coupling algorithm optimizing simultaneously energy and reserves with explicit offers. Then, this work is applied to the region Central Western Europe (CWE) to compare the proposed co-optimized market clearing to usual sequential markets: clearing energy first or clearing reserves first. This study shows an increase in social welfare with the proposed co-optimization approach.

## Methods

A formulation of hybrid bids coupling energy and reserve offers is proposed. While allowing market players to model the technical specificities of each equipment, the proposed bid formulation allows the coupling algorithm to optimize the amount of energy and reserve for each offer.

A mixed integer linear program similar to EUPHEMIA was developed, incorporating both energy and reserve offers. The algorithm was implemented in PROMETHEUS, a platform developed by RTE to simulate market design models. Quantities and prices are determined in a two-step primal-dual optimization.

Energy market bids were generated through portfolio optimization based on different price scenarios, renewable energy generation and load forecasts. Using these offers as a foundation, hybrid energy/reserve offers were then created, taking into account the technical parameters of each equipment. TSO reserve requirements were calculated from risks associated with different production plans and load forecasts. For this study, specifically manual frequency restoration reserve (mFRR) offers were generated for upward and downward needs.

The proposed methodology allows to optimally set the amount of energy and reserve for each market player thus increasing the social welfare and avoiding unnecessary scarcity of one of these two products. Simulation work is presented to highlight the optimality of the co-optimization solution.

## Results

Simulations were carried out on stylized European countries in the Central Western European (CWE) region, on a winter month: Belgium, France, Germany/Austria and the Netherlands. Time granularity was set to 30 minutes and the model was run over several periods, using load and generation data from 2017. The flow-based method was used for grid constraints. The simulations compare the liquidity and social welfare obtained with sequential markets clearing energy before reserves, sequential markets clearing reserves before energy, and the simultaneous market clearing co-optimizing energy and reserve.

Simulations show an increase in social welfare in the co-optimized case. The results also show that in sequential markets, clearing energy first risks a scarcity of offers in the following reserve market that could be avoided with the co-optimization method. On the other hand, clearing reserves first risks a lost opportunity cost for the market players that is completely eliminated in the co-optimized market clearing.

As a result, in the co-optimized market clearing, market players are incentivized to offer their full reserve capacities. Additionally, in sequential markets, market players are likely to add a price premium to reduce the risk of the lost opportunity cost, which again, is avoided in co-optimized markets. Other effects on prices and flows arising from the co-optimization are put forward as well.

## Conclusions

Co-optimization represents the optimal solution with respect to social welfare and liquidity. Given the potential computational cost of the implementation of a co-optimized energy and reserve market clearing, there is a need to quantify the potential benefits. This study shows that co-optimization represents the ideal solution.

Considering foreseen electrical system evolutions such as the increasing share of renewable energies, the need of co-optimized energy and reserve market clearing is likely to grow as the unpredictability of the markets and the need for reserve will increase. Thus, additional studies will be performed using future scenarios as defined in RTE’s Bilan Prévisionnel to further analyze the effects of co-optimization given different energy mixes.

## References

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