Impact from Different Reserve Allocation Strategies in Hydropower Systems

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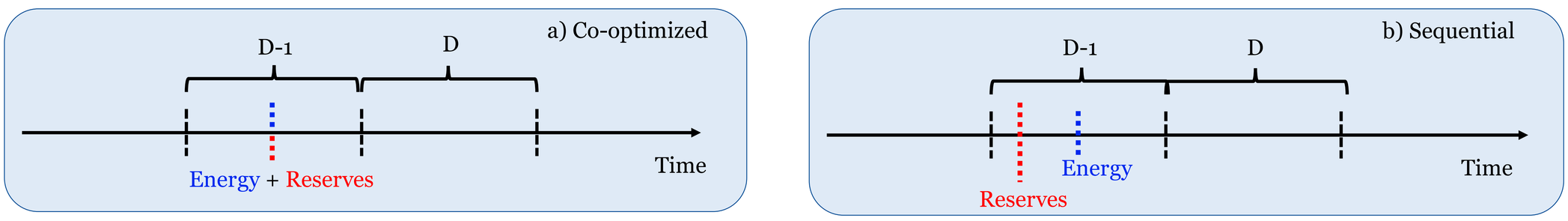
1 Introduction

- Power systems are evolving with the increasing integration of variable renewable energy sources (VRES), such as wind and solar. As a result, balancing reserves are becoming more important for maintaining the continuous balance between supply and demand.
- Balancing reserves and energy are inherently linked, as they are typically provided by the same generation resources. Their joint use of limited generation capacity, shared operating costs, and transmission constraints underscores the need for coordinated planning between energy and reserve allocation.
- In this work, we investigate the implications of different reserve allocation strategies in a highly renewable energy system. Using a deterministic model that integrates hydropower, wind, and demand, we aim to compare sequential and co-optimized energy and reserve procurements in the day-ahead market stage.

Day-Ahead Market



A simplified representation of a) co-optimized and b) sequential procurement of energy and reserves in the day-ahead market stage. The procurement structure then influence how generation resources allocate capacity between energy and reserves.

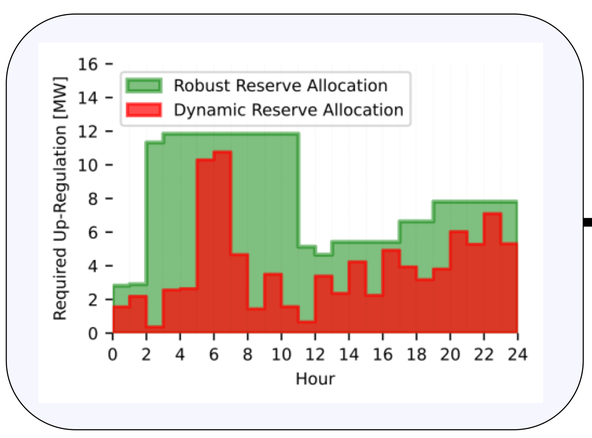
2 Modeling Framework

- We model a hydropower-dominated system using an optimization problem that determines the optimal hourly dispatch of hydropower units.
- The reserve requirements are estimated beforehand using either a robust or dynamic approach and are provided as fixed input to the model, alongside reservoir inflows and demand.

Reserve Allocation Strategies

a) Dynamic allocation: Sets hourly reserves based on expected operating conditions.
b) Robust allocation: Uses a rolling window and assigns the maximum observed need within it, with an added buffer for uncertainty.

These allocation strategies reflect the two different procurement structures.



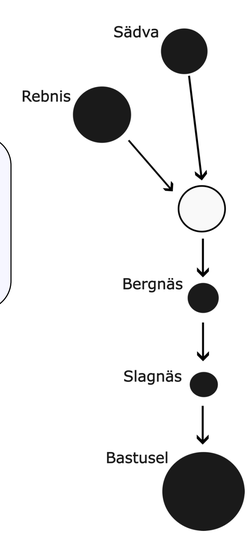
Optimization Problem (OP)

$$\max \sum_{i \in I} (\text{Value of stored water}_{i,T} - \text{Penalty for abrupt discharge shifts}_i)$$

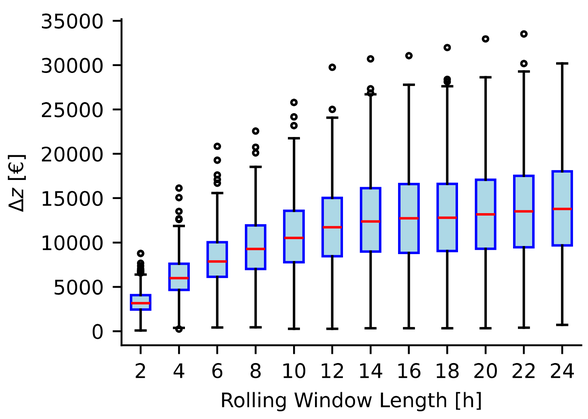
s.t.

- **Hydrological balance:** $M_{i,t} = M_{i,t-1} + V_{i,t} - Q_{i,t} - S_{i,t} + \sum_{k \in A_i^Q} Q_{k,t} + \sum_{k \in A_i^S} S_{k,t}$
- **Operational and regulatory constraints:** limits on discharge, spillage, and reservoir content
- **Unit commitment:** binary $u_{i,t}$ with production and reserve bounds
- **Reserve requirements:** hydro + wind must satisfy up/down requirements
- **Energy balance:** hydro production meets residual demand

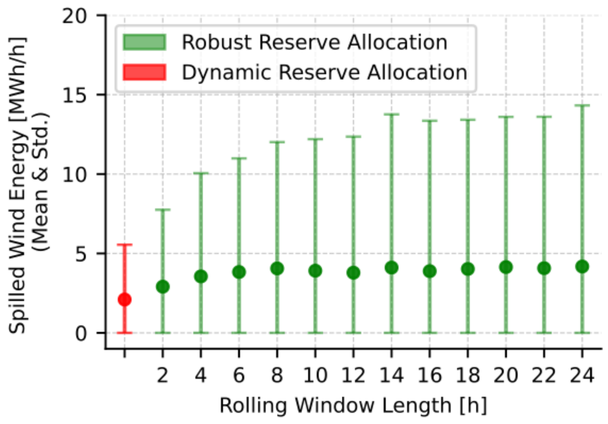
Optimal Discharge Plan



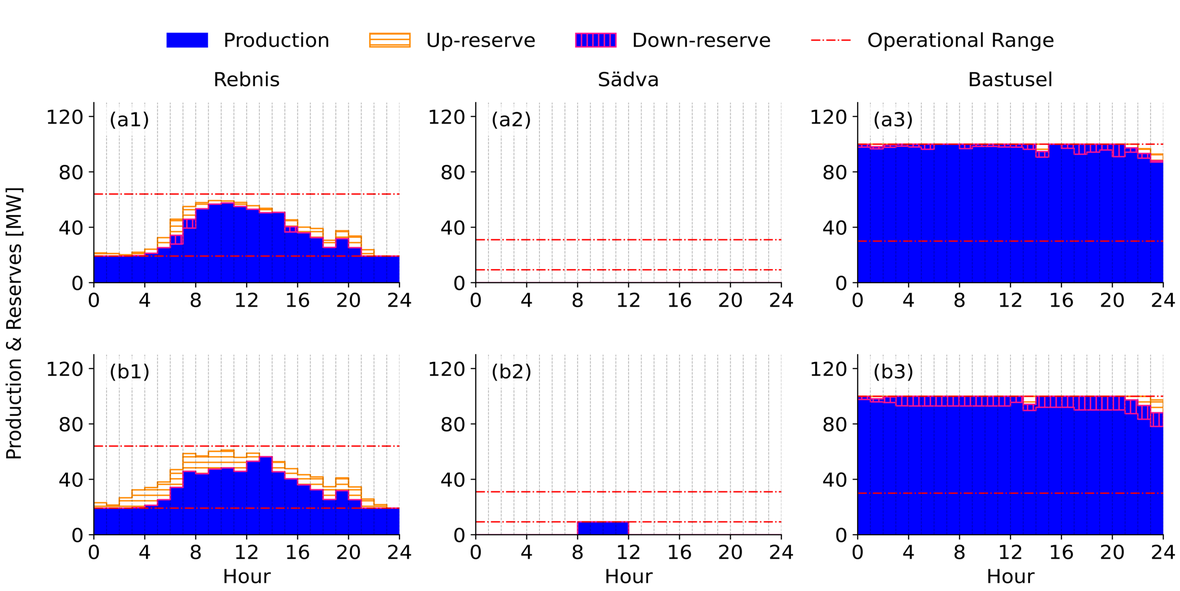
3 Results



Left: Difference in optimal objective value $\Delta z = z_{dyn} - z_{rob}$ increases with rolling window length, reflecting the growing conservatism of the robust strategy.



Right: Spilled wind energy under robust and dynamic reserve allocations. Results show that dynamic allocation reduces wind curtailment.



Comparison of the resulting operation of the three largest hydropower plants over a whole day under the a) dynamic reserve allocation and the b) robust reserve allocation with an 8-hour long rolling window.

4 Conclusions

- The study highlights the benefits of aligning reserve allocation more closely with the conditions expected at the time of operation.
- Future work should explore improved co-optimization of energy and reserves, for example by iteratively refining reserve needs from an initial dispatch, as well as expanding the model to include energy storage.

References

[1] V. Jónsdóttir, L. Söder, and L. Nordström, “Impact from Different Reserve Allocation Strategies in Hydropower Systems,” presented at the 21st International Conference on the European Energy Market, Lisbon, Portugal, 2025.