Extended Benders Decomposition for CVaR-constrained unit commitment decisions in pan-European energy system models considering feed-in uncertainties

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IAEE European Conference

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Methodology and Approach

Validation

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Introduction
Motivation

Energy Transition

- Vast increase of variable renewable generation
- Growing (absolute) forecasting errors affecting trading on spot markets

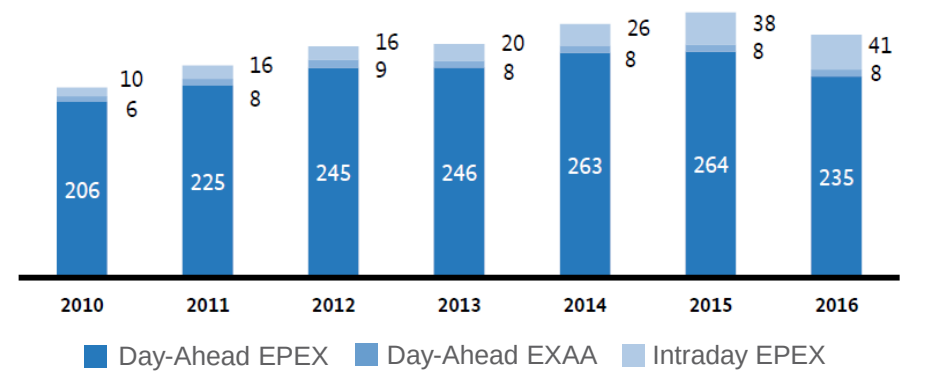
Marketing Implications

- Increasing relevance of intraday/realtime trading to compensate for forecasting errors
- Marketing risks due to uncertain prices and quantities

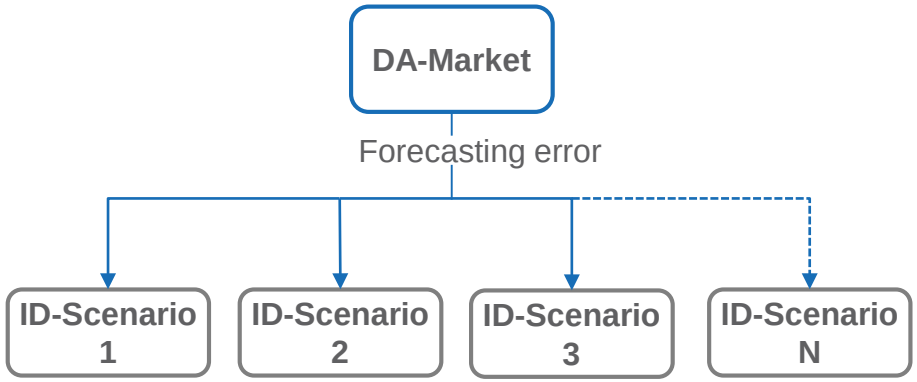
Fundamental Market Modeling

- Integration of uncertainties into fundamental uc-models leads to high computational burden through:
  - ➢ Integration of forecasting-error scenarios
  - ➢ Integration of risk constraints reflecting realistic risk-averse behaviour

Traded quantities at EPEX Spot and EXAA in TWh



Source: Monitoringbericht 2017 BNetzA



Introduction
Objective

Integration of uncertainties through forecasting errors and risk-averse behaviour into an existing pan-European unit commitment model

Implementaion of a robust decomposition approach within the single power plant optimization allowing for risk-constraints (CVaR)

Validation and analysis of modeling results using empirical price- and quantity data from 2014

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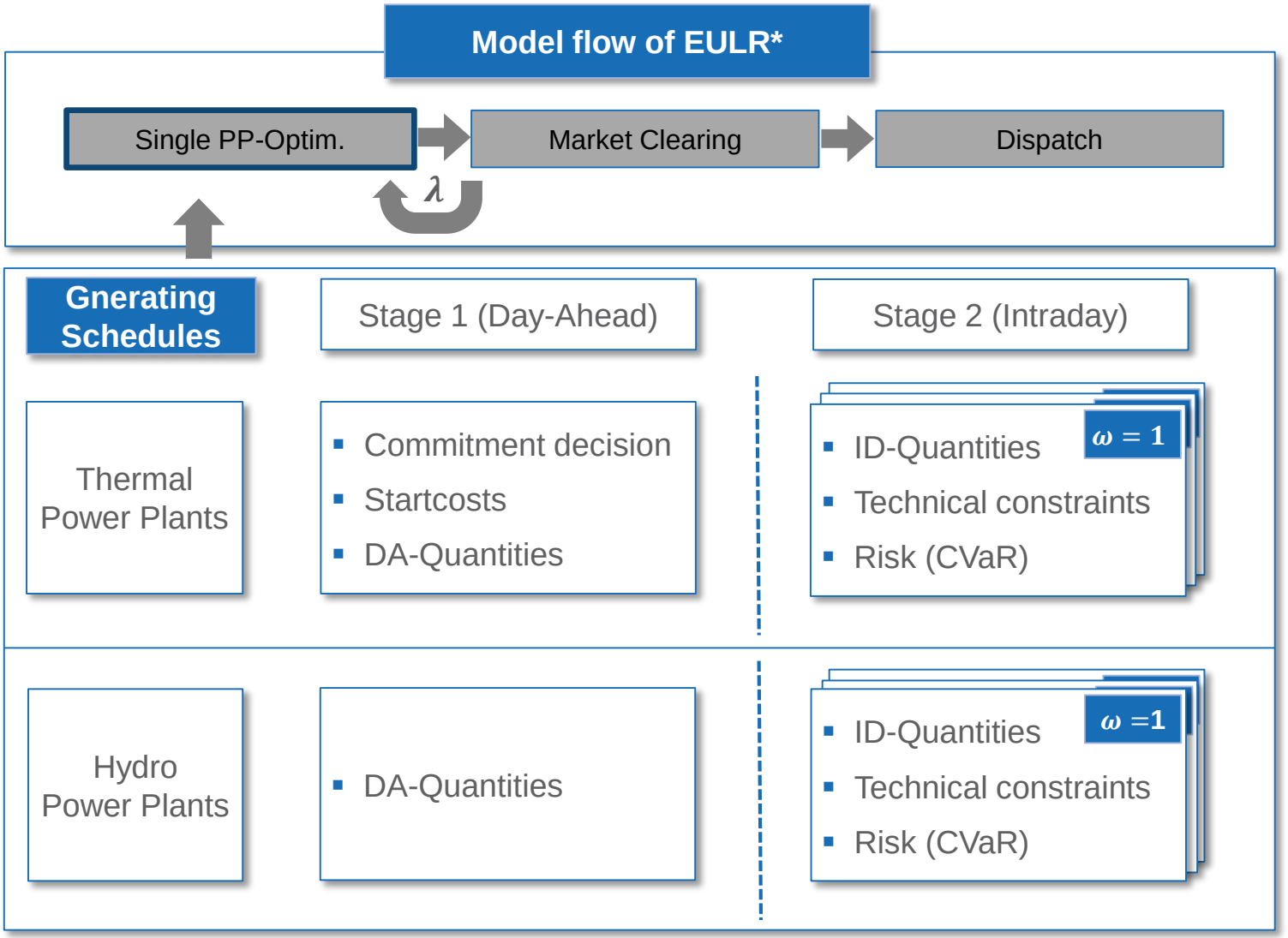
Methodology and Approach

Integrating a two-stage stochastic uc into an existing uc



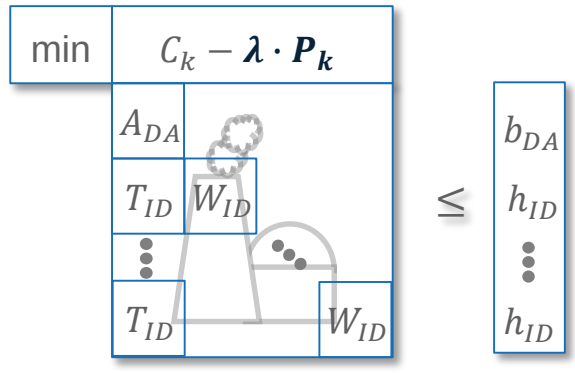
*: S. Raths, Marktsimulationsverfahren fuer einen dezentral gepraegten Strommarkt, Dissertation, Aachen, 2019

Methodology and Approach

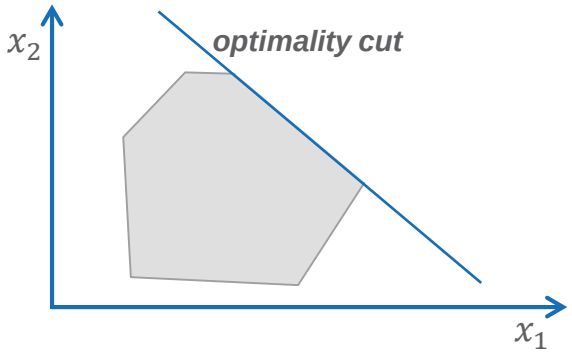
Benders decomposition of thermal power plants

- Benders decomposition:
  - Splitting into one master problem and several subproblems
  - Iterative cutting of the solution space
- Masterproblem:
  - Coupling the scenarios
  - Day-ahead marketing decision x^V
- Subproblems:
  - Individual scenarios
  - Intraday marketing decision subject to x^V from msterproblem
  - Returning *feasibility* oder *optimality as new r*estriction for the masterproblem
- Iterative converging

Matrix structure



Cutting planes



Methodology and Approach

Benders decomposition s.t. conditional value at risk

Masterproblem

$$\min \quad (1+\beta)\cdot c^T \cdot \boldsymbol{x} + \theta_1 + \beta \cdot \theta_2$$

$$\text{s.t.} \quad A \leq b$$

$$\mathbb{E}\text{-Cut} \quad -\theta_1 \leq 0$$

$$\text{CVaR-Cut} \quad -\theta_2 \leq 0$$

$\boldsymbol{x}$: DA decision variables
β: risk aversion parameter
c^T: DA cost coefficients
A: unit restrictions
θ_1: lower bound $\mathbb{E}(ZFW_{ID})$
θ_2: upper bound $CVaR(ZFW_{ID})$

$\boldsymbol{x^V}$

Subproblem — ID Szenario 1

$$\min \quad q^T \cdot \boldsymbol{y_{\omega_1}}$$

$$\text{s.t.} \quad W_{\omega_1} + T_{\omega_1} \cdot \boldsymbol{x^V} \leq h$$

$\boldsymbol{y_{\omega_1}}$: ID decision variables.
q^T: ID cost coefficients.
W_{ω_1}: recursion matrix
T_{ω_1}: technology matrix

Iteration

Every iteration adds the following to the masterproblem:

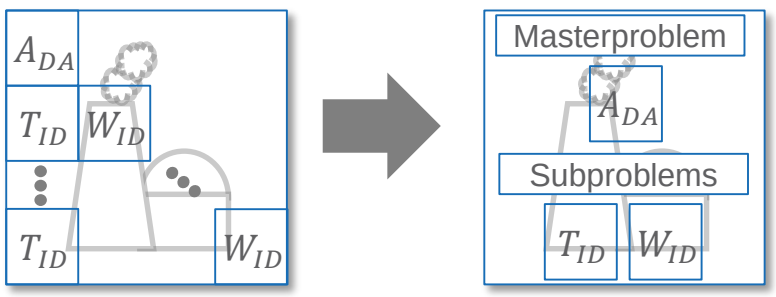
- Cutting plane of the expected value of ID-costs
- Cutting plane for CVaR
- Auxiliary variables for CVaR-Cut

Modification of the original Benders decomposition especially for risk-averse decision processes

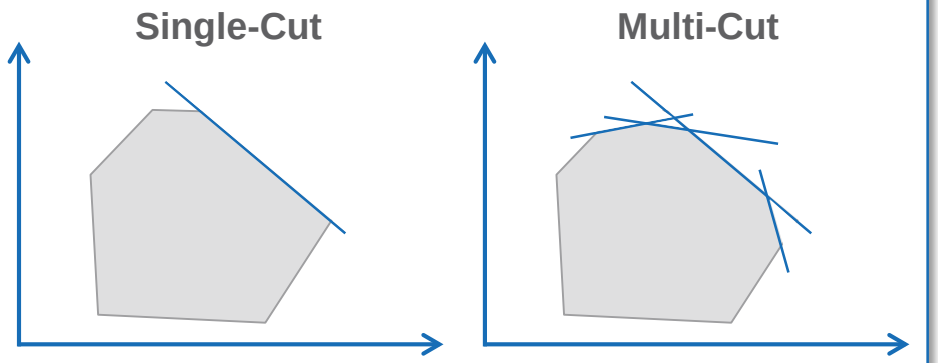
Methodology and Approach

Method extensions for runtime/memory optimization

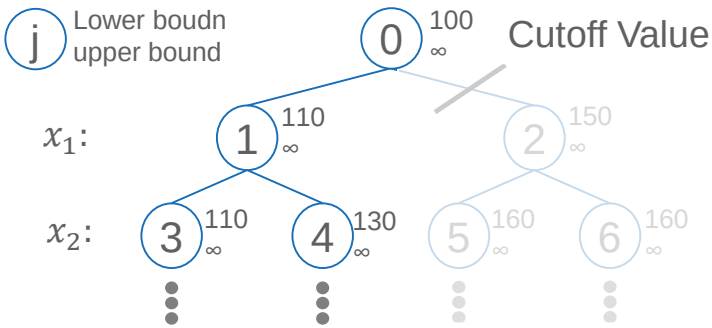
Decomposed model build-up



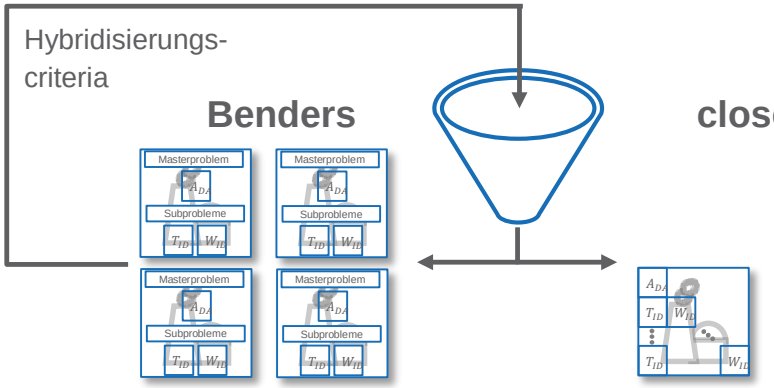
Multi-Cut-Extensions



MIP-Starts / B&B Cutoffs



Hybridisation



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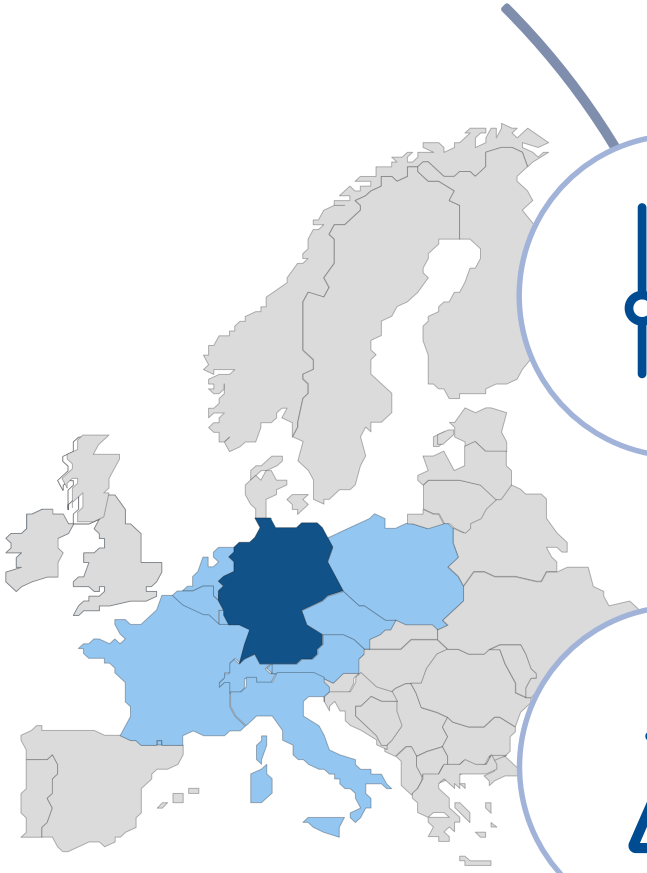
What was done so far?



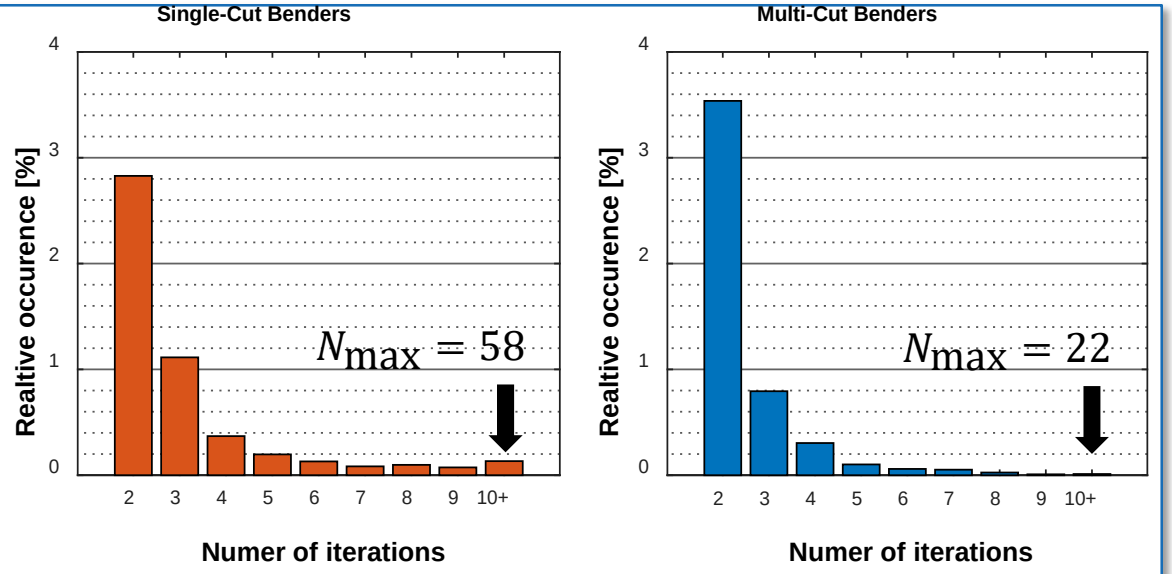
- Core Europe day-ahead, Germany intraday
- Calculation for 2014 in an hourly resolution
- 20 intraday scenarios

- Robust convergence for all generation types
- Significant runtime improvements compared to
  - closed solution and compared to
  - Benders w/o add-ons

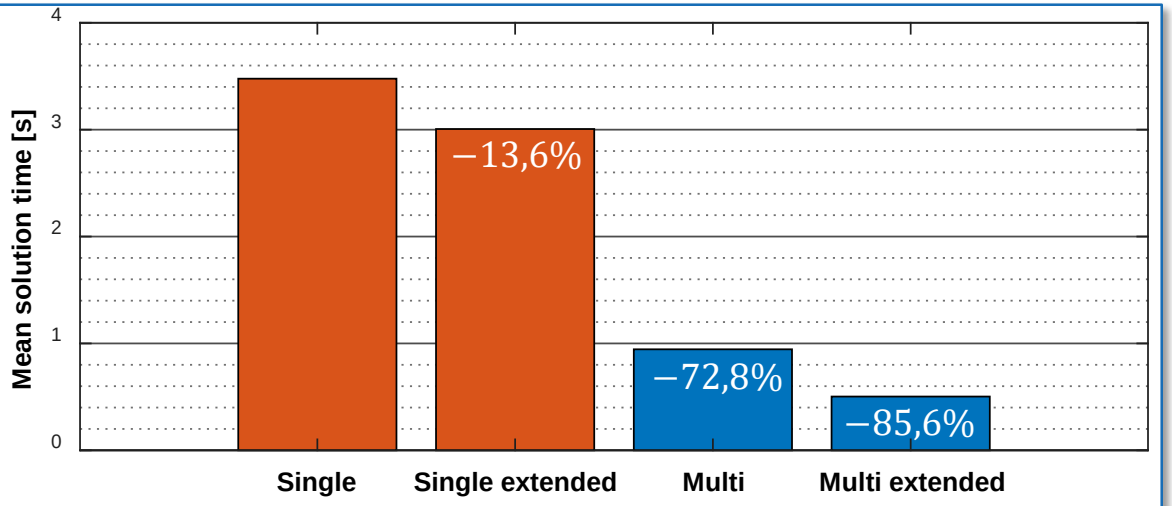
Validation

Runtime improvements due to add-ons

- The majority of power plant models converge completely within one iteration.
  - 94,97 % in Single-Cut-Mode
  - 95,11 % in Multi-Cut-Mode
- Multi-cut variant always requires less or the same number of iterations as single-cut variant



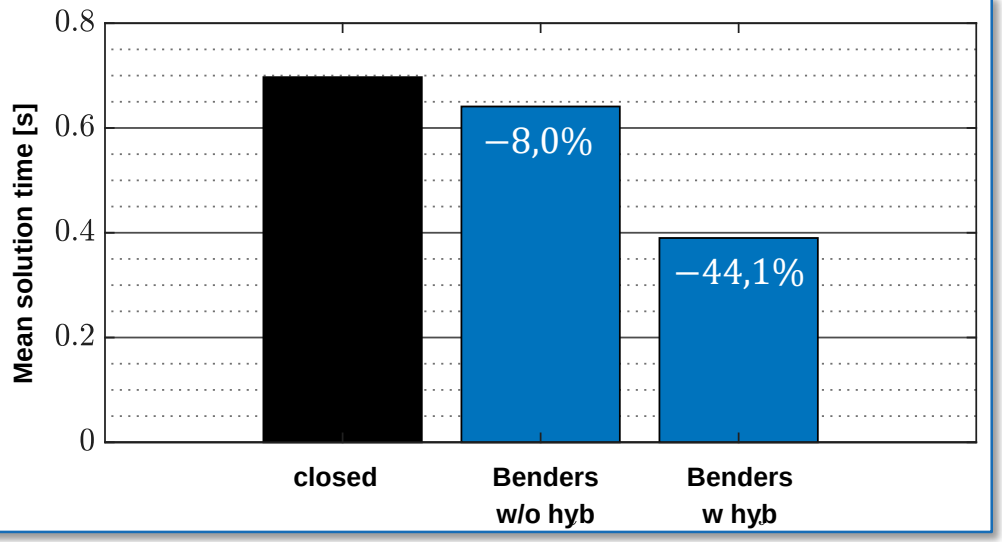
- Significant reduction of the solution time with the Multi-Cut variant
- Further reduction through implemented extensions:
  - MIP-Starts
  - B&B Cutoffs



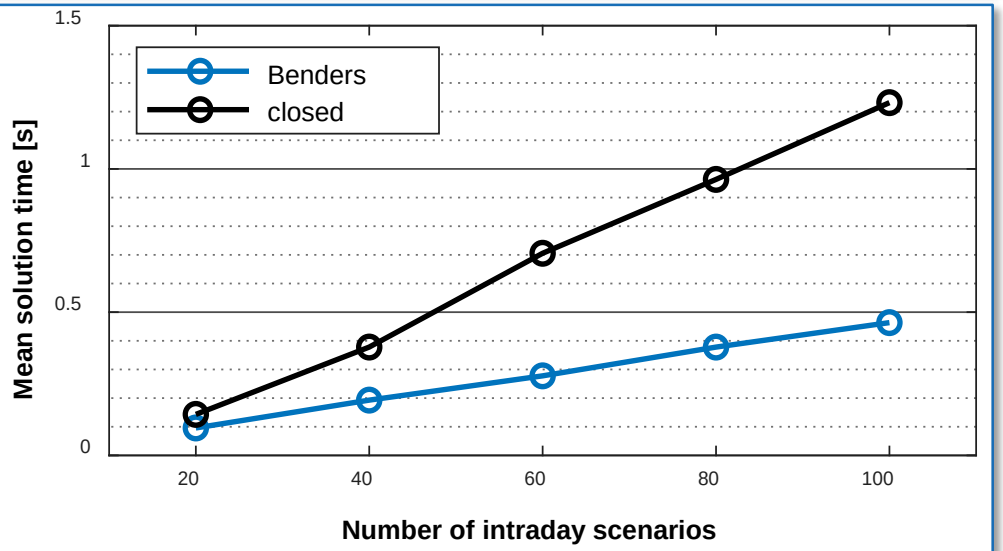
Validation

Runtime improvements due to decomposition

- Average solution time over all thermal power plants for one year
- Extended Benders process combined with hybridization approach leads to a significant reduction in solving time



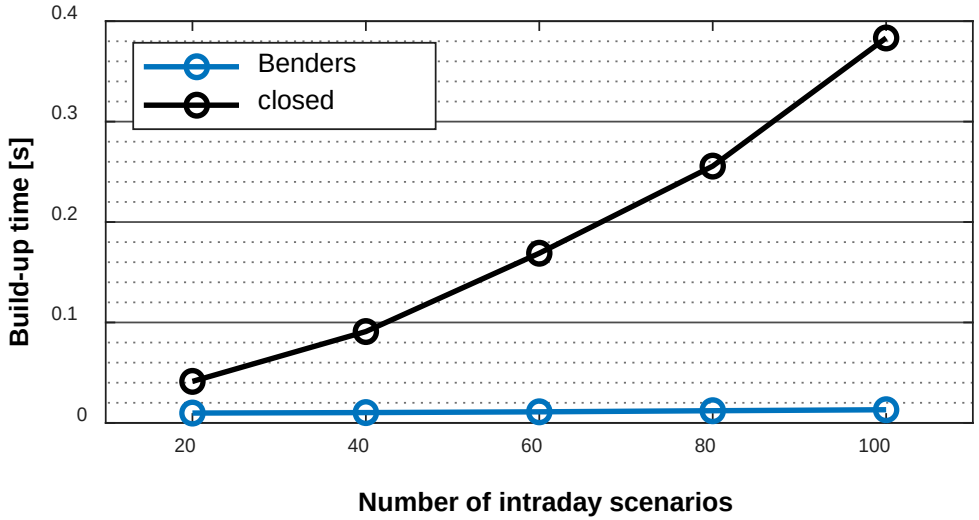
- Average solution time across all thermal power plants for selected week on desktop computer
- Linear increase of the solution time with the number of scenarios
- Increasing solving time improvement for benders



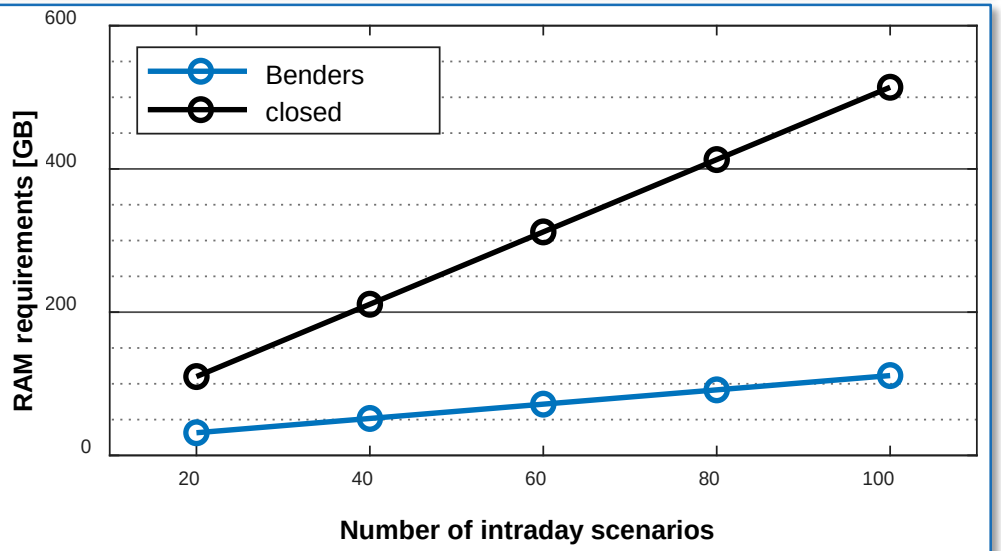
Validation

Build-up time and RAM requirements

- Build-up time independend of model instance
- Diagonalization of restriction matrices in closed solution time-consuming
- Constant build-up time for benders due to decomposed model construction (no diagonalization)



- Linear increase of the absolute RAM requirement in both cases
- Reduced RAM requirement due to decomposed model structure



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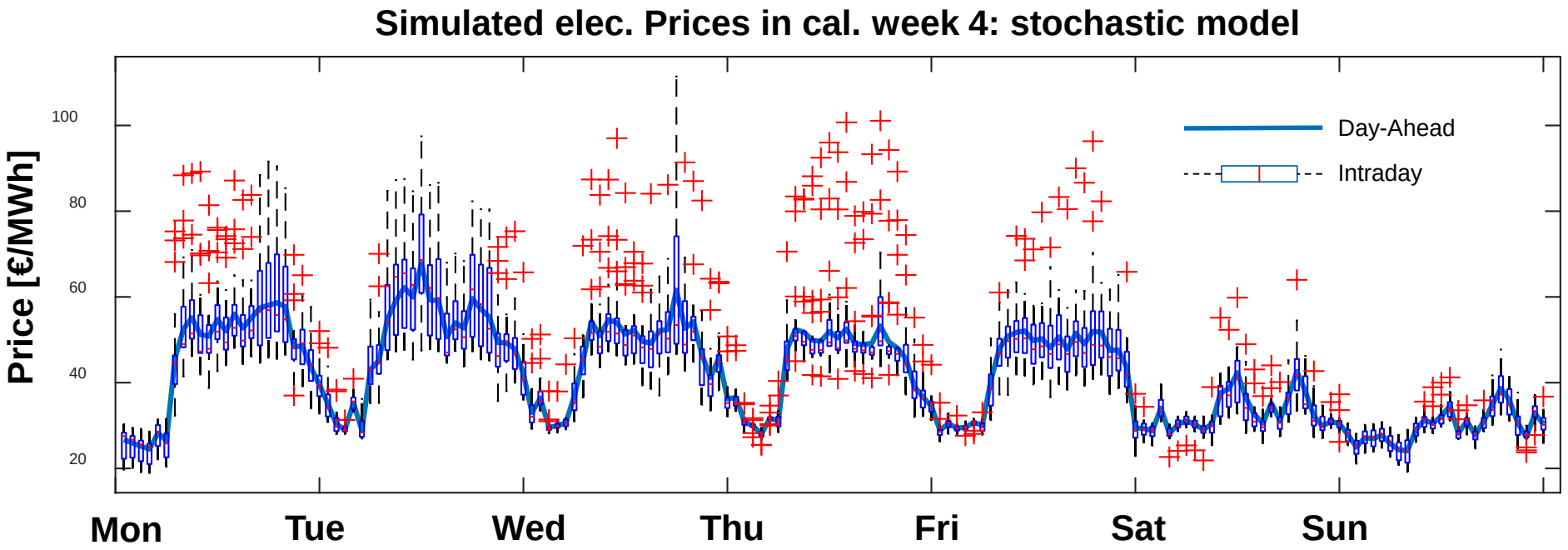
Simulated electricity prices stochastic model



Price spread

- Forecasting error shows an offset
- Implicit incentive for power plant starts

Yearly optimization results

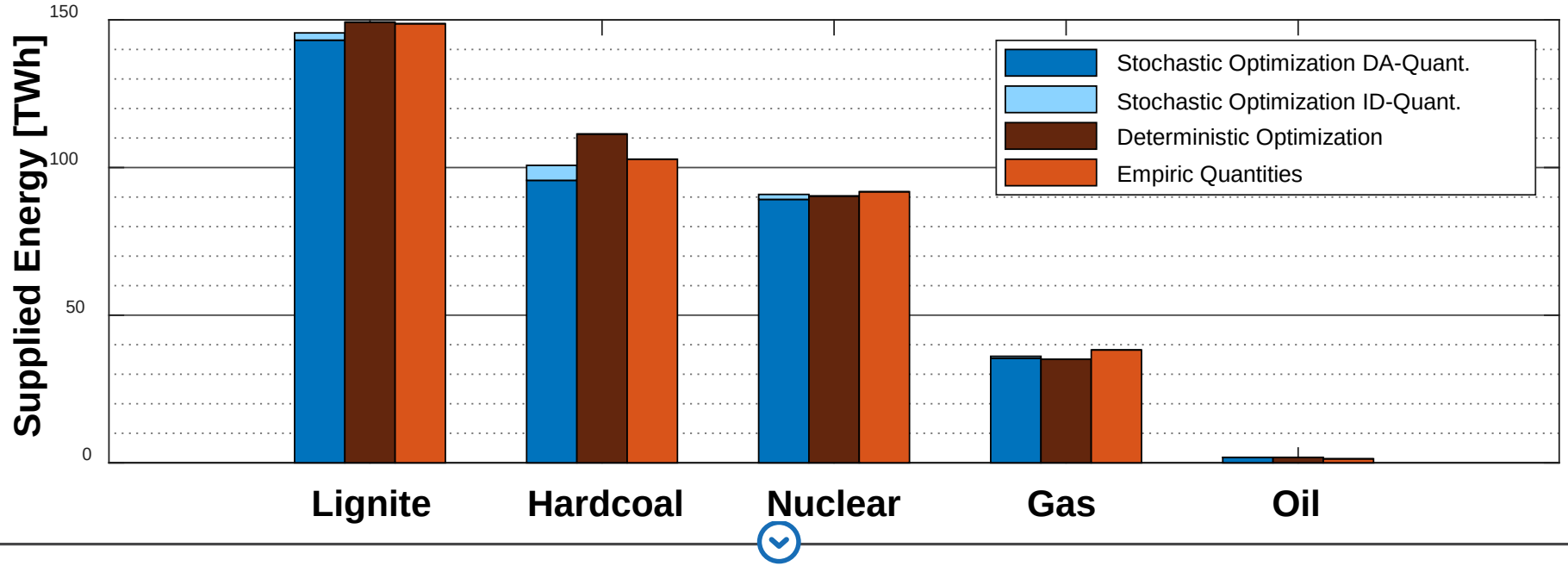
	mean		Std-dev	
	Day-Ahead	Intraday	Day-Ahead	Intraday
Empirical	32,76 $\frac{€}{MWh}$	33,14 $\frac{€}{MWh}$	12,77 $\frac{€}{MWh}$	13,4 $\frac{€}{MWh}$
Optimization	31,37 $\frac{€}{MWh}$	31,76 $\frac{€}{MWh}$	7,73 $\frac{€}{MWh}$	9,14 $\frac{€}{MWh}$

Exemplary Results

Physical production and marketing quantities

- Comparison of generation quantities of stochastic simulation with real data (ENTSO-E) and simulated quantities from deterministic simulation

- Intraday marketing volume: balance of positive and negative trading volumes (weighted with the probability of occurrence of the scenarios)



Satisfactory representation of the real production quantities

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Summary

1. Integration of the intraday market stage into a pan-European electricity market simulation
2. Reliable convergence of the extended benders decomposition taking into account risk aversion
3. Comparison to closed solution
   - Significant runtime advantage (solution and buildup time)
   - Reduced RAM requirements due to decomposition
4. Comparison with empirical price and production data for 2014: Satisfactory depiction of real market activity

Summary and Outlook

Outlook

1. Integration of intraday starts in single scenarios
   - Not compatible with benders decomposition
   - Heuristics needed
2. Extension of the hybridization approach by machine learning models: ex-ante estimation of runtimes depending on the model instance
3. Application of this approach to future scenarios and validation of relevance/impact of intraday markets in future

Thank you for your attention!

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