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Investigations on Factors Influencing the Operational Benefit of Stochastic Optimization in Generation and Trading Planning

- Introduction
- Stochastic Optimization Model
- Exemplary Investigations
- Summary

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Motivation

- Optimization methods used for short-term generation and trading planning to determine unit commitment and marketing of units at spot markets for electrical energy
- Commitment problem is subject to time coupling constraints with various time horizons
  - e.g. minimum up- and down-times (short-term)
  - e.g. primary energy constraints (long-term)

➔ Consideration of complete time horizon for day-ahead commitment decision necessary

- Parameters determining optimal unit commitment are partially uncertain
  - price uncertainties
  - uncertainties of quantity

➔ Optimal day-ahead decision influenced by uncertain parameters in the future

- Stochastic optimization methods based on scenario trees allow consideration of uncertainties in planning process
- Practical applications show benefit of stochastic optimization opposed to deterministic

➔ Investigations on factors influencing operational benefit by performing a day-by-day simulation of day-ahead unit commitment and marketing decision process

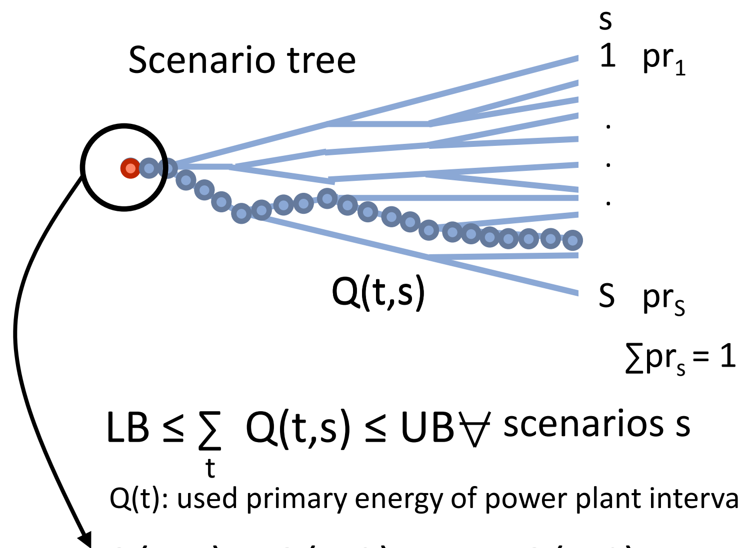
Stochastic Optimization of Generation and Trading

- Day ahead planning requires high modeling accuracy and performance of results
- → Use of mathematical exact, closed-form method preferred
- Formulation of unit commitment problem as mixed-integer quadratic program
- Objective function: maximization of expectation value of contribution margin (example of one thermal unit marketed solely at spot market)

$$\max \sum_{s}^{\text{scenario}} pr_s \sum_{t}^{\text{time}} \big(\underbrace{P(t,s)}_{\text{power output}} \cdot \underbrace{p(t,s)}_{\text{price at spot market}} - \underbrace{K(t,s)}_{\text{generation costs}} \big)$$

Considered cost components:

- down-time (in-) dependent start-up costs
- stationary costs (esp. primary energy)



$\sum pr_s = 1$

$LB \leq \sum_t Q(t,s) \leq UB \; \forall$ scenarios s

Q(t): used primary energy of power plant interval t

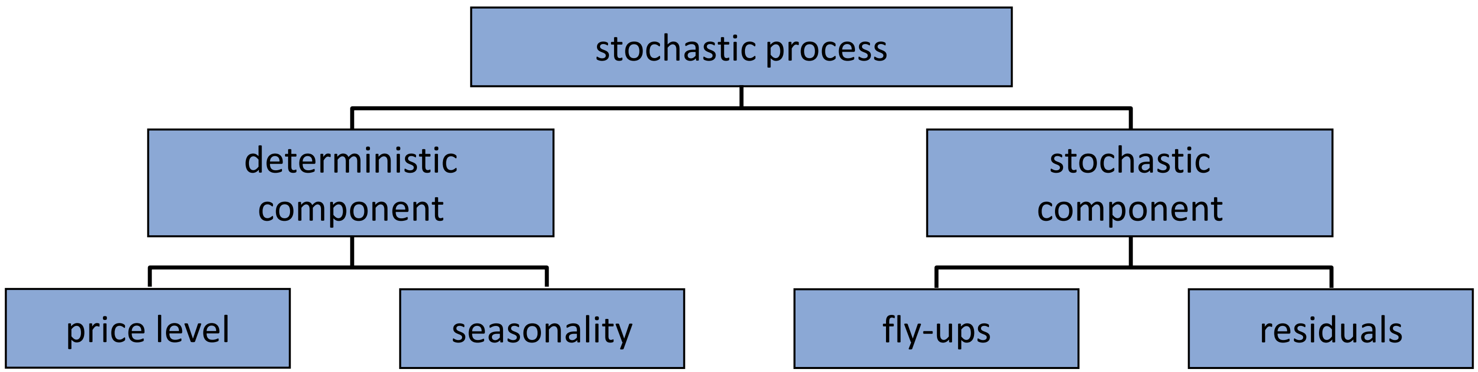
$Q(1,1) = Q(1,2) = \ldots = Q(1,S)$

- Maximization subject to:
  - minimum and maximum power output
  - minimum up- and down-times
  - maximum ramp-rates
  - primary energy constraints
- Extensions: interconnected hydro plants, reserve markets (provision power / energy)

IAEW

Modelling of Planning Uncertainties (I)

- Relevant planning uncertainties
  - Price uncertainties
    - spot market, reserve market, primary energy prices, emission certificates
  - Uncertainties of quantity
    - natural inflow, request of reserve energy, outages
- Modeling of uncertainties as stochastic processes
- Example of electricity price model as most complex uncertainty



price level:
- historic price level
- expected value of price level based on future prices

seasonality:
- trigonometric function
- day categories

fly-ups:
- separate processes for positive and negative fly-ups (γ distribution)

residuals:
- ARMA process (short-term uncertainty)
- Random Walk (long-term uncertainty)

Modelling of Planning Uncertainties (II)

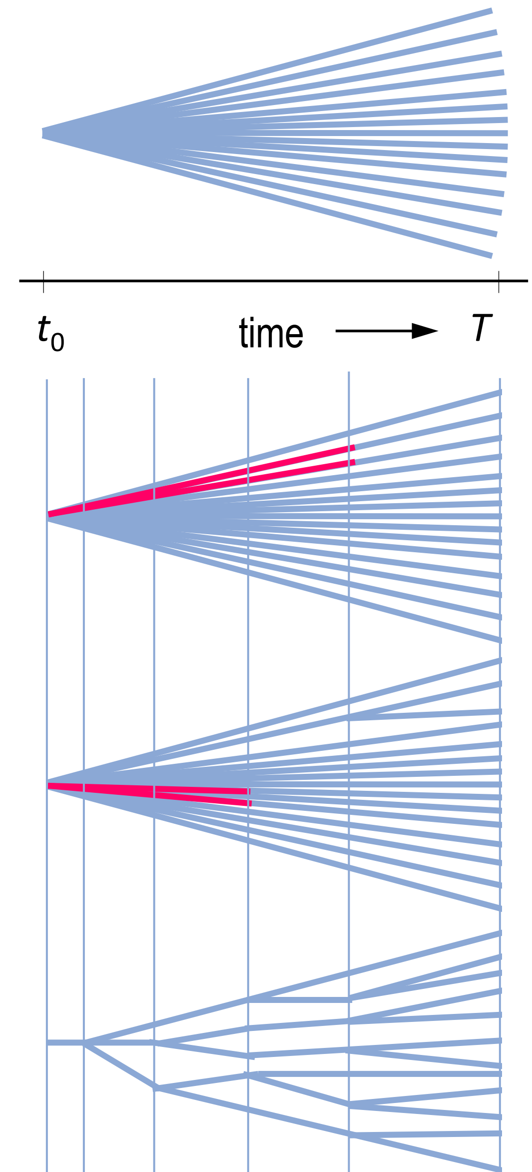
Basis:

- Multitude of realizations of stochastic process

Scenario tree generation method:

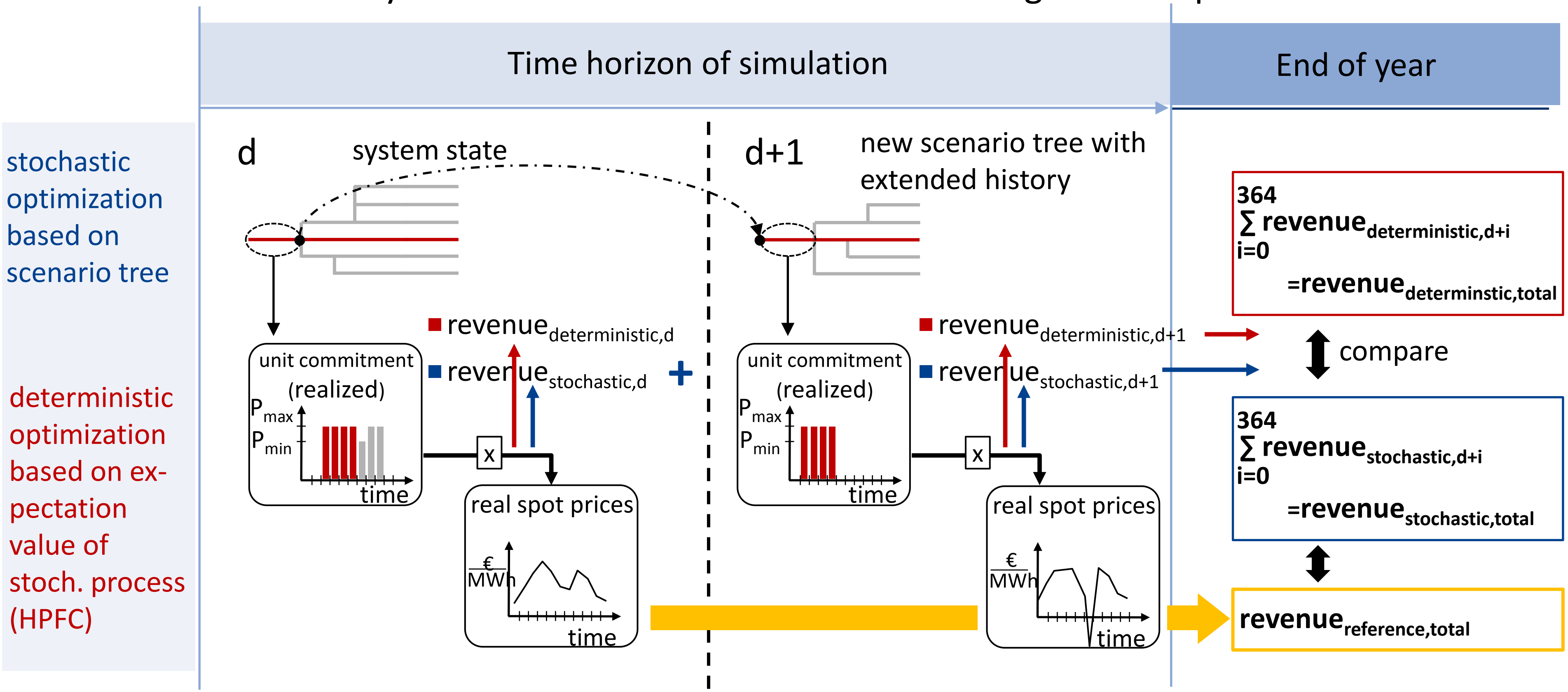
- Separation of appropriate segments
- Pairwise distance calculation (Kantorovič distance)
- Elimination of scenario with smallest probability metric
- Probability added to closest scenario
- → Scenario tree with a defined approximation accuracy
- → Maintain original characteristics
- → Reduction of scenario tree to tractable size

- → Result of deterministic start segment gives desired day-ahead unit commitment decision



Methodology of Investigations

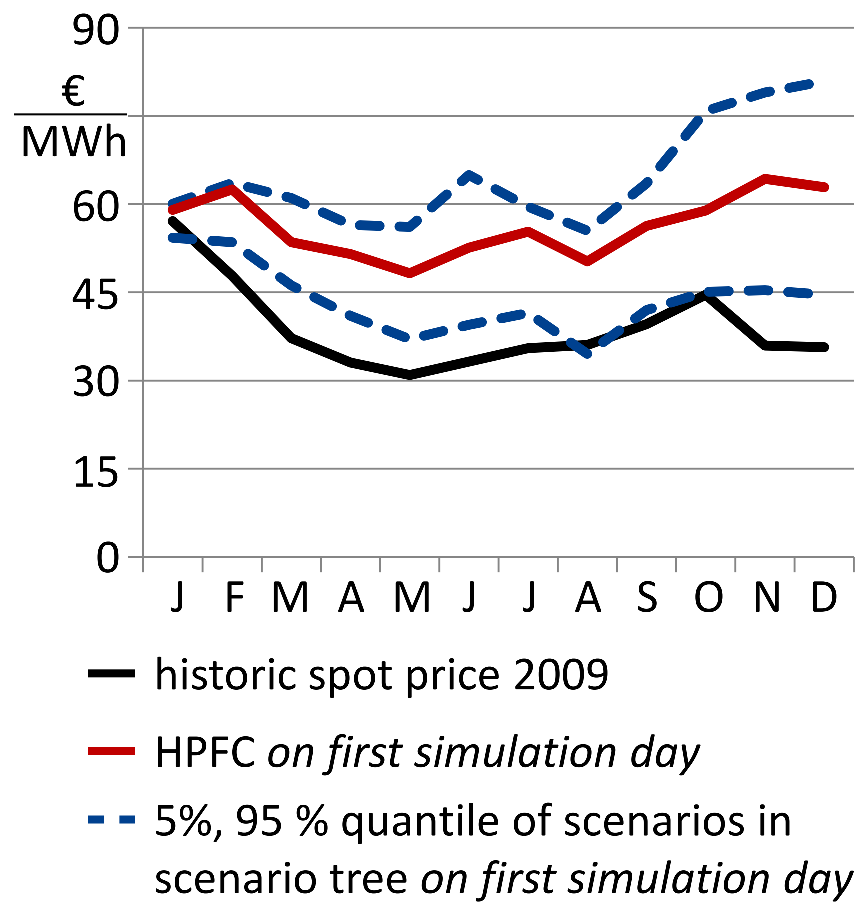
- Evaluation of deterministic and stochastic day-ahead optimization using a day-by-day simulation of day-ahead unit commitment and marketing decision process



- Comparison of results also to ex-post optimal unit commitment as reference

Model System

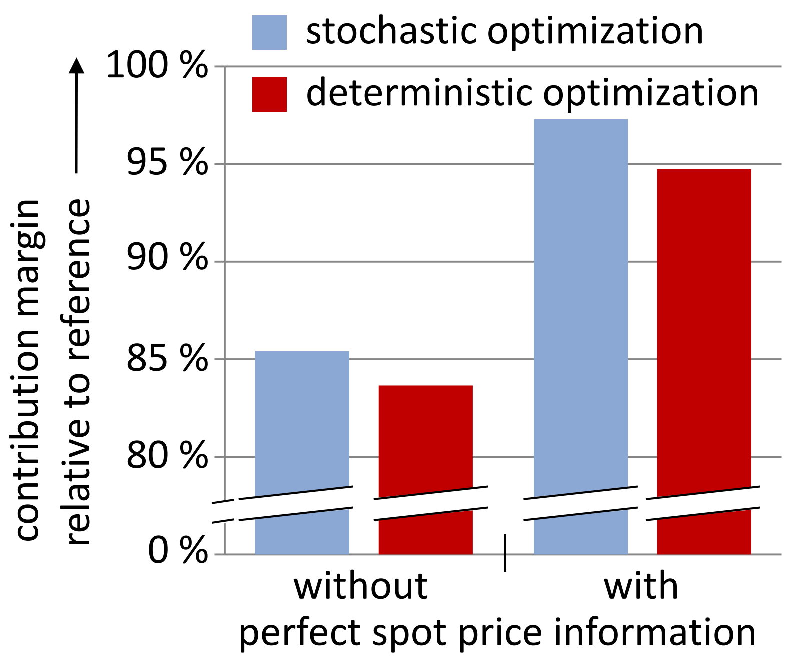
- Historic year of 2009 considered
- Power Plant: Combined-cycle gas turbine (CCGT)
  - installed capacity: 800 MW (minimum output: 320 MW)
  - efficiency: 58 % (at maximum capacity)
  - minimum up-/down-times (5h / 8h)
  - energy restriction on natural gas
    minimum: 17,204 TJ
    maximum: 19,354 TJ
  - natural gas price: based on TTF (monthly adjusted)
  - CO_2-emission certificate price monthly adjusted
- Only marketing at day-ahead spot market (no hedging strategy considered)
- Spot prices for electricity considered as uncertainty
- Scenario tree already anticipates low price developments



Comparison of Stochastic and Determinsitic Day-Ahead Planning

- Results from day-by-day simulation compared to ex-post optimal day-ahead marketing
- → Stochastic optimization yields higher contribution margin of 2.2 % (590 TEUR)

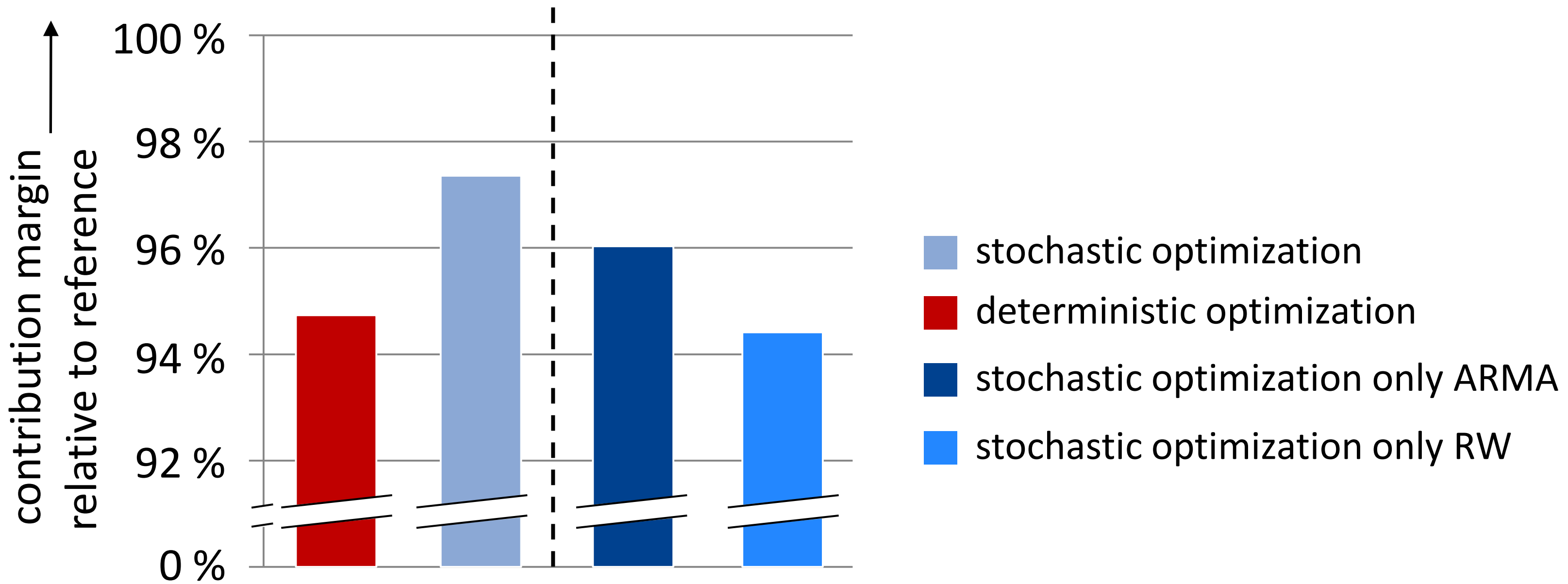
- Gap to reference due to several effects
  - suboptimal use of scarce of resources (primary energy)
  - suboptimal day-ahead spot prognosis
  - suboptimal start-up / shut-down decisions
- Day-ahead spot prognosis not focus of stochastic process
- → Separation of this effect by using perfect information on day-ahead prices



- → Perfect information on day-ahead spot prices not sufficient for optimal results in system with time-coupling constraints
- → Stochastic optimization allows for higher contribution margin of 2.7 % (850 TEUR) also with perfect spot information

Influence of Stochastic Process

- Scenario tree based on stochastic process consisting of two factors
  - Short-term uncertainties modeled by ARMA-process (parameterized by spot prices)
  - Long-term uncertainties modeled by random walk (RW) (parameterized by future prices)

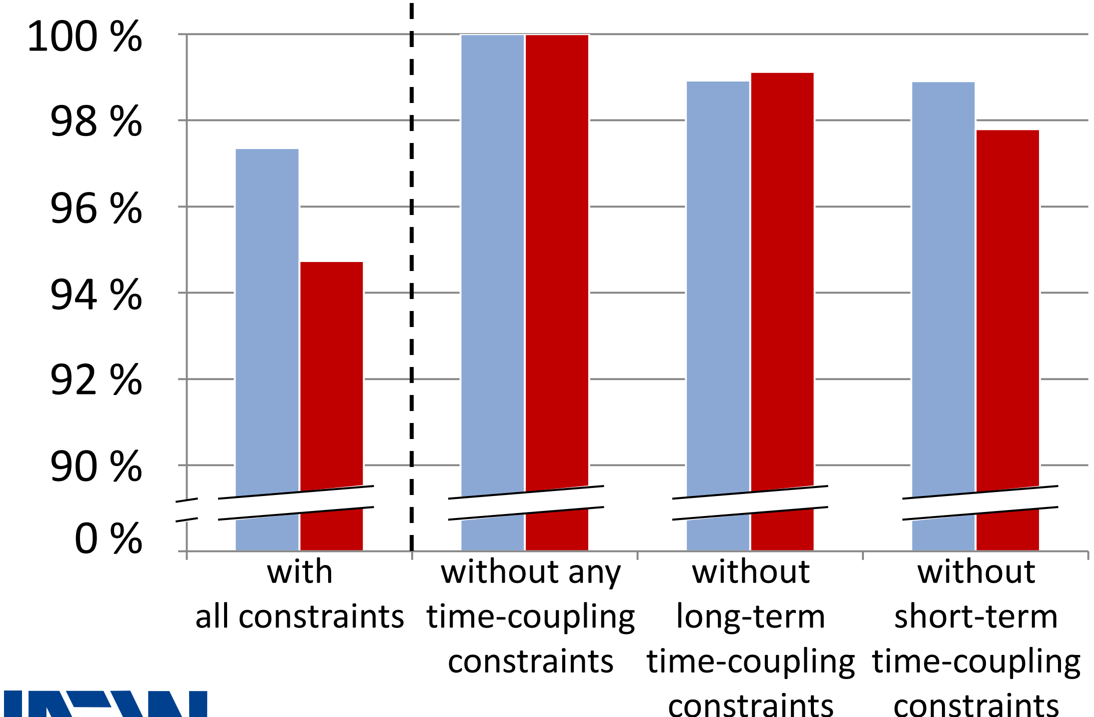


→ Both factors contribute significantly to benefit of stochastic optimization

→ Negligence of short-term stochastics compensates benefits of stochastic optimization

Influence of Model System (Time-Coupling Constraints)

- Investigated model system consists of different time-coupling constraints
  - minimum up- and down-times (short-term)
  - take-or-pay restriction on natural gas (long-term)
- Investigation on the influence of time-coupling constraints by ceteris paribus dropping long- and/or short-term constraints and comparing to accordingly adjusted reference



→ Without time-coupling constraints no benefit from perfect information on future

→ Without long-term coupling constraints no benefit from stochastic optimization

→ Combination of long- and short-term constraints with disproportionally high influence on benefit from stochastic optimization

Conclusions and Outlook

- Day-ahead marketing of power plants has to consider time-coupling constraints and is subject to uncertainties
- Stochastic optimization methods based on scenario trees allow consideration of uncertainties in planning process and promise higher contribution margins in operational use
- → Investigations on operational benefit by performing a day-by-day simulation of day-ahead unit commitment and marketing decision process
- Exemplary simulation of historic year 2009 for a combined-cycle gas turbine with take-or-pay restriction on natural gas and uncertain prices for electricity
- → Significant higher contribution margin with stochastic optimization even with perfect information on next day's spot market prices
- → Modeling of short- and long-term stochastics of electricity prices necessary to fully utilize potential of stochastic optimization
- → Combination of long- and short-term time-coupling constraints with disproportionally high influence on benefit of stochastic optimization
- Future investigations on broader basis of historic situations and consideration of further uncertainties, particular primary energy prices and emission certificates