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# StoOpt – Comparison of deterministic and stochastic optimization approaches in the German electricity and reserve markets

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# Price uncertainty – opportunity and threat for flexible portfolios



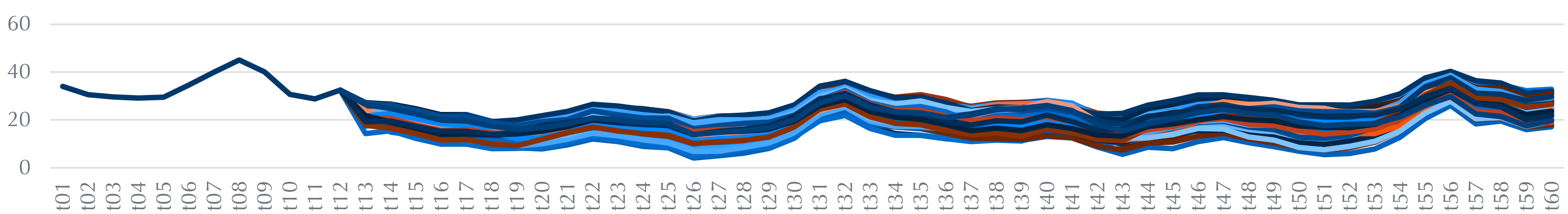
Motivation

- Optimal marketing of flexible CHP portfolios needs to account for uncertainties
  - Electricity Prices, Reserve Market Prices, Heat Demand Forecasts, …
- However, many portfolio owners still mostly rely on deterministic optimization methods

→ Point forecasts are readily available

→ Optimization runtimes are adequate for auction schedules

- But is this really the **optimal** marketing strategy?
- What potential might be unlocked by **stochastic** marketing optimization?



# Agenda



StoOpt –deterministic and stochastic optimization approaches in the German electricity and reserve markets

# StoOpt.NRW: IT Tools for the Sustainable Management of CHP and Storage Systems

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On the Research Project: *StoOpt.NRW*

- Partners:
  - Chair of Energy Economics (EWL) of UDE (consortium leader)
  - ProCom GmbH
    - Medium-sized (about 100 employees) IT consultant firm
    - Based in Aachen (HQ), Berlin and Ningbo (China)
    - Provider of various energy market-related IT services and applications
- Project awarded by the "Leitmarktwettbewerb EnergieUmweltwirtschaft.NRW"
- Duration: 38 months (04/2016-05/2019)
- Project Funding:
  - OP EFRE NRW (Operational program for the promotion of investment in growth and employment of the European Fonds for Regional Development of North-Rhine Westphalia)

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ProCom bringt Transparenz



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# Basic concept of stochastic optimization

## Methodology

**Uncertainty representation**
- Identify relevant uncertainty factors and model them

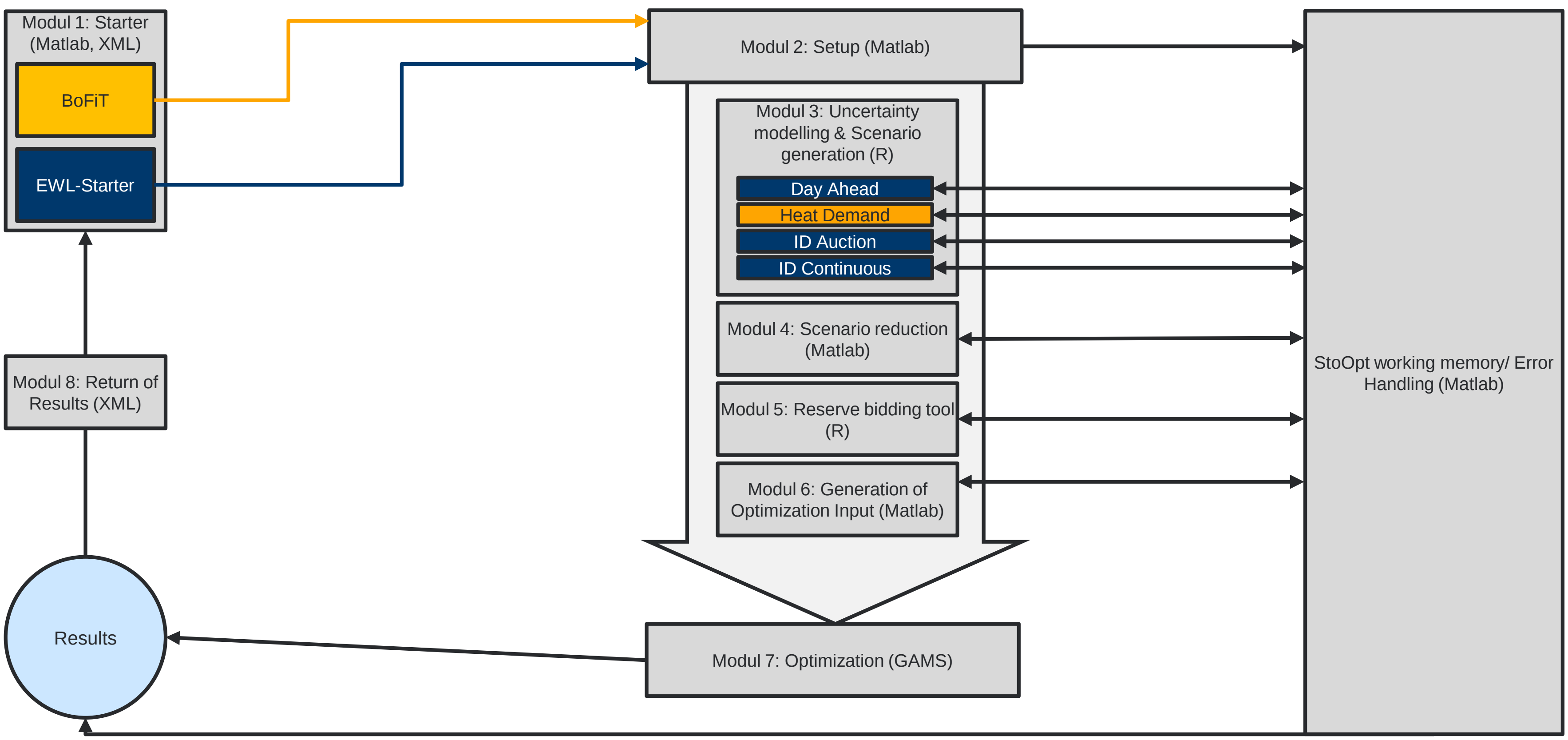
**Stochastic decision structures**
- Identify time horizons of desired optimization
- When are your relevant parameter realizations certain? When are they uncertain? Are they becoming more diverse over time? → Derive decision structure and scenario tree

**Scenario generation**
- Simulate future development paths to discretize continuous distributions
- Reduce your plurality of paths to a smaller and more manageable set of consistent scenarios and assign probabilities

**Solve Stochastic Program**
- Formulate and solve the relevant stochastic optimization problem

# StoOpt.NRW – Implementation of the calculation kernel

## Methodology



# Decision interdependencies between different markets (I)

Methodology

- Example: Weekly primary reserve decisions must take all subsequent markets into account!

| Di | Mi | Do | Fr | Sa | So | Mo | Di | Mi | Do | Fr | Sa | So |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t-12 | t-11 | t-10 | t-9 | t-8 | t-7 | t-6 | t-5 | t-4 | t-3 | t-2 | t-1 | t |

**15:00**
FCR Auction
**16:00**
Results

**08:00**
FRR-a Auction
**09:00**
Results

**10:00**
FRR-m Auction
**11:00**
Results

**12:00**
1h DA-Auction
**12:40**
Results

**15:00**
¼ h IDA Auction
**15:10**
Results

**Delivery Period**
FCR

→ Both uncertainty modelling and the dispatch optimization model need to reflect these opportunities



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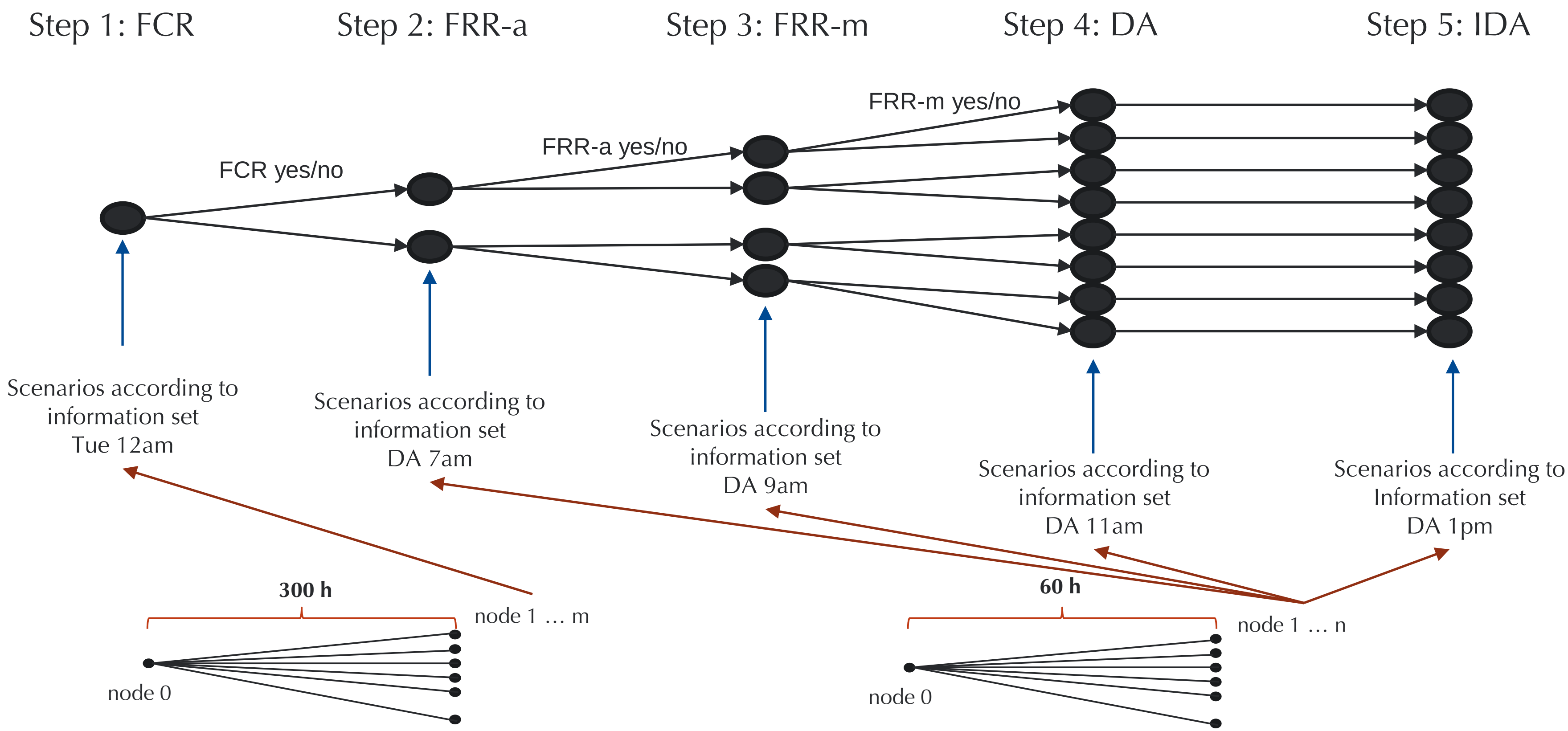
# Decision interdependencies between different markets (II)

Methodology

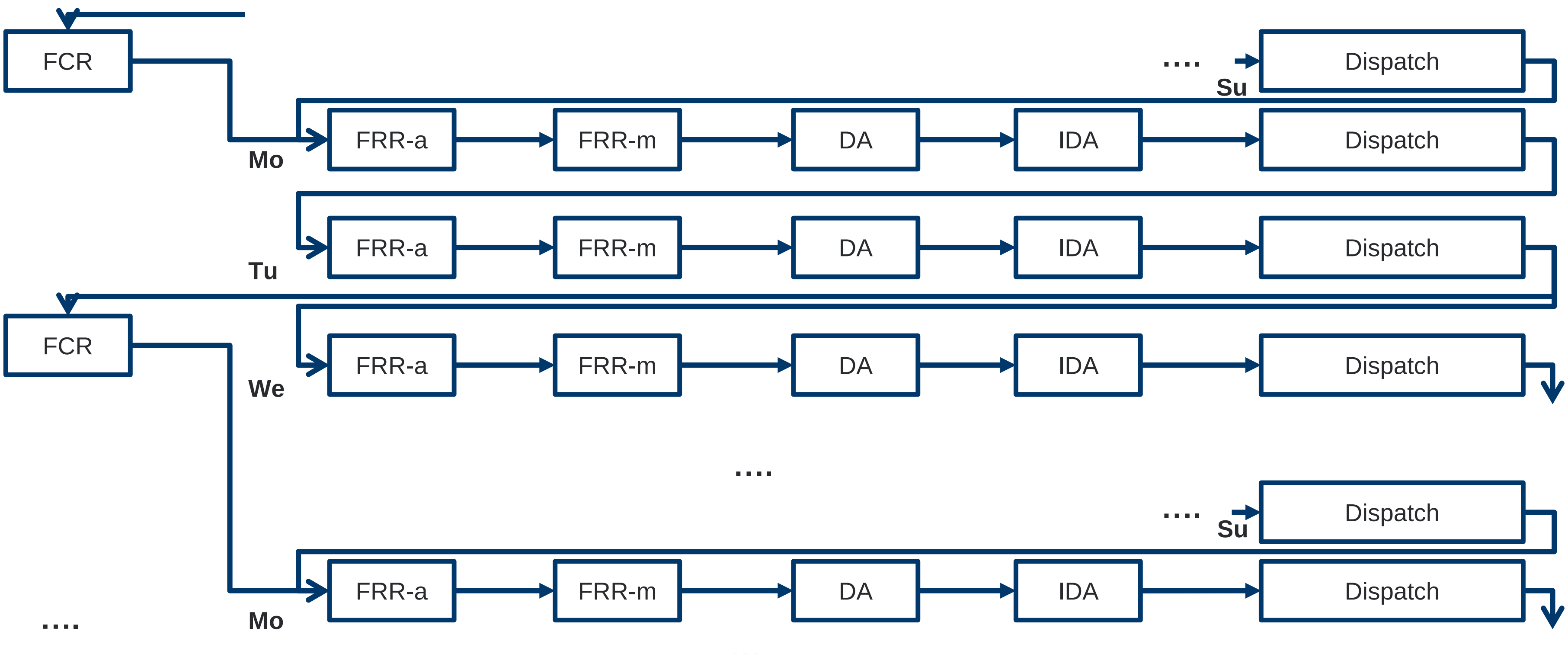
## Decision Structure




## Scenario tree structure

# Sequence of decisions for long-term application

## Methodology

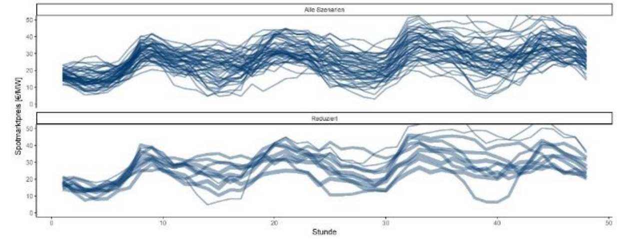


# Uncertainty modelling: from distributions to scenarios

Methodology

- Here: focus on week-ahead and day-ahead electricity price uncertainty modelling
  - However, in the research project, heat uncertainty was also addressed

- Panel and rolling window approach (Beran, Vogler and Weber 2017)
  - Parameters are estimated and fixed for each hour $h$ and each quarter hour $qh$ on the basis of 730 days
  - LASSO with two different distributions was identified fitting DA and IDA
- Monte Carlo simulation of 1000 price paths
  - Week-ahead: 300 h, Day-Ahead: 240 qh
- Scenario reduction for optimization model
  - Based on approach of Römisch and Heitsch (2003)
  - Addition of two extreme price scenarios ahead of the reduction



# Reserve (provision) bid optimization

## Methodology

- Reserve markets differ from electricity markets
  - Pay-as-bid, no price-taker assumption
  - Therefore, bid quantity and prices need to be optimized jointly!
  - → No linear problem, not directly compatible with mixed-integer optimization

- Chosen approach here: Swider and Weber (2007), in a pre-optimization
  - Optimization of expected profits taking into account
    - Expected opportunity costs of reserve provision (based on electricity price scenarios)
    - Own price impact
    - Historical reserve price distribution* by quantile regression
    - Possible bid sizes and corresponding optimal bid price (brute force)
  - Choosing quantity/price constellation with highest expected profit; bid price is forwarded to the stochastic optimization model

# Stochastic Unit Commitment and Dispatch Model

## Methodology

- Implemented in GAMS, solved with CPLEX 12.5.1(standard solver settings), optimality gap 1%, RESLIM= 100.000 s (~28 h)

- Stochastic unit commitment and dispatch model
  - originally based on Brand and Weber (2005), extended by Woll and Weber (2006), Kempgens (2018) and Dietrich et al. (2020)
  - including binary and integer variables (→ MILP)
  - Two-stages (deterministic and stochastic)
  - Decision variables include (but are not limited to)
    - Power and heat production, marketed amounts (in bidding curves), storage operation
  - Implements both equality constraints and inequations (~80)
  - Objective: maximization of portfolio profit
    - Not considered: heat revenues, reserve *energy* activation

# Agenda

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# Case study: 4 "months" of 2016

Results (so far)

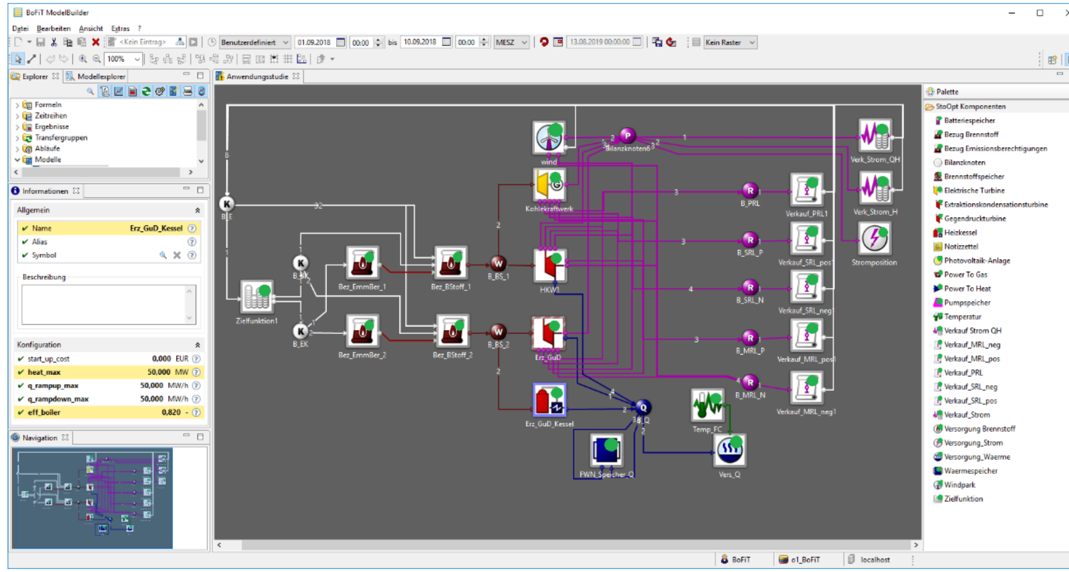
- Due to the weekly schedule of FCR, we chose 4-week periods (28 days), one period per season
- Winter: 04/01/2016-31/01/2016 (+FCR auction on 29/12/2015)
- Spring: 04/04/2016-01/05/2016 (+FCR auction on 29/03/2016)
- Summer: 04/07/2016-31/07/2016 (+FCR auction on 28/06/2016)
- Autumn: 05/09/2016-02/10/2016 (+FCR auction on 30/08/2016)
- 150 optimizations per "month" (5 week-ahead + 145 daily optimizations)

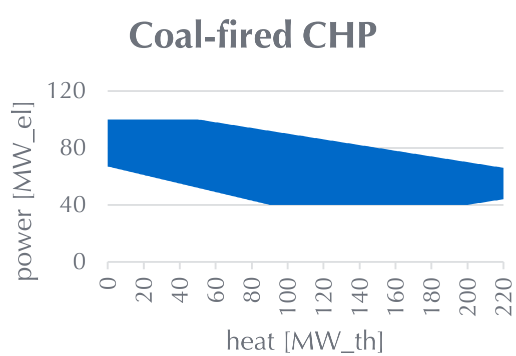
# Case study: Portfolio under study

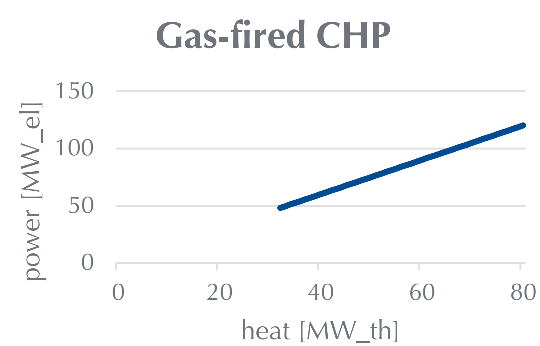


## Results (so far)

- Gas-fired CHP plant (backpressure turbine)
  - $P_{max} = 120\ MW,\ Q_{max} = 80\ MW$
- Coal-fired CHP plant (extraction condensing turbine)
  - $P_{max} = 100\ MW,\ Q_{max} = 220\ MW$
- Coal plant without cogeneration
  - $P_{max} = 100\ MW$
- Wind park (subject to German market premium scheme)
  - $infeed_{max} = 33.5\ MW$
- Heat boiler
  - $Q_{max} = 50\ MW$
- Heat storage
  - $vol_{max} = 250\ MWh$



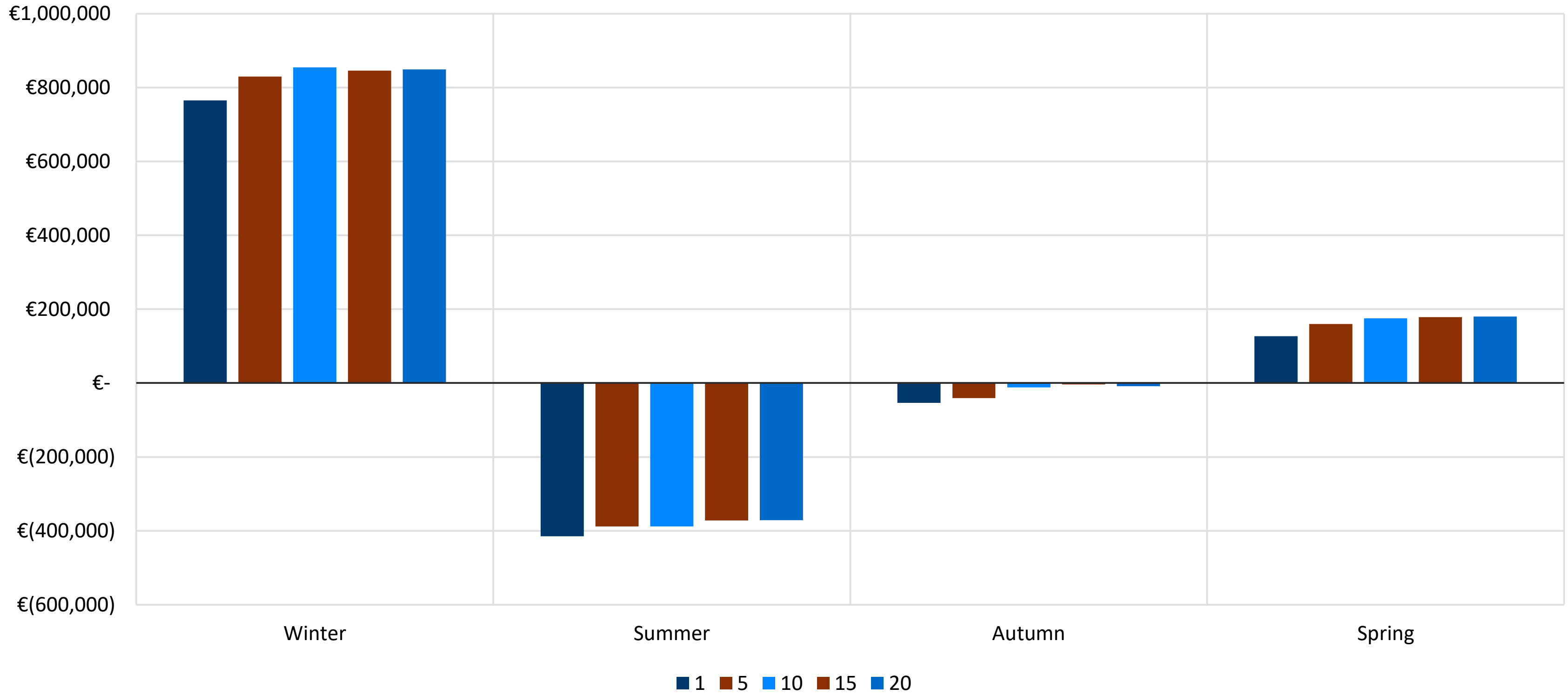


# Monthly profits with different numbers of scenarios

Results (so far)

- Value of Stochastic Optimization always positive
  - However, there seems to be an early saturation point → bug or feature?



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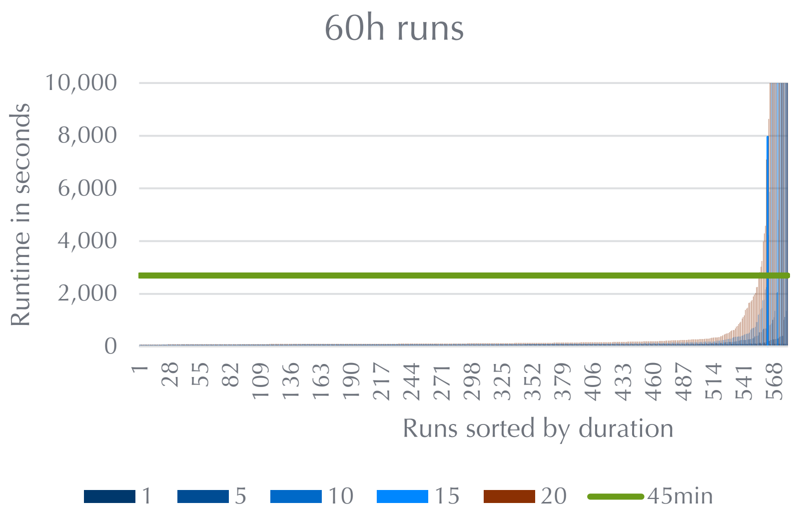
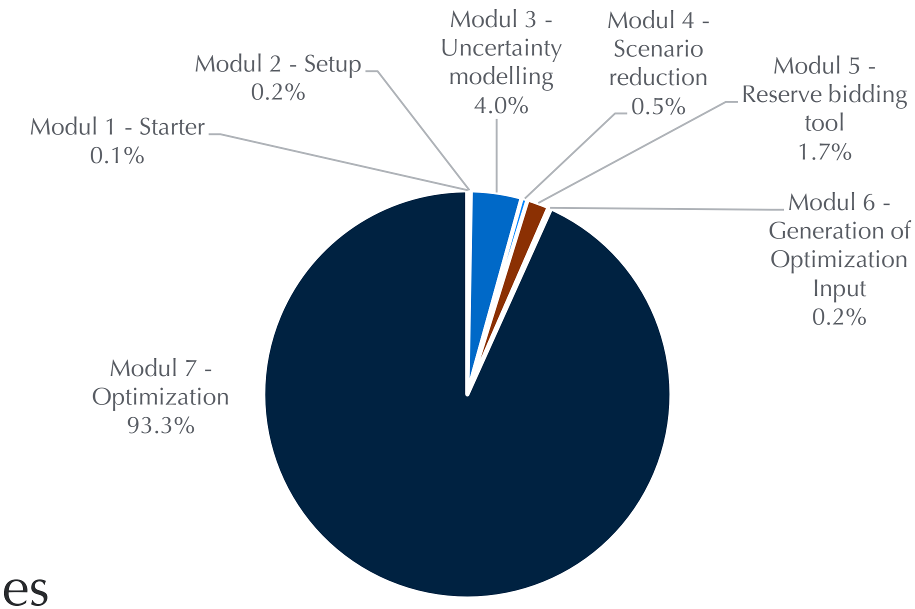
# Computation times – a closer look

Results (so far)

- All runs were carried out on a desktop PC, no parallel runs
  - 16 GB RAM, 3.4 GHz CPU (4 cores)
- Computation times rise with no. of scenarios (as expected)
- Market lead times require a timely result (e.g. < 45 min for FRR-m)




→ Optimization dominates runtimes

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# Conclusions



- Our research shows (again) **the validity and potentials of the stochastic optimization approach** and demonstrates its **applicability in the developed, very detailed prototype**

- The **curse of dimensionality** of stochastic optimization models is profound for equation-driven models such as CHP systems

- Unclear origin of early saturation point:
  - Optimization terminations due to exceeding runtimes, pre-optimization of reserve, problems in the interaction of price scenarios and bidding curves?
- This model is **still work in progress**!



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# Further planned improvements



- Improvements planned until paper publication
  - Modelling of “perfect foresight”
  - Modelling of daily FCR provision
  - Having full-year runs

- Possible improvements for further investigations
  - Improved consideration of **Continuous Intraday** trading (→ lack of uncertainty data)
  - (Improved) consideration of electricity market **bidding curves and block products**
  - Investigation of **problem simplifications / decomposition opportunities** to in turn allow for higher no. of scenarios

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# Thank you for your attention!

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