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The prospect of heat from CHP with green fuels – a comparative analysis for 2035 using the StoOpt framework

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Investitionen in Wachstum und Beschäftigung
Ministerium für Wirtschaft, Energie, Industrie, Mittelstand und Handwerk des Landes Nordrhein-Westfalen
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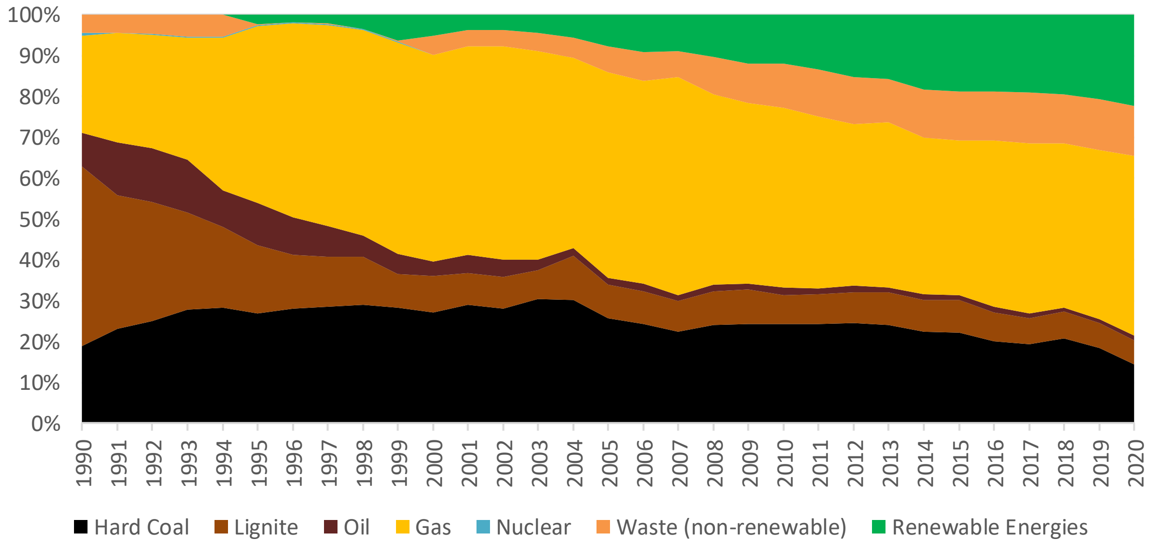
Agenda

The prospect of heat from CHP with green fuels – a comparative analysis for 2035 using the StoOpt framework

Heat generation in the decarbonized energy system

- Heat generation is a **key element** of the sustainable energy system of the future
- Decarbonization of heat has been a stony path so far
  - 49,5% of households use natural gas, 25% heating oil
  - About **14% of apartments** in Germany are connected to **district heating networks** (2020, BDEW)
- In 2020, **roughly 22 percent of district heating** came from renewables
- Two hopes for "quick" decarbonization
  - **Electrification and renewable expansion** in both the electricity and heat sector, i.e. using large-scale Power-to-heat applications (P2H)
  - **(Import of) Green Hydrogen, e.g. for CHP applications**
  - P2H especially for low-price periods, CHP for higher-price periods → **A perfect match?**

Shares of energy carriers in fuel usage for district heating



Source: BMWK, „Energiedaten gesamt" (Jan. 2022)

- With
  - Existing CHP plants as a dominant sector-coupling technology
  - The supposed electrification of heating
  - The (potential) generation and use of green hydrogen

depending on the path chosen, **very different heating energy futures** may arise.

- Questions:
  - What happens to heating costs, if renewable expansion is not sped up by a lot and electricity prices increase?
  - What happens to the costs, if a lot of excess renewable plants are built?
  - What happens to H_2-fired power plants in contrast to natural gas-fired plants?

- This work is aiming to **quantify differences** between a pluralility of diverse scenarios from the point of view of **individual heating grid operators**
  - For this, the stochastic optimization framework *StoOpt* is used

Background: the research project StoOpt.NRW

- Partners:
  - Chair of Energy Economics (EWL) of UDE (consortium leader)
  - ProCom GmbH
    - Medium-sized (about 50-100 employees) IT consultant firm
    - Based in Aachen (Germany, HQ) and Ningbo (China)
    - Provider of various energy market-related IT services and applications
    - Was taken over by Volue ASA after the project ended (in 2021)
- 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)

Basic concept of stochastic optimization

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Methodology (1/5)

1 2 3 4 5 6

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

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Quick overview: chosen approaches

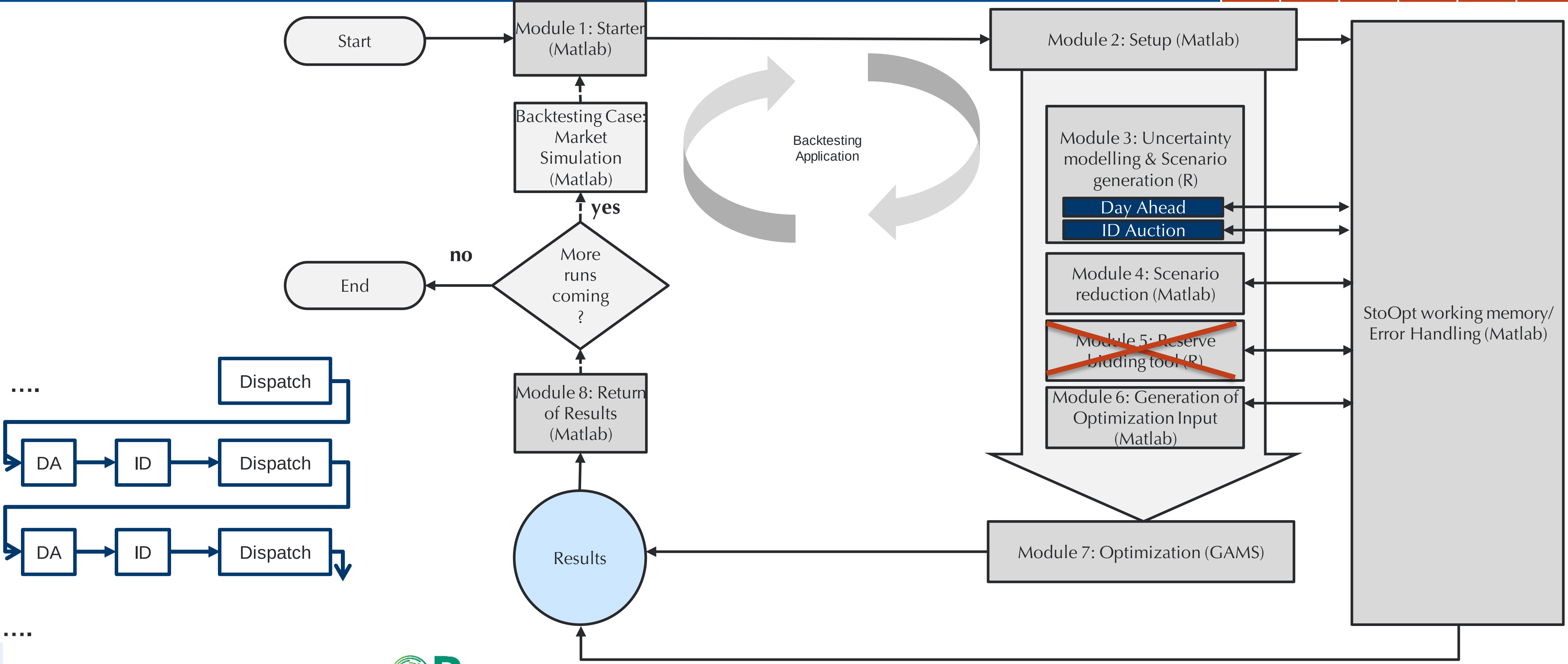
- Uncertainty modelling of short-term electricity prices
  - Focus on day-ahead electricity price uncertainty, modelled by panel and rolling window approach, LASSO (cf. Beran, Vogler and Weber, 2017)
  - Heat demand is not assumed to be uncertain (but uncertainty modelling was also addressed in the initial research project)
    - Timeseries simulated with approach by Felten et al. (2017) for district heating network with about 876 GWh of yearly heat demand

- Scenario generation and reduction
  - Monte Carlo simulation of 1000 price paths, scenario reduction based on approach of Römisch and Heitsch (2003)

- Stochastic unit commitment and dispatch optimization
  - Two-stage MILP model (based on Dietrich, Furtwängler and Weber, 2020)
  - Profit maximization of a heat portfolio, about 80 defined restriction types, max. optimization time: 15 minutes
  - Optimality criterion: max absolute gap of 1000 (Euros)

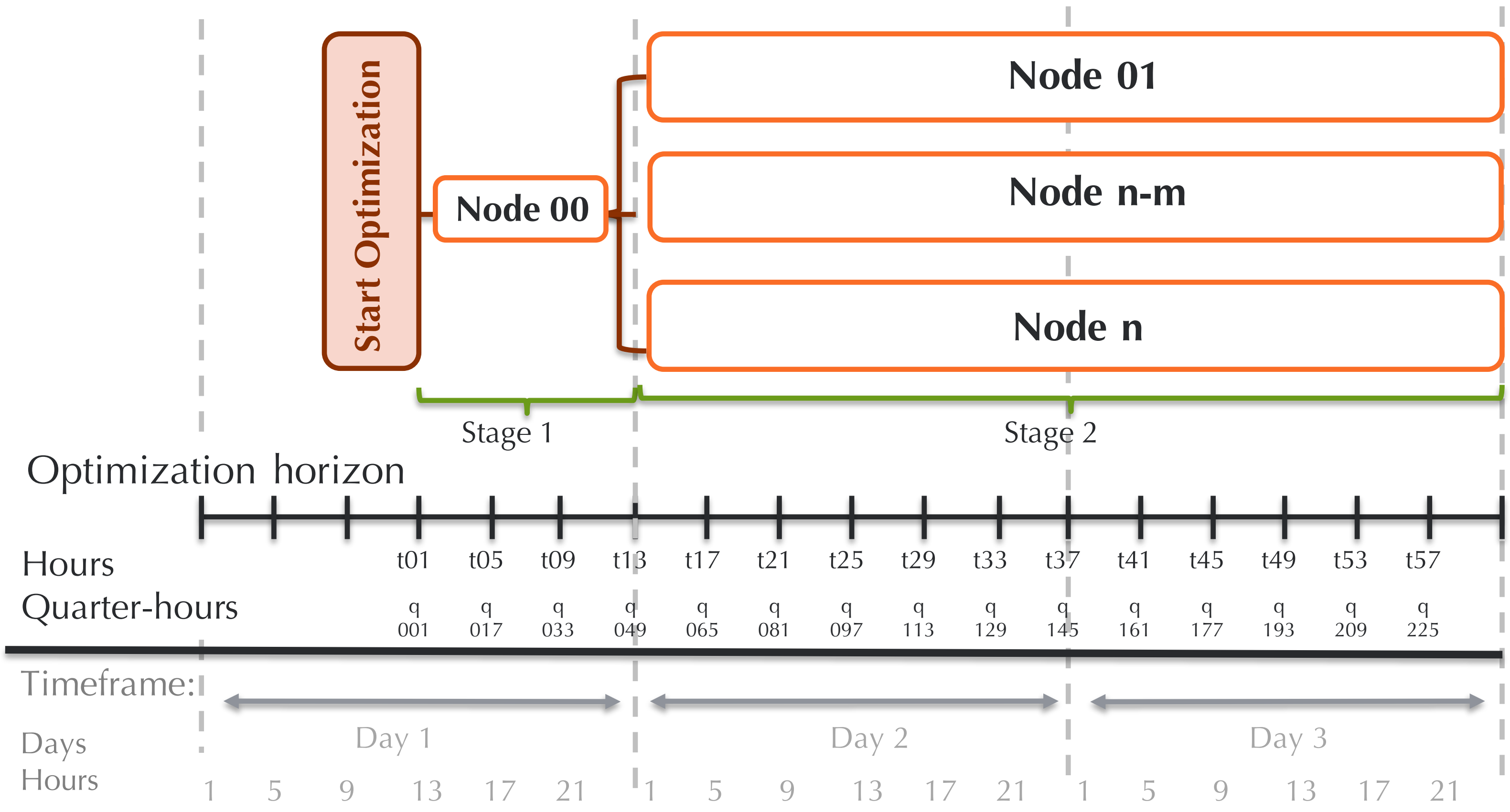
Implementation of the calculation kernel

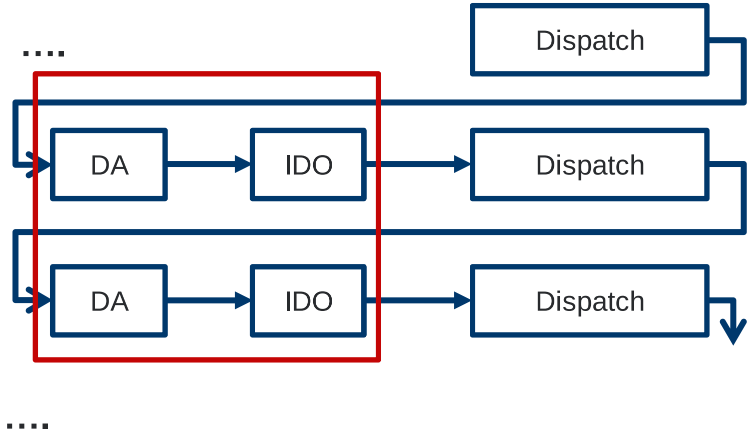
Methodology (3/5)



Optimization horizon and uncertain time periods – Day-Ahead and Intraday Opening Auction

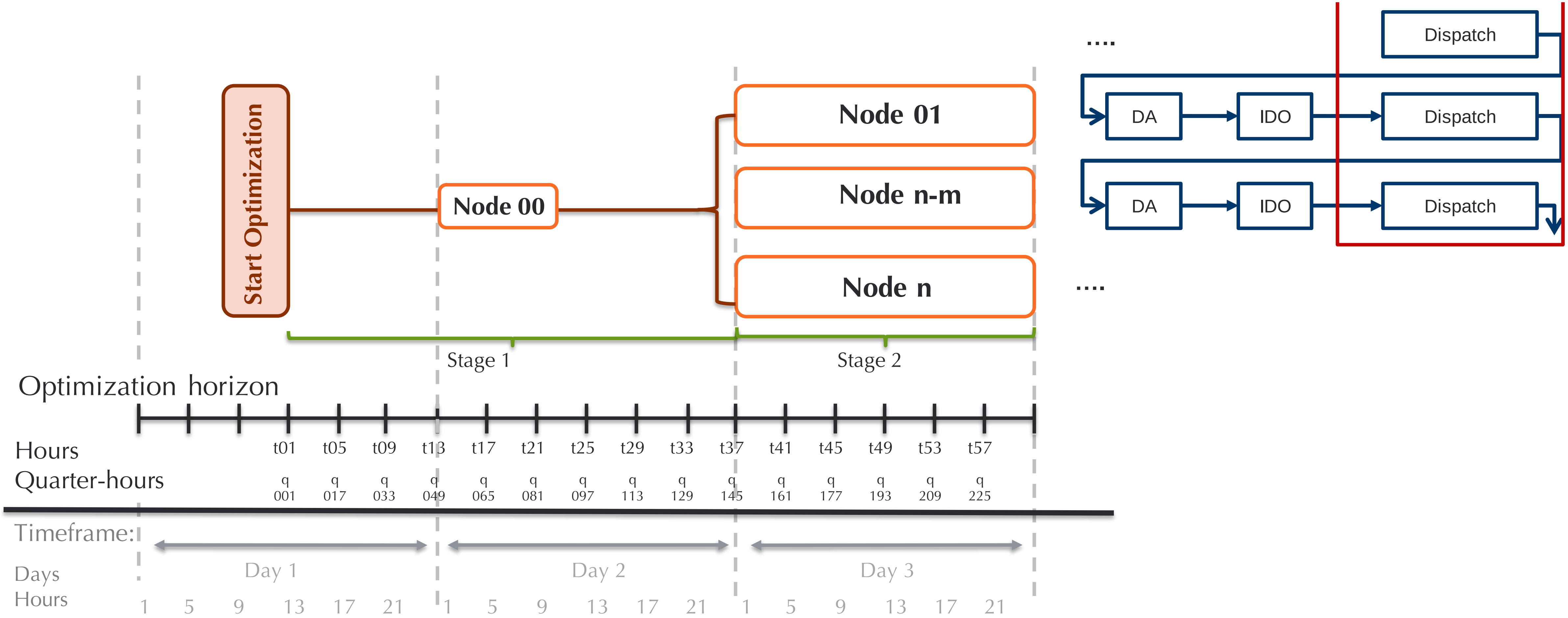
Methodology (4/5)





Optimization horizon and uncertain time periods – Dispatch

Methodology (5/5)



Qualitative description & assumptions

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Long-term scenarios

1 2 3 **4** 5 6

- Three scenarios are modelled – to obtain three very different, but consistent, energy futures for 2035
  - Scenario A: „2035 before the crisis": Data & Assumptions according to **Grid Expansion Plan 2020**
  - Scenario B: „2035 adjusted": Scenario A, but taking into account the **Easter Package goals** of the German Government for renewable generation and electrification of heat and transport, and higher gas prices
  - Scenario C: „2035 all-renewable": electricity sector has been **fully decarbonized** by abundant renewable generation installation, plus high-speed sector coupling

Amounts 2035 [TWh]	Total electricity demand	Total generation from PV	Total generation from Wind	Net Cross-Border exchange (Import: +)
A	657.2	102.0	236.7	+67.7
B	750.0	186.3	314.4	-24.4
C	1,070.0	171.4	1,093.1	+79,6

Prices 2035 [€/MWh]	Natural Gas	H2	CO2
A	25.60	80.00	77.00
B	45.00	80.00	77.00
C	-	80.00	-

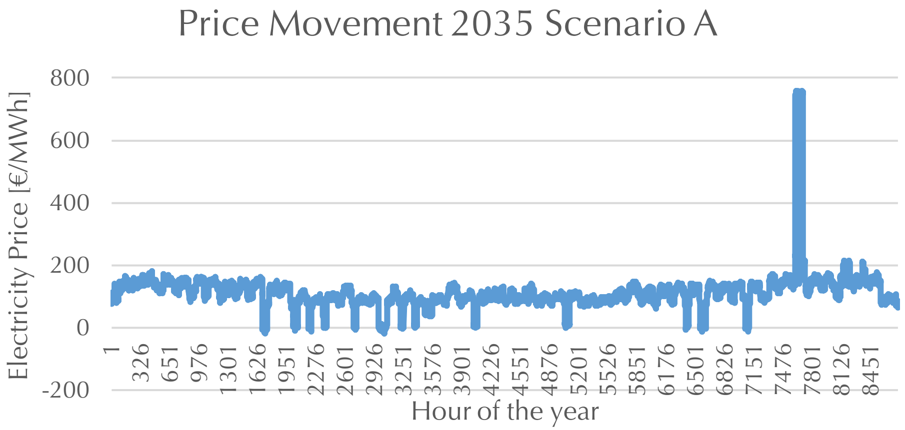
Capacities 2035 [GW] (excerpt)	Natural Gas / CHP	H2 /CHP
A	28.35 / 21.70	14.13 / 12.70
B	28.35 / 21.70	14.13 / 12.70
C	-	202.08 / 130.87

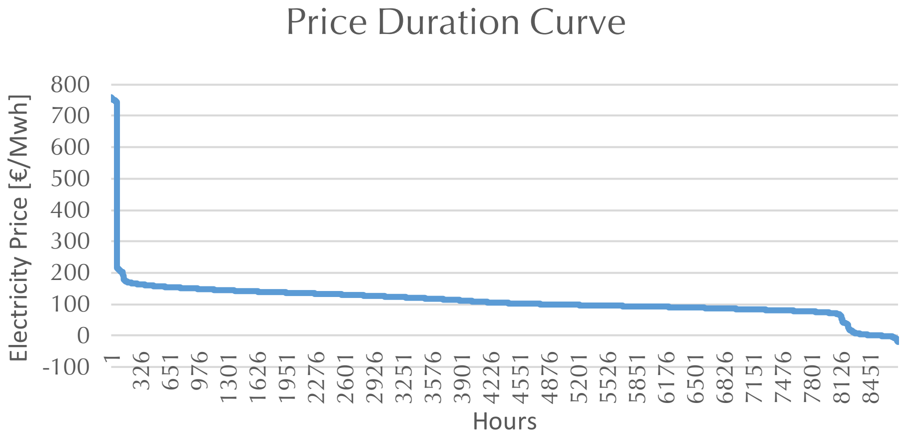
Methodology & Results (Scenario A)

- Application of an existing model-chain to generate hourly electricity price profiles for 2035
  - **ParFuM**: Parsimonious Fundamental Model (Kallabis et al., 2015), (Beran et al., 2018)

  → Fundamental prices (assumption: no negative prices with negative residual load)
  - **Hybridspot**: Uncertainty modelling of day-ahead prices and the deviations of quarter-hourly IDO prices

  → Extension of fundamental price movement by a stochastic price pattern (ARMA(1,1)-GARCH(1,1) model fitted with historical price deviations)



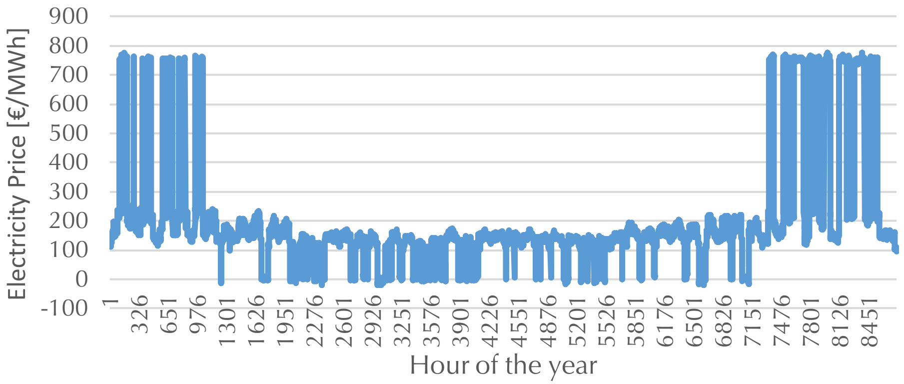


Parameter	Value
Min	-19,75
Max	759,48
Mean	110,35
Median	103,73

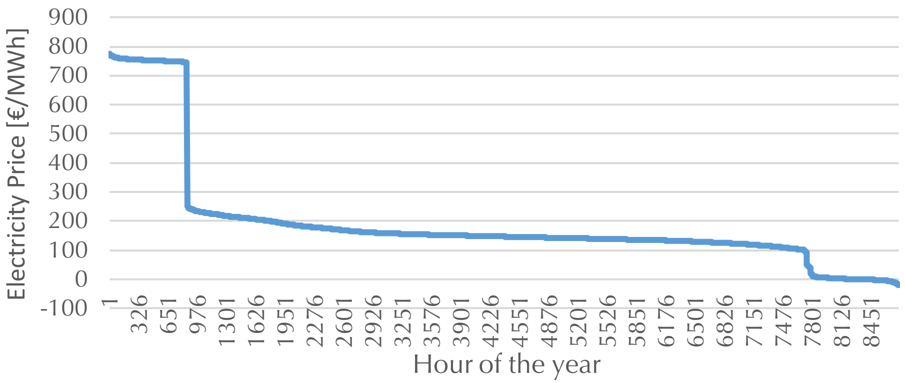
Price Scenario Results (Scenario B & C)

Long-term scenarios

Price Movement 2035 Scenario B

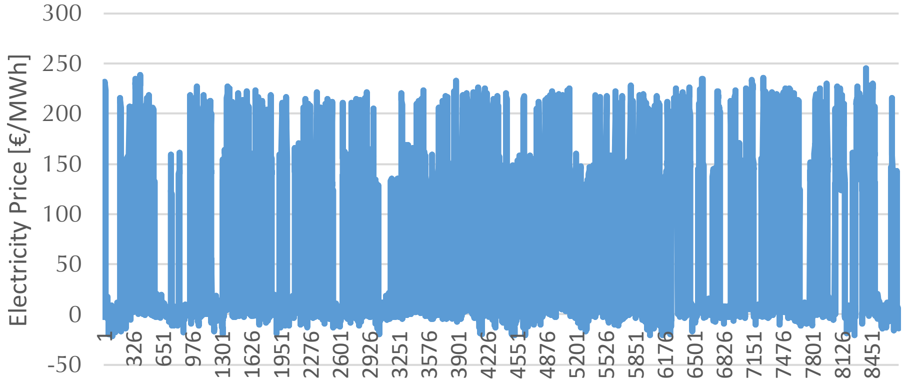


Price Duration Curve

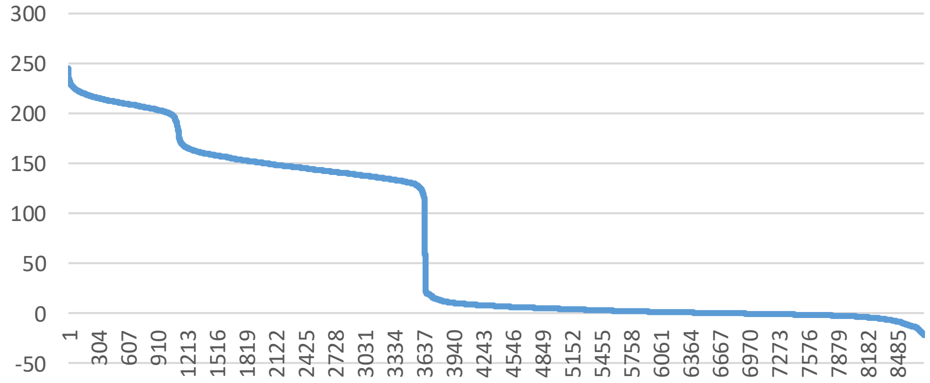


Parameter	Wert
Min	-20,21
Max	775,73
Mean	196,20
Median	146,74

Price Movement 2035 Scenario C



Price Duration Curve



Parameter	Wert
Min	-21,44
Max	244,92
Mean	70,13
Median	7,33

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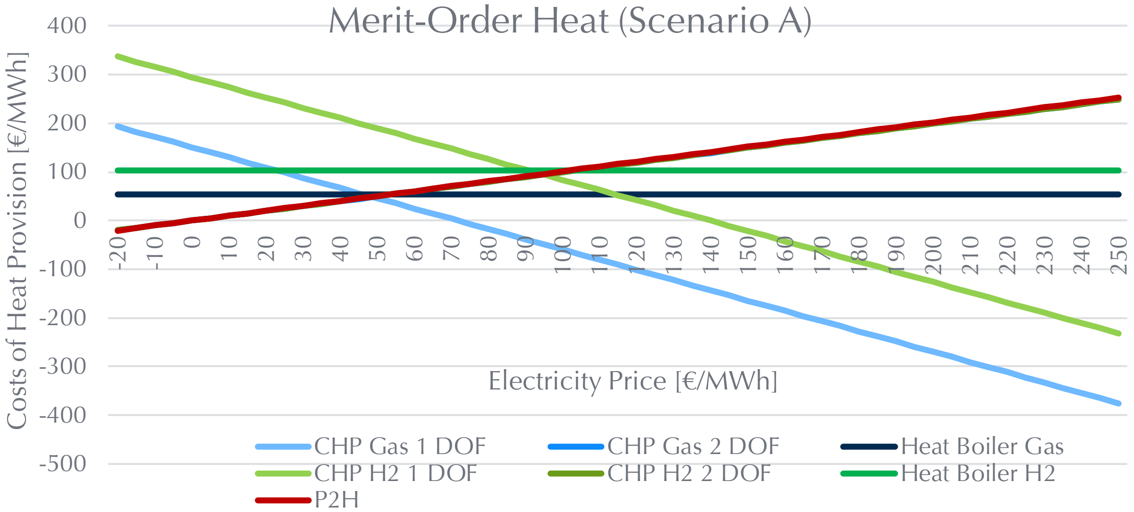
Stochastic Optimization: Investigated Cases

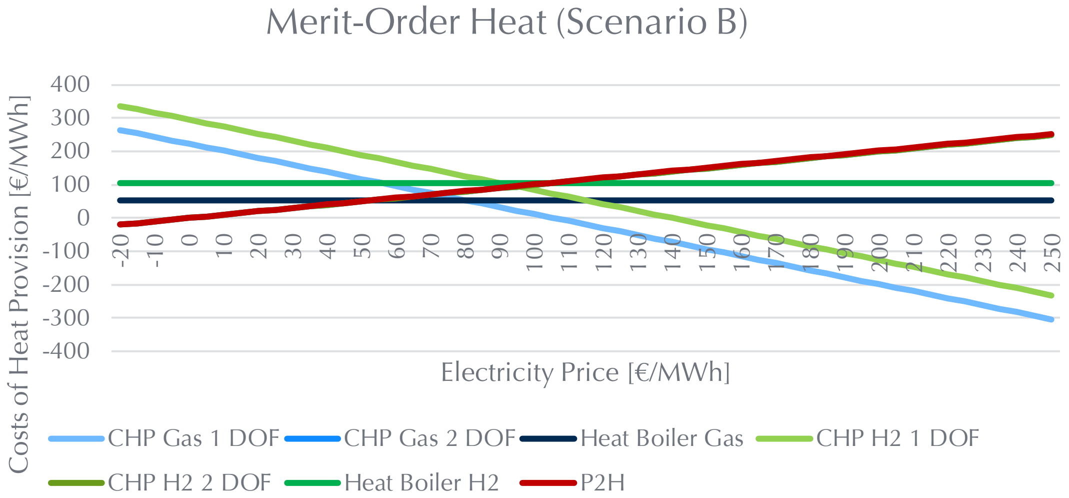
- Application of the StoOpt Model with perfect foresight, respectively 1 and 10 scenario(s) under uncertainty to full-year 2035
- District heating grid with annual heat demand of 876 GWh_{th} and maximum heat demand of 263 MW_{th}
- For scenario A & B:
  - Case 1a & b:
    - CCG/HT CHP plant with 2 degrees of freedom (extraction condensing turbine), max power: 259 MW_{el}/161 MW_{th}, start-up cost: 24k€
    - Heat Boiler with efficiency of 77% (large enough to cover demand at any time)
    - Power-to-Heat plant with efficiency of 99% (100 MW_{el})
    - Heat Storage with max. capacity of 1100 MWh_{th}
  - Case 2a & b:
    - Gas motor plant with 1 degree of freedom, max. power 206 MW_{el}/ 206 MW_{th}
    - Heat Boiler, P2H, Heat storage as above

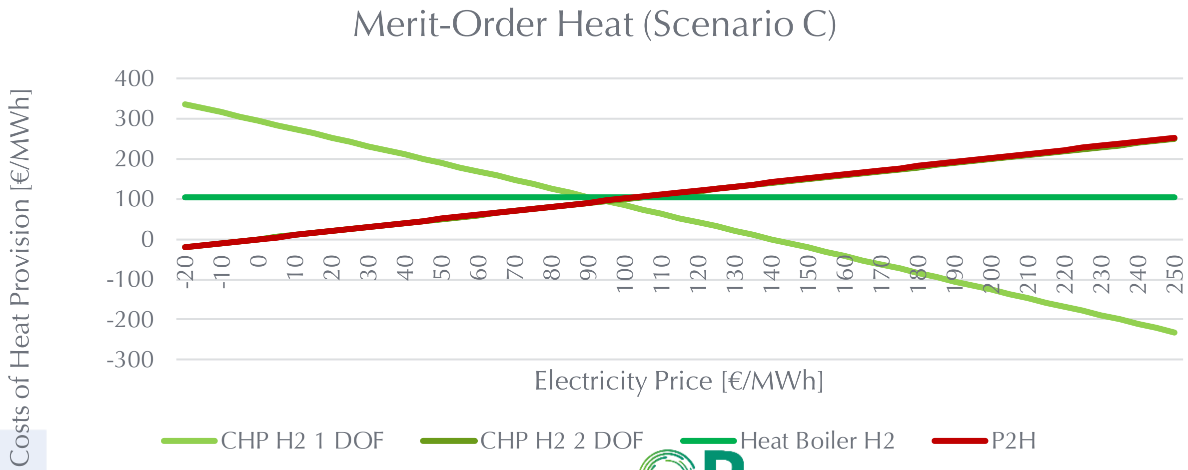
    With a = Natural gas and b = H_2
- For scenario C: only Case 1b & 2b

Pre-Analysis: Merit-Order of Heat provision for the modelled long-term scenarios

Preliminary Results







Cheapest heat provision technologies:

# hours	Scenario A	Scenario B	Scenario C
CHP Gas	8144	7957	-
CHP H2	0	0	3999
P2H	616	803	5111

(Stochastic) Optimization: First Results (CHP)

- The obtained results of the StoOpt model are each contrasted to a reference case where only P2H and Boiler (**using the same fuel**) are available

  → Difference can be interpreted as contribution margin of a new investment

- Does an investment in new plants pay off (without capacity mechanisms, subsidies, or depending on higher heat revenues)?

  → Computation of an annuity that needs to be covered (CCGT CHP: ~37.48 mln €, gas motor CHP: ~27.84 mln €)

  – Assumptions:

    – lifetime: 25 a, investment cost of 1170 €/kW_{el} for CCGT (gas motors: 775 €/kW_{el}), O&M cost 3% of invest for CHP (gas motors: 4,5%), interest rate: 8%

First Results: Annual profit (=contribution margin – annuity)

1 scen (perfect foresight with rolling horizon)	Scenario A	Scenario B	Scenario C
Gas CHP	+52.94 mln €	+190.83 mln €	-
H2 CHP	-29.90 mln €	+126,50 mln €	-15.83 mln €

1 scen (uncertainty)	Scenario A	Scenario B	Scenario C
Gas CHP	+25.94 mln €	+138.19 mln €	-
H2 CHP	-44.03 mln €	+94.48 mln €	-105.83 mln €

10 scen (uncertainty)	Scenario A	Scenario B	Scenario C
Gas CHP	+45.18 mln €	+177.63 mln €	-
H2 CHP	-36.46 mln €	+113.47 mln €	-40.10 mln €

First conclusions & next steps

- The first results indicate that
  - **High price levels** (due to scarcity) still could lead to business cases for natural gas CHP in 2035
  - **Meanwhile, H_2 CHP could struggle** at the presumed fuel price level of 80 €/MWh
  - The supposed **„perfect match“** of H_2 CHP and Power-to-Heat **might be undercut** if generation hours of H2 CHP drop below the ex-ante supposed number of hours
  - Possible reasons
    - Prices fluctuate a lot during individual days (starting costs & short-term price uncertainty)
    - Prices don‘t rise over H_2 marginal cost level often

- Runs still pending:
  - 10 scenario cases (→ how much revenue can be saved by stochastic optimization?)
  - Case 2 (Natural Gas/H_2 motor plants) with lower investment costs

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Thank you for your attention!

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