Dealing with uncertainty and disruptive events in generation expansion planning models

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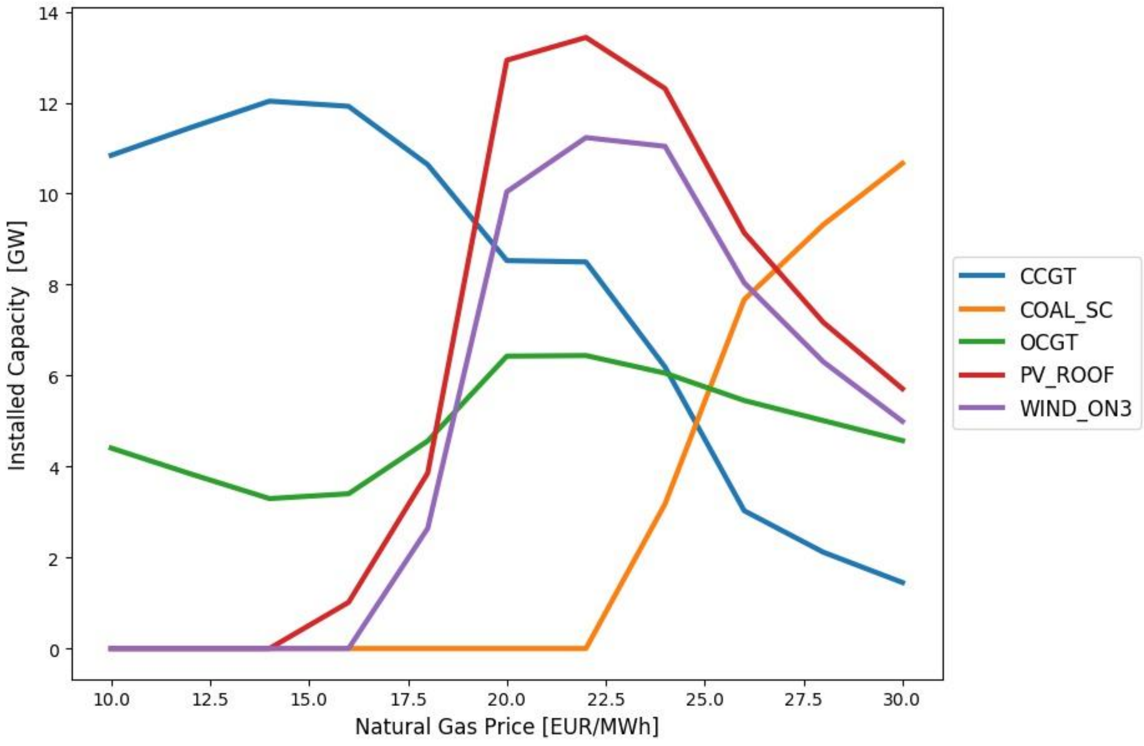
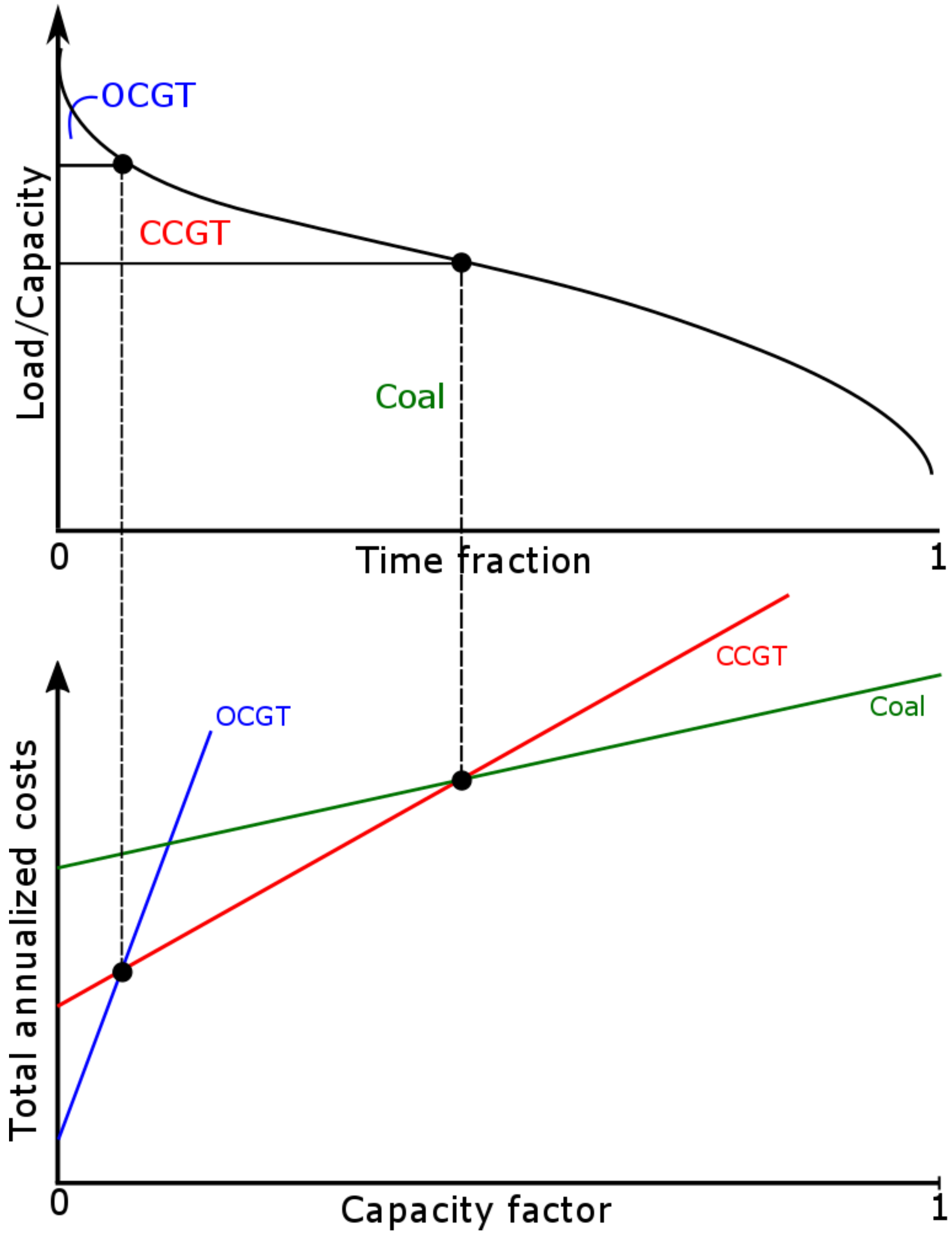
Context – Generation Expansion Models

- **Central planner** perspective
  - Minimize NPV total system cost (LP)
- **Long-term** energy planning
  - Planning horizon spanning multiple decades
- **Bottom-up** approach
  - Energy system modeled from technology level
  - No macro-economic feedbacks included
- **Cf. TIMES**

Context – Impact of Uncertainty

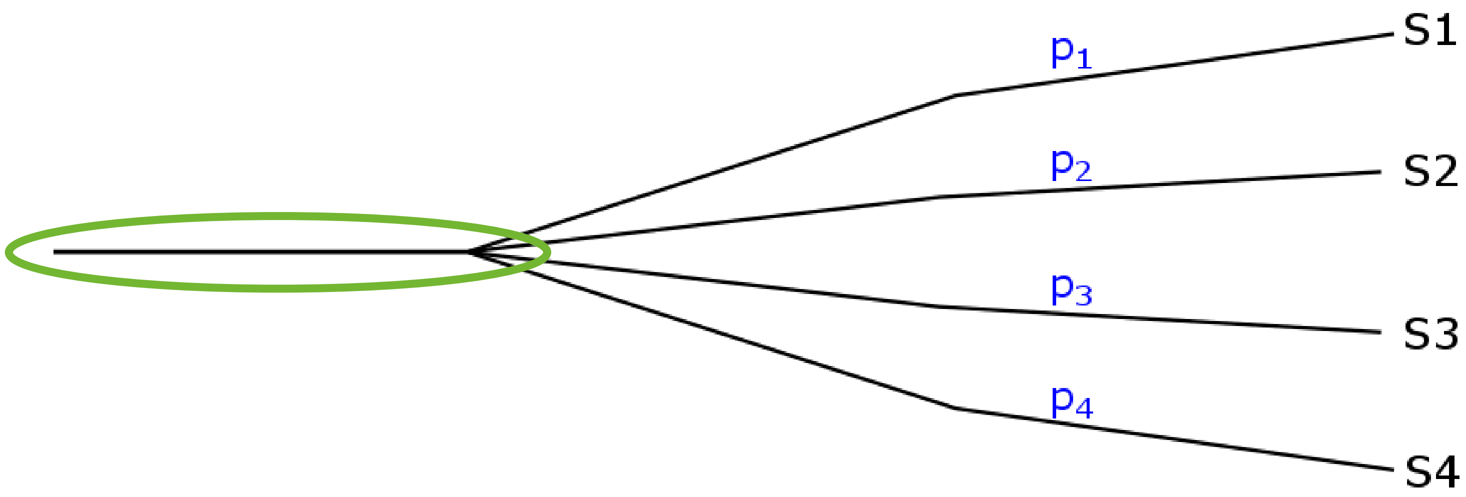
- Screening curve methodology…
- Sensitivity analysis…





Context - Stochastic programming

- **Aim: Decide on a single set of investments now, while facing uncertainty in the future.**



- Minimize **expected** NPV of total system cost

- First stage investment decisions are the same for every scenario

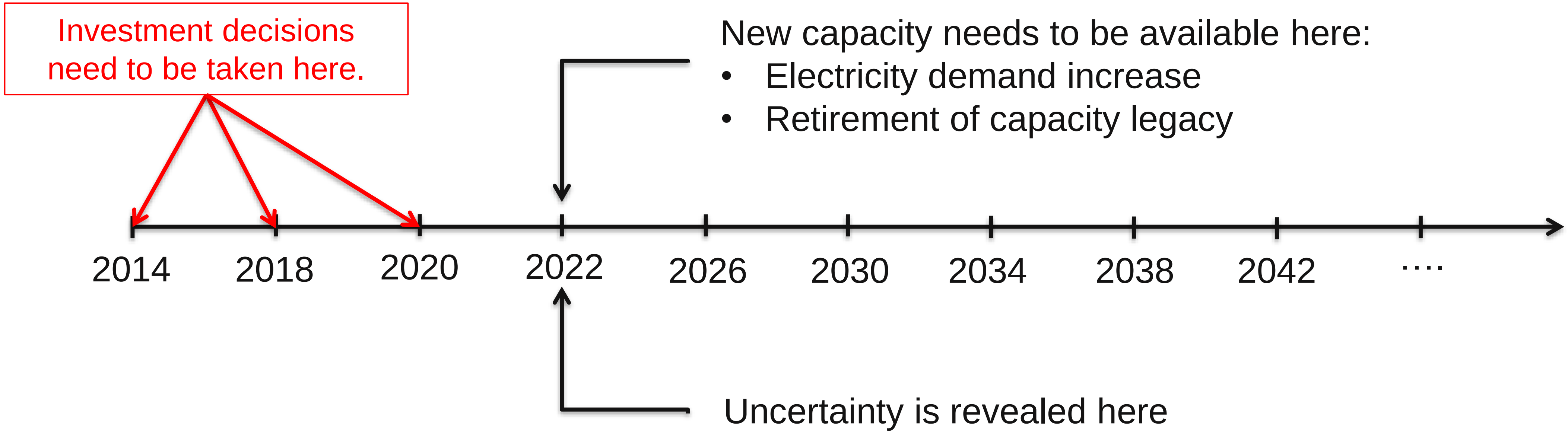
Research Questions

- How do investment decisions based on stochastic programming perform in comparison to other investment decisions?

- Does the occurrence of an unexpected shock have an impact on investment decisions?

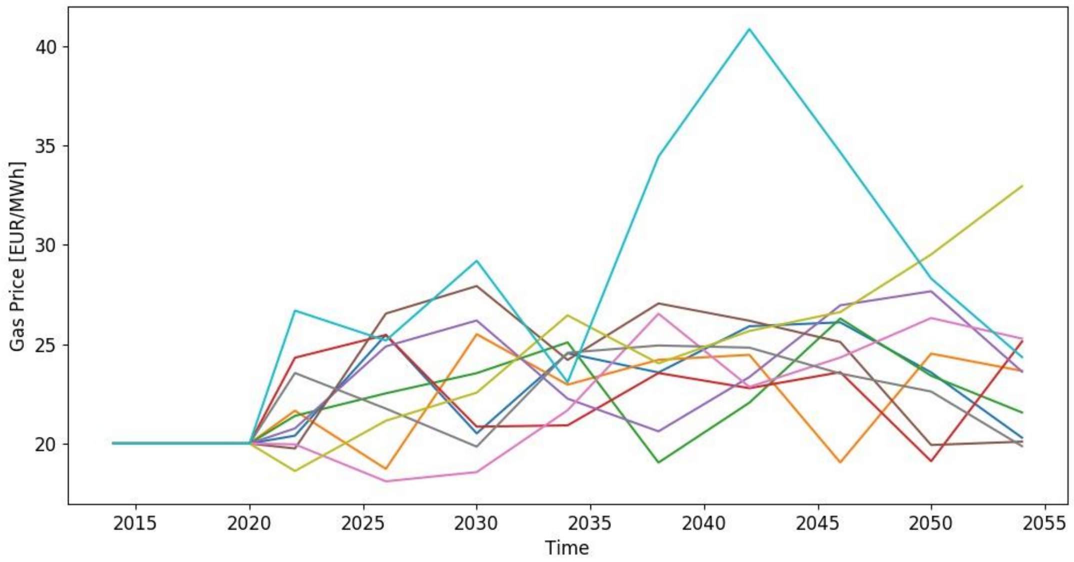
- In this presentation: gas price uncertainty based on historical data

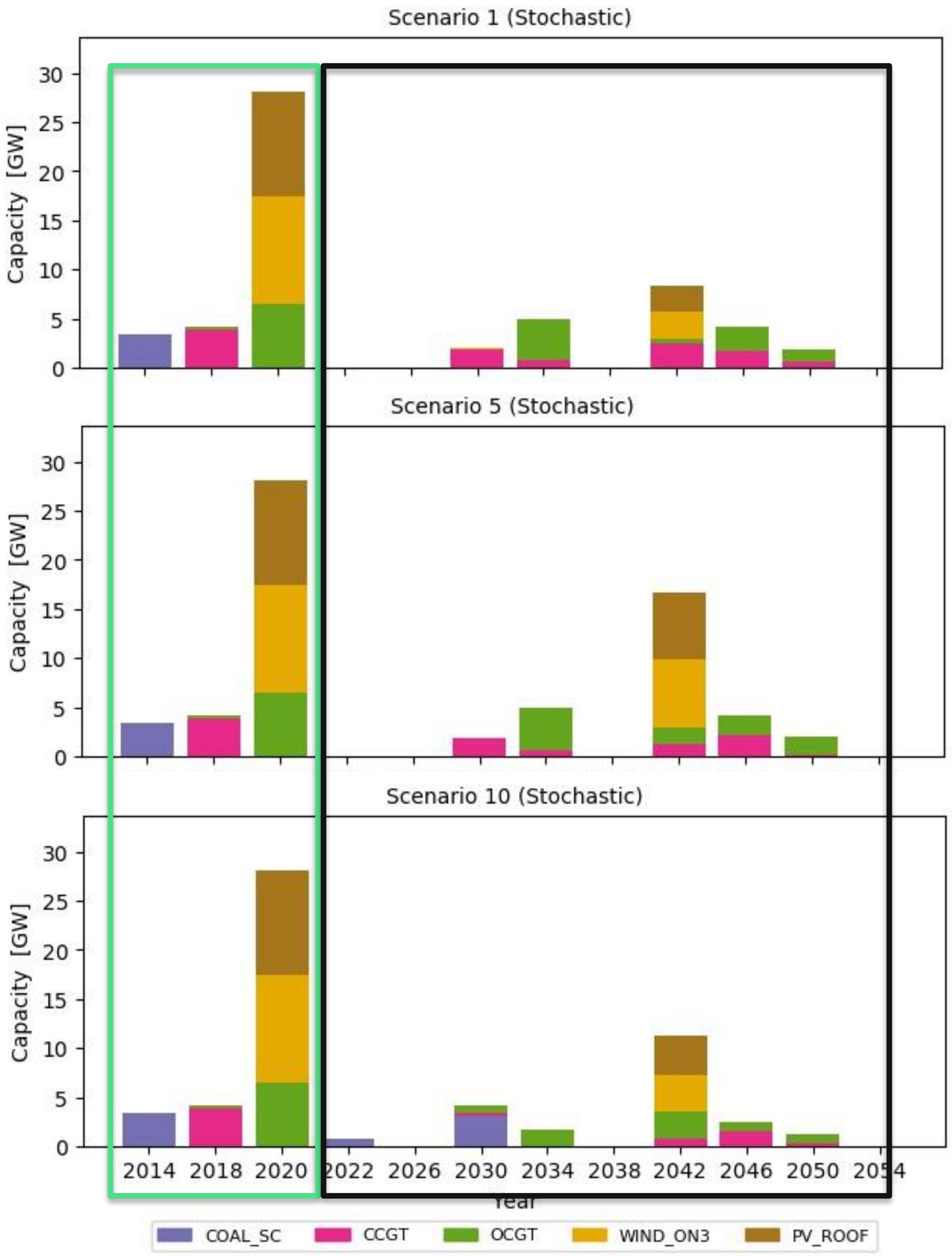
Methodology - Model Settings



- Determine first-stage investments based on:
  - Scenario tree – 10 scenarios (Stochastic programming)
  - Average Scenario (Deterministic)
  - Worst Case Scenario (Deterministic)

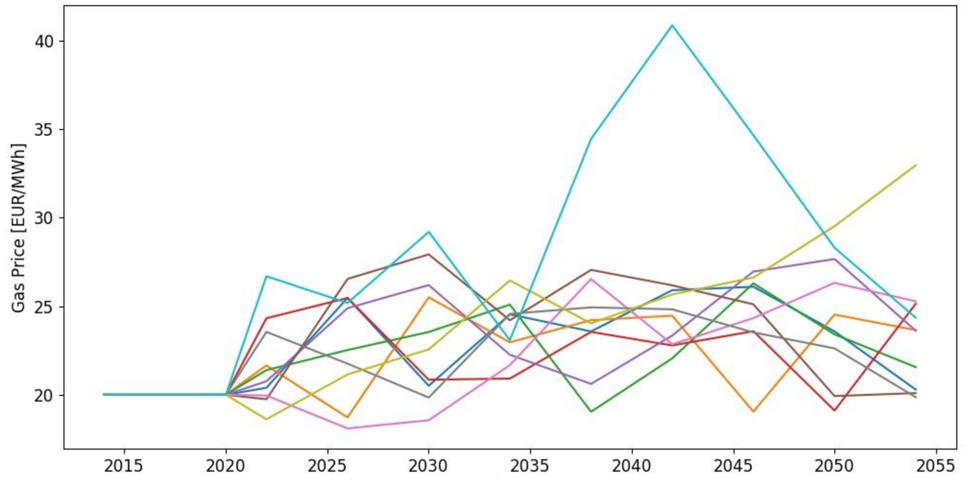
Results – Stochastic Investments

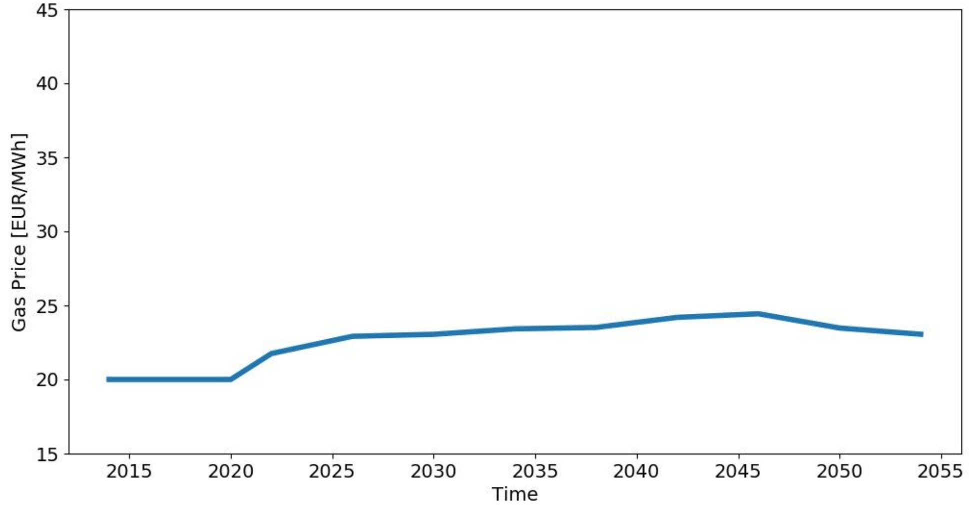


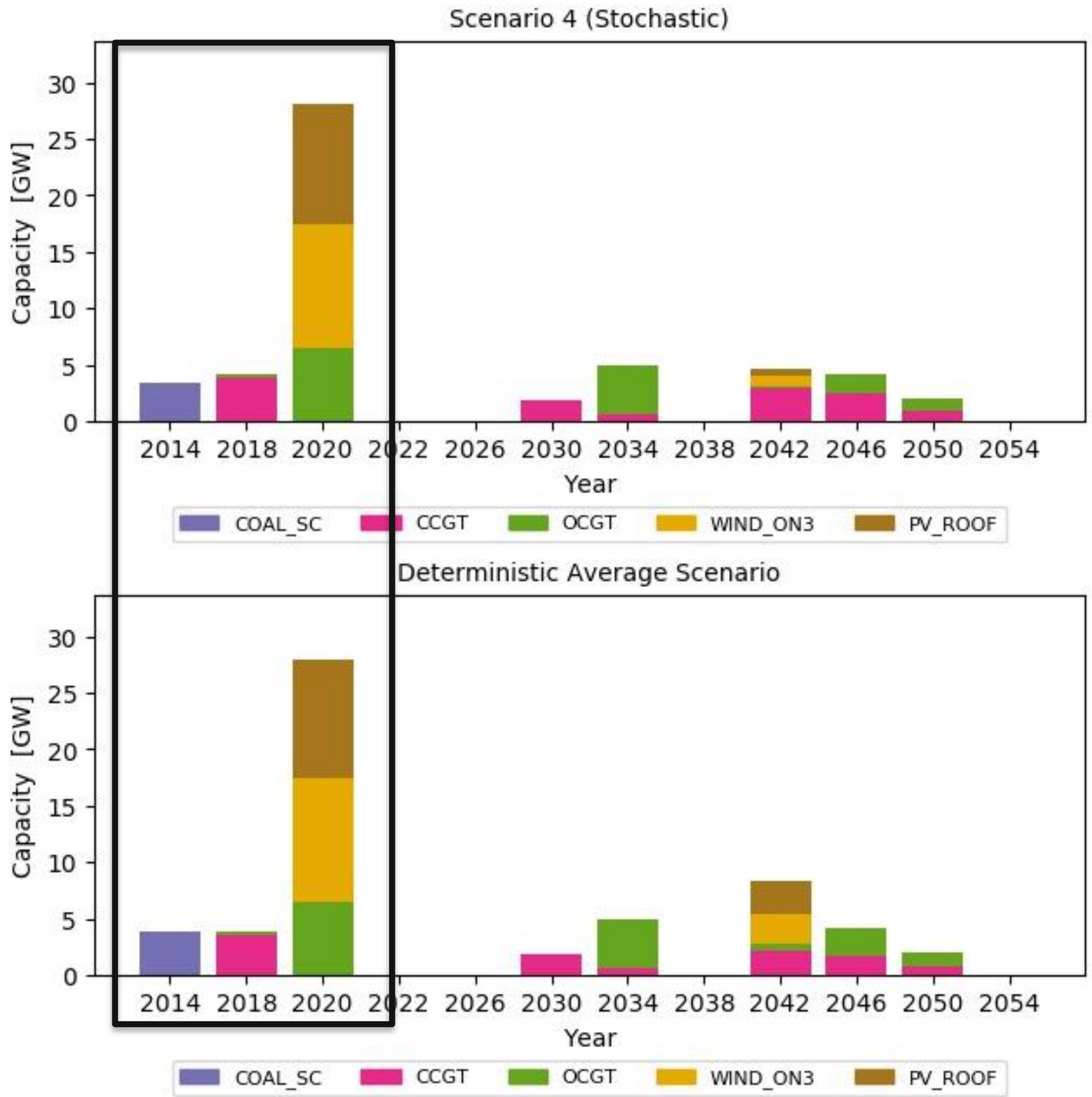


- First-stage investment decisions are identical for every scenario in the scenario-tree.
- Other investments are allowed to differ between the scenarios.

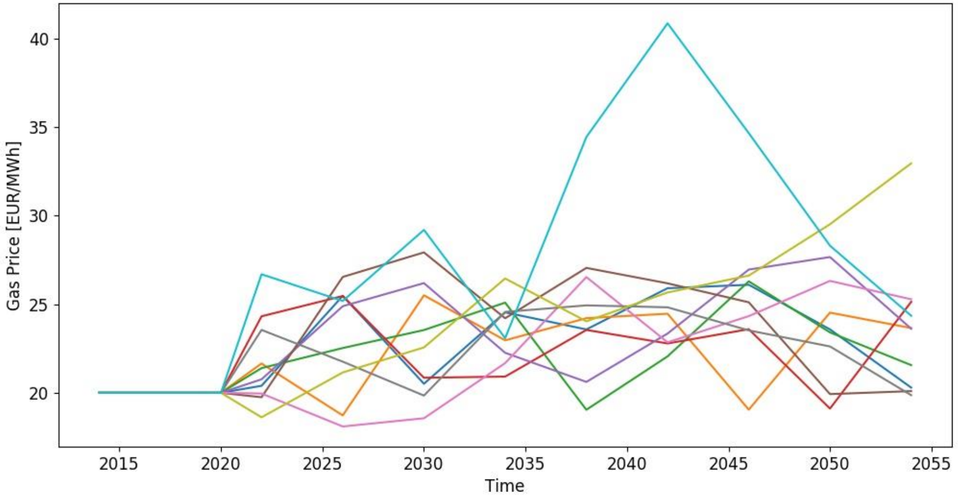
Results – Stochastic vs Deterministic Average Scenario

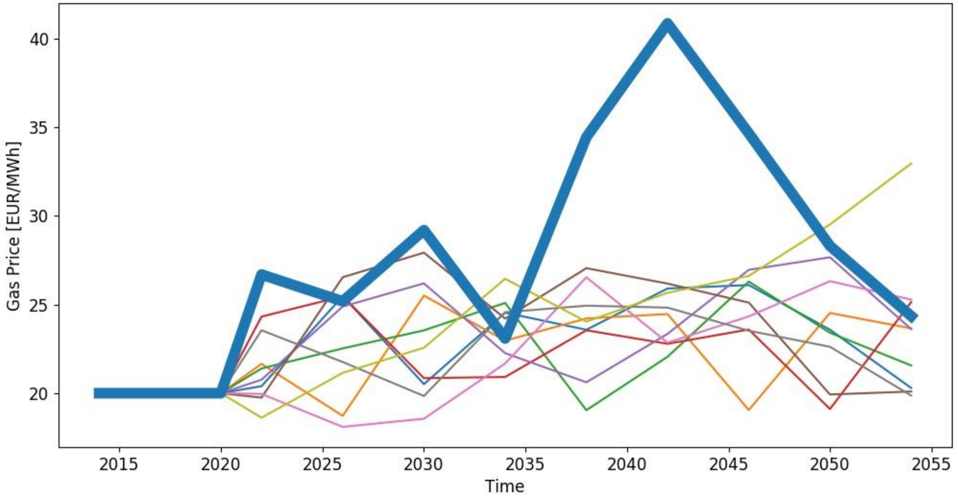


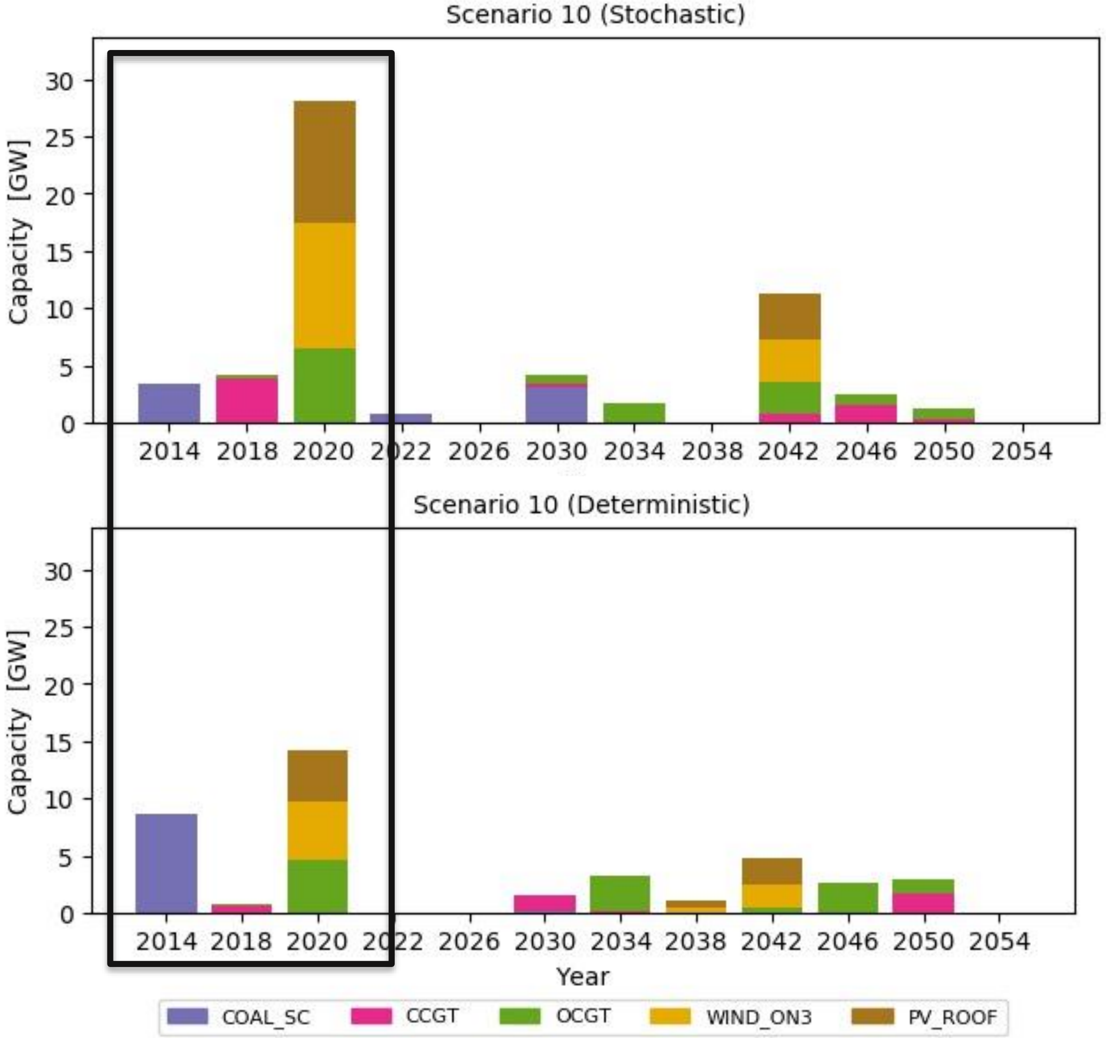




Results – Stochastic vs Worst Case

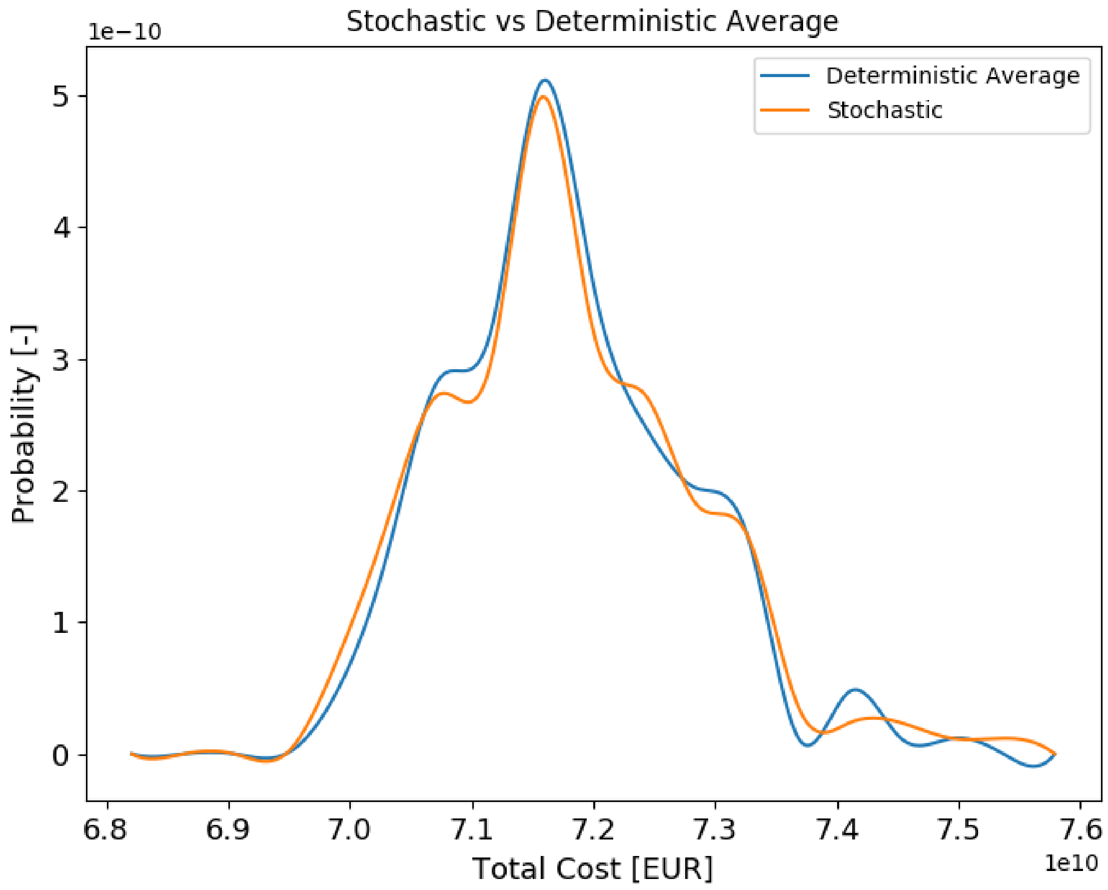


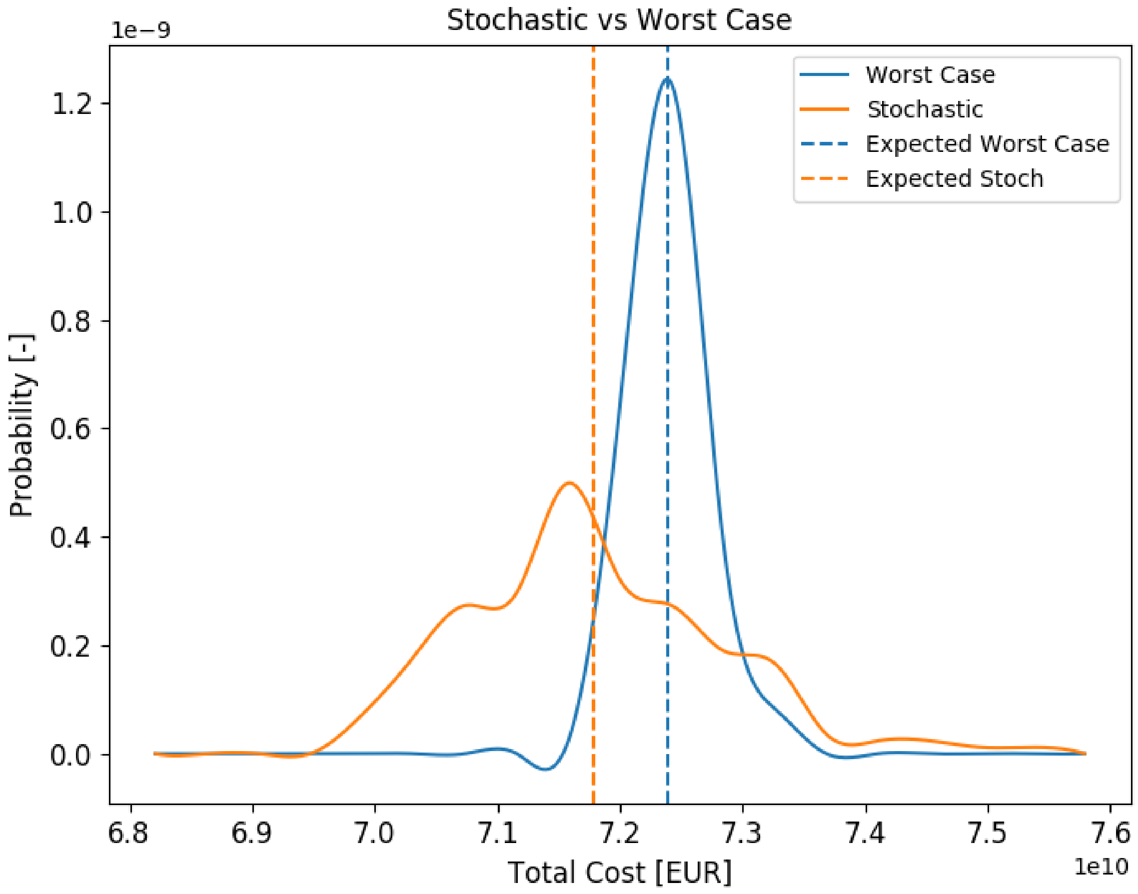




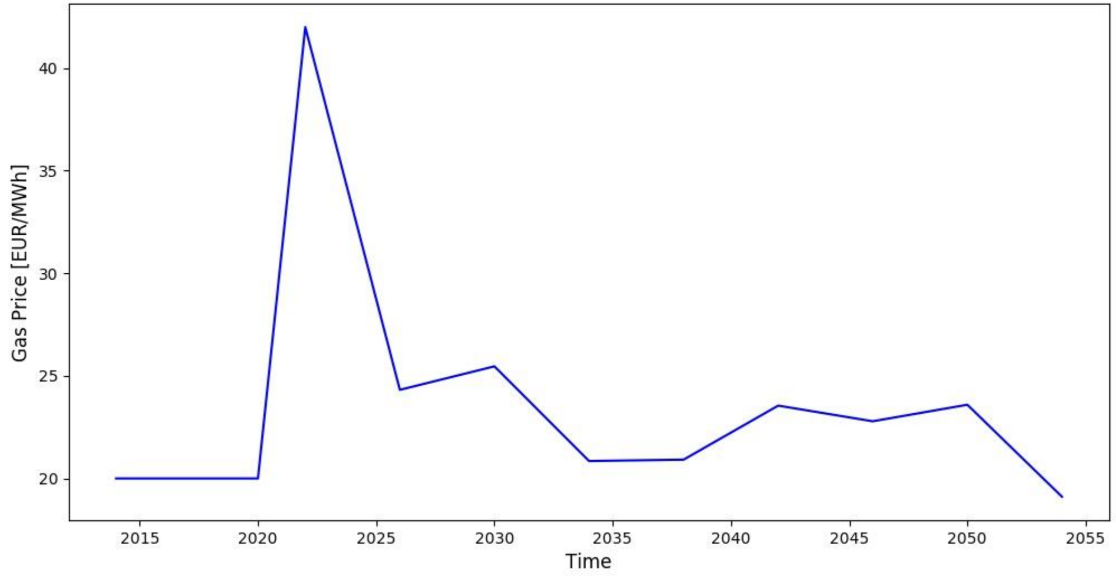
Results – Out-of-Sample Analysis

- Comparing cost distribution of 200 generated scenarios

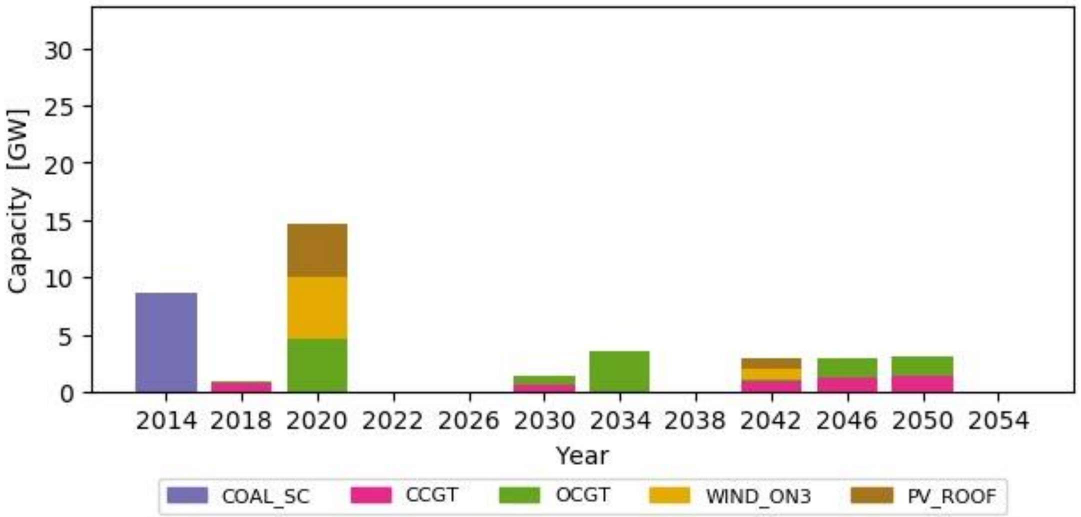




Results - Gas Price Shock



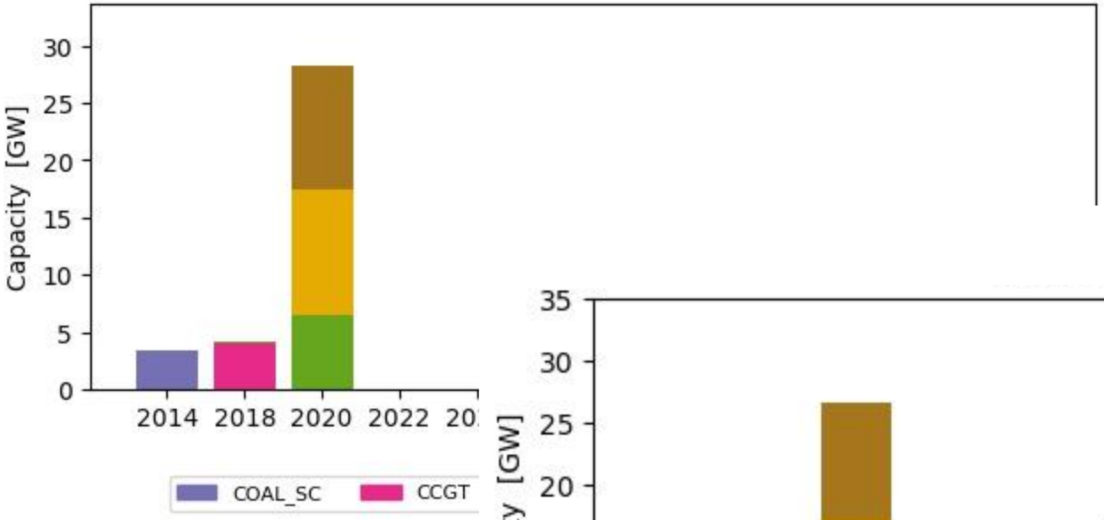
Deterministic optimization



- Gas price shocks do have an impact on optimal investments.
- From which probability do these shocks influence a SP solution?

Results - Gas Price Shock

1%



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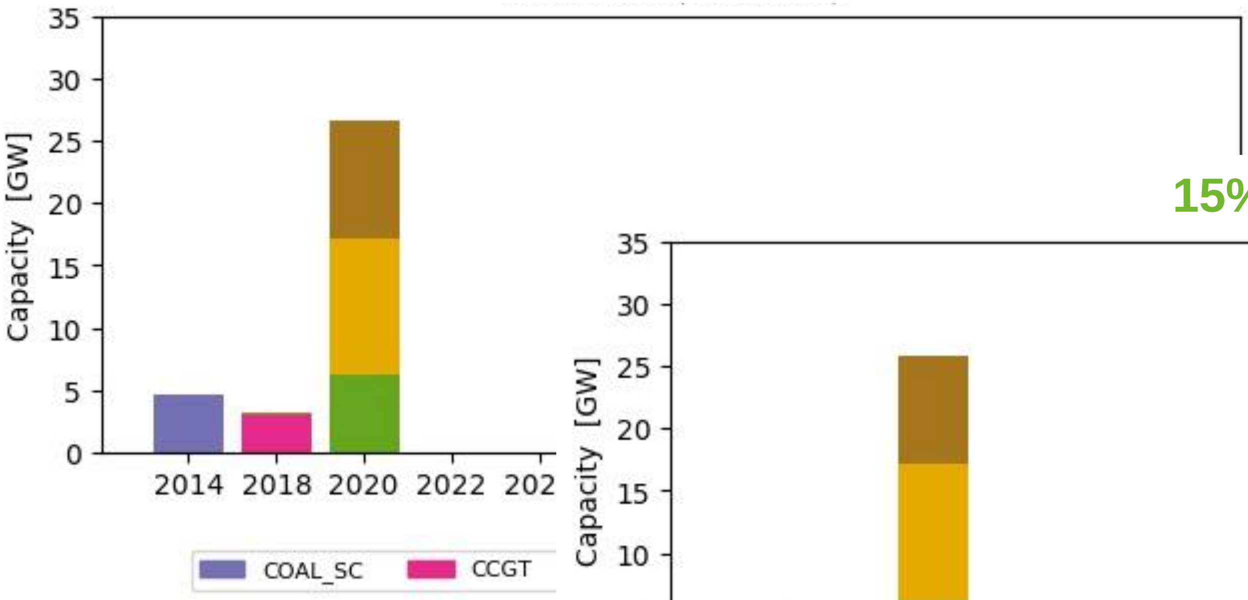

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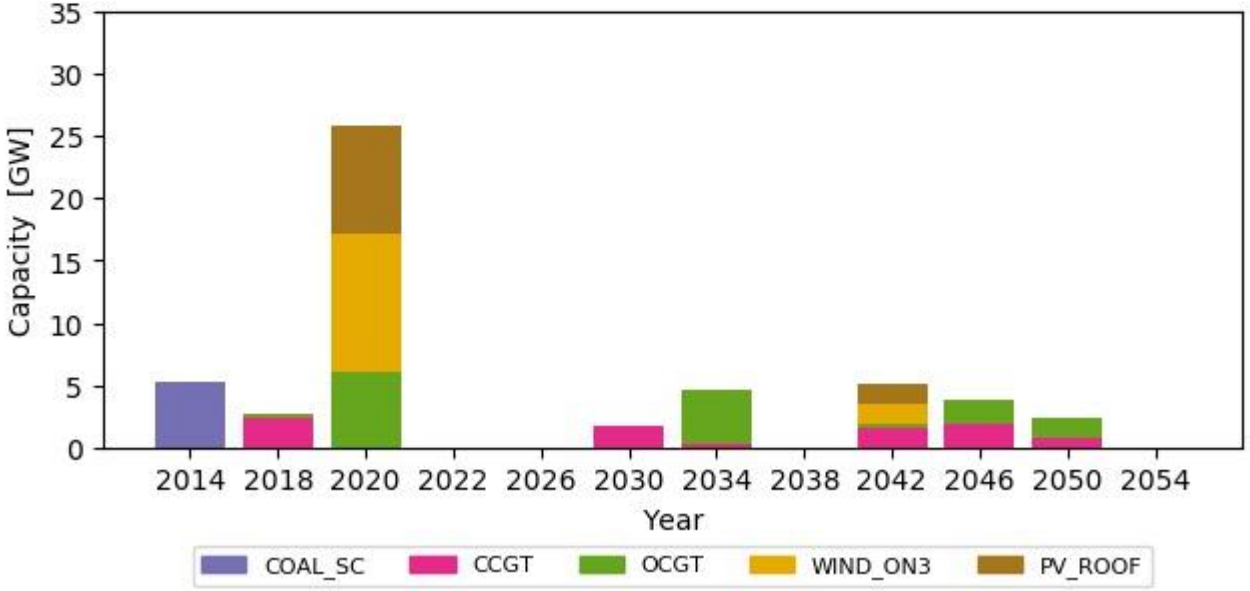


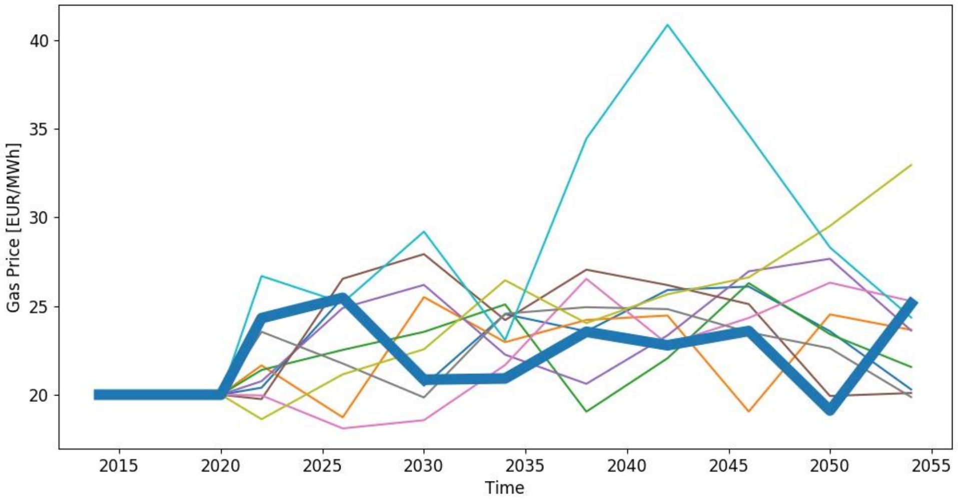
Conclusions

- In presented model setting:
  - Value of stochastic solution is strongly dependent on benchmark.
  - Difference between investment decisions based on SP and DA are small.
  - Compared to worst case scenario, SP has value on average.

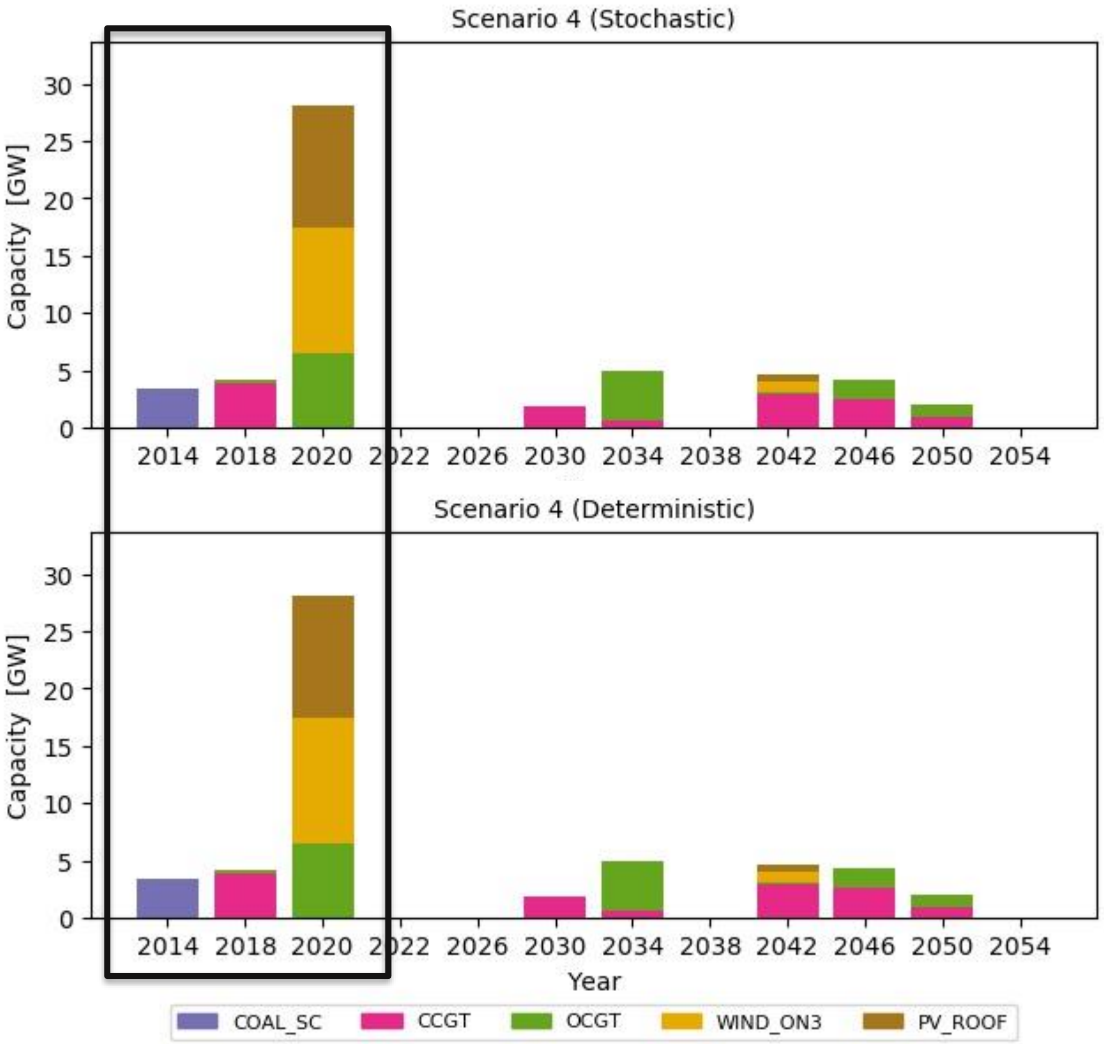
- Concerning unexpected shocks:
  - Impact of gas price shocks on stochastic solution are limited.
  - Need for rethinking scenario tree structure?

Results – Stochastic vs Perfect Foresight

- High probability scenario (p = 0.16)

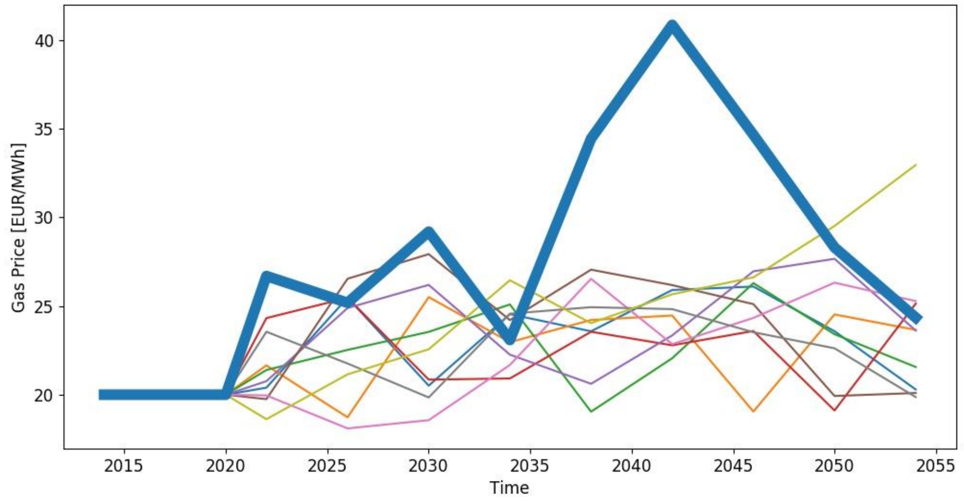


- Investment decisions are very much alike

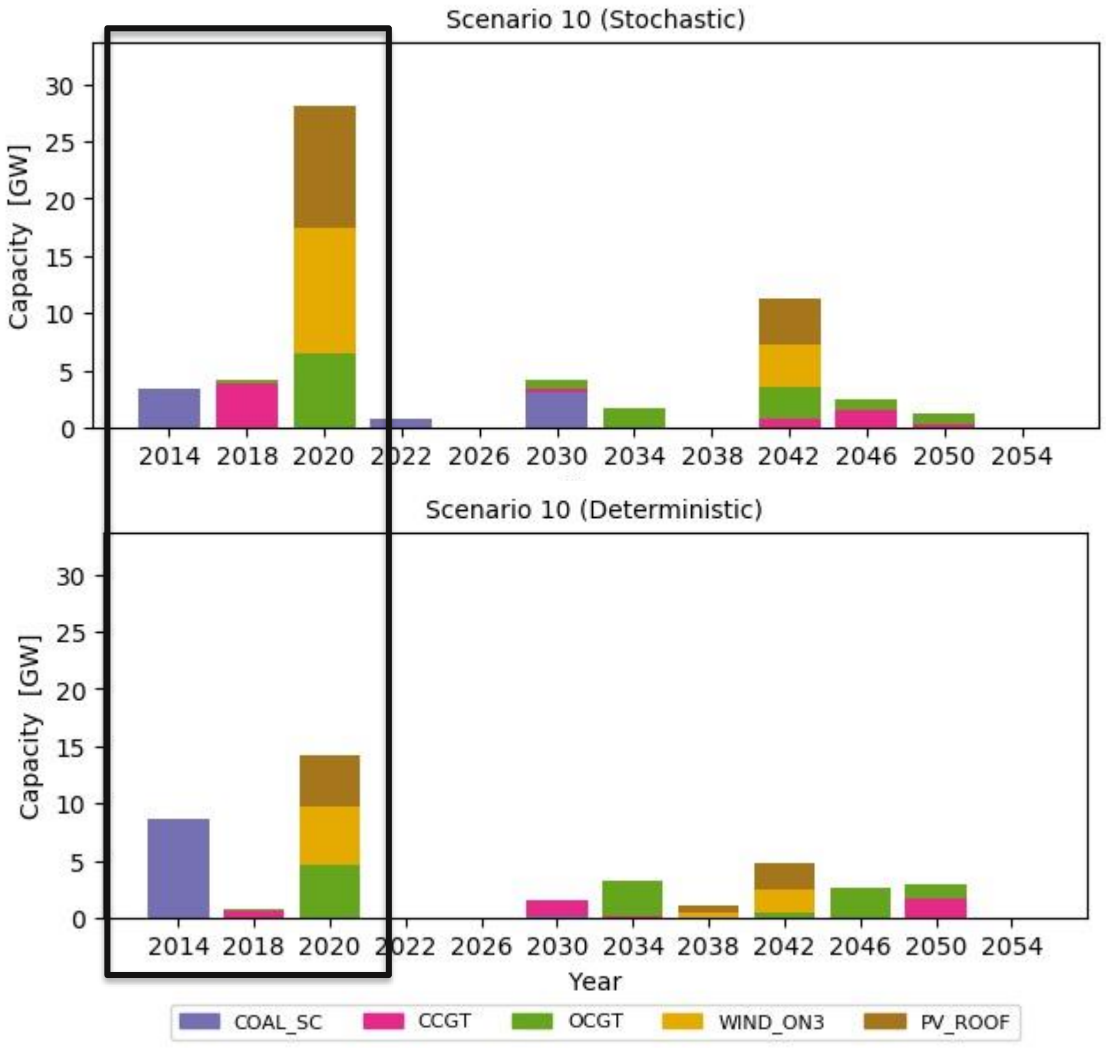


Results – Stochastic vs Perfect Foresight

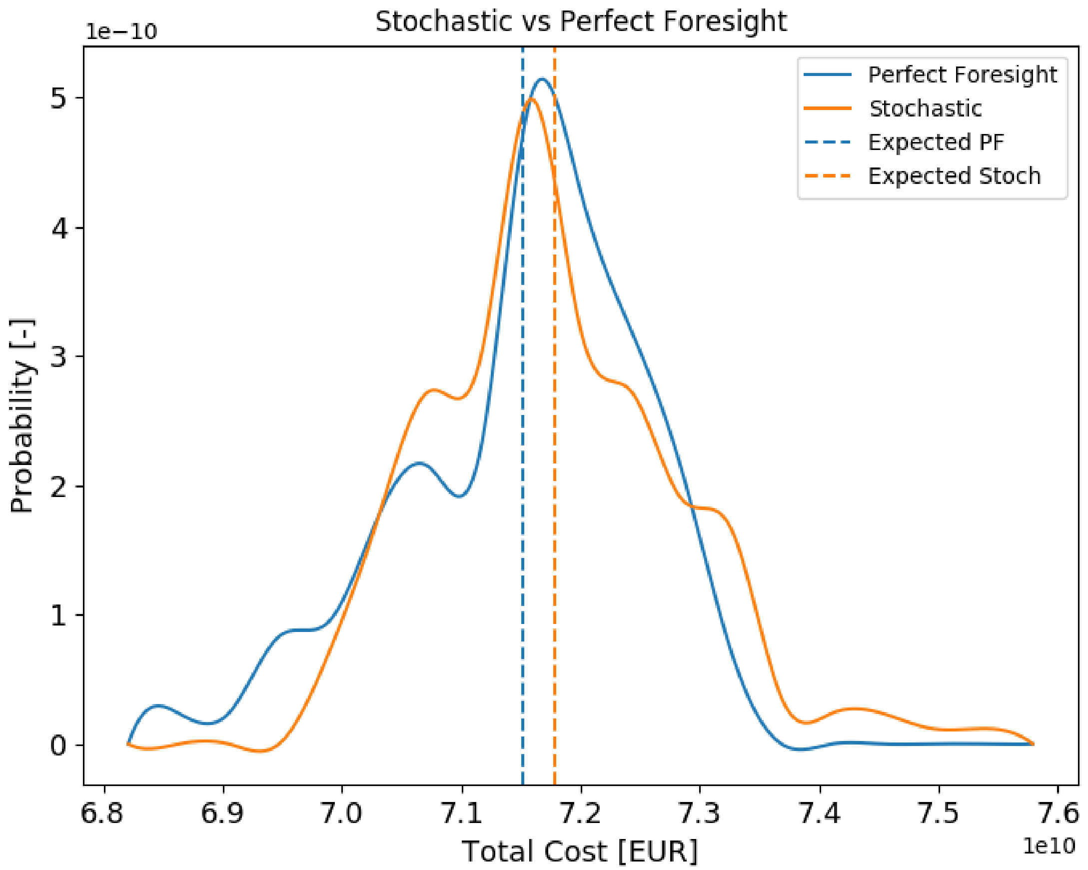
- Low probability scenario (p = 0.014)



- Investment decisions are different.



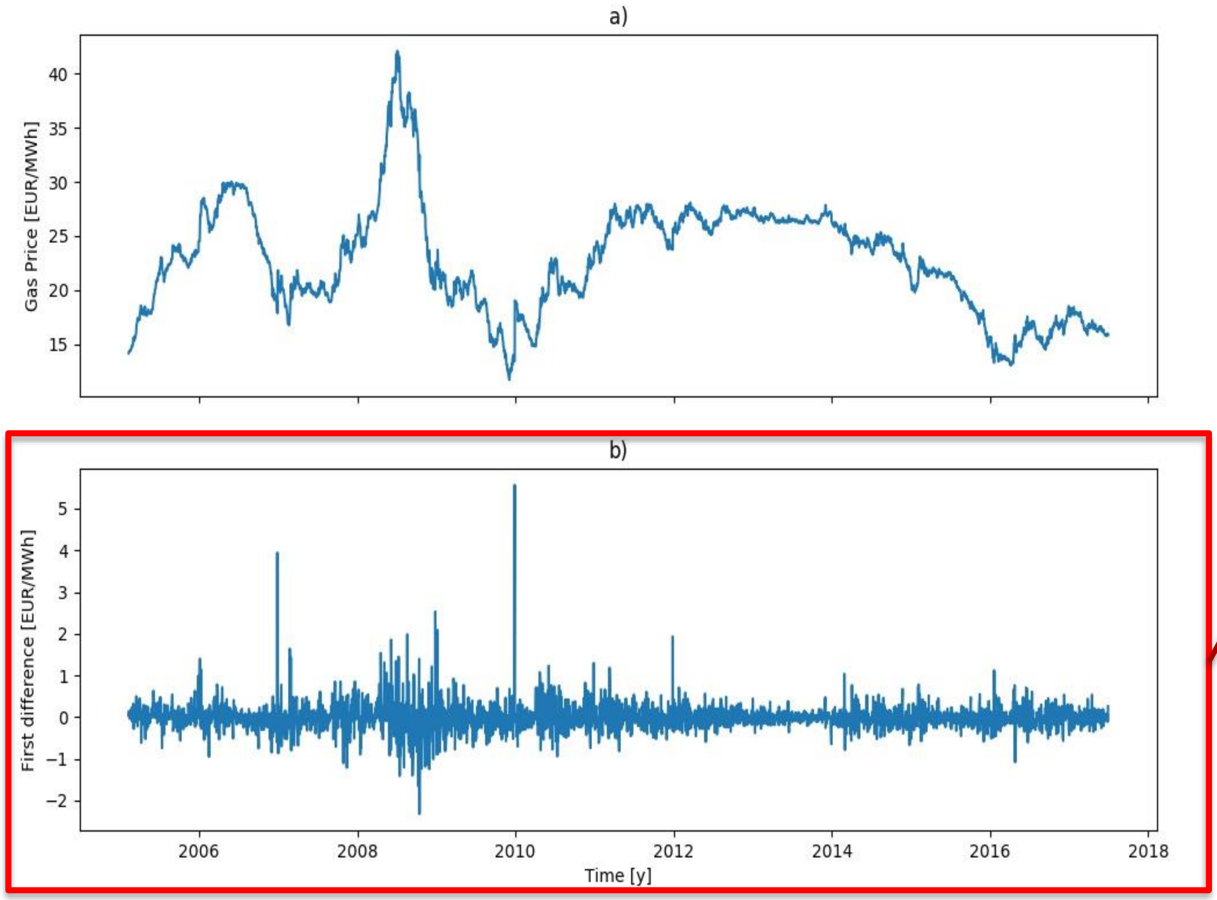
Results – Out-of-Sample Analysis



- Cost distribution of 200 newly generated scenarios
- EVPI is positive

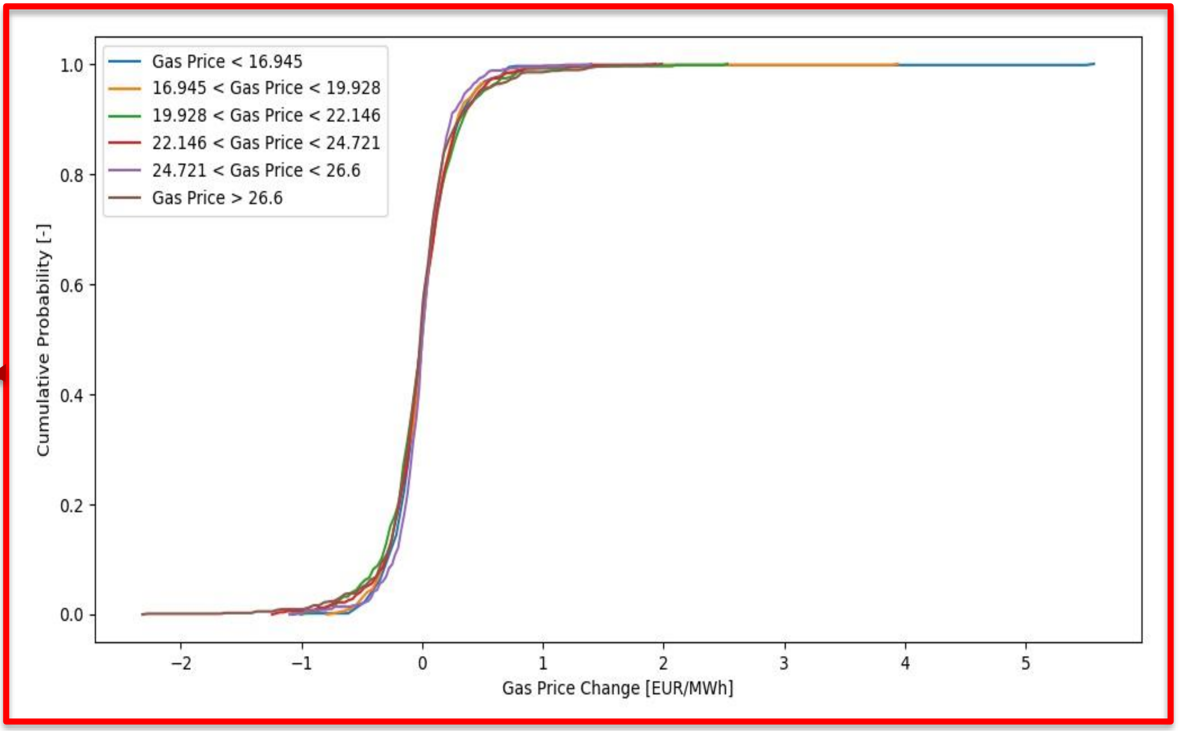
Methodology – Scenario Generation

Historical data (TTF Hub):



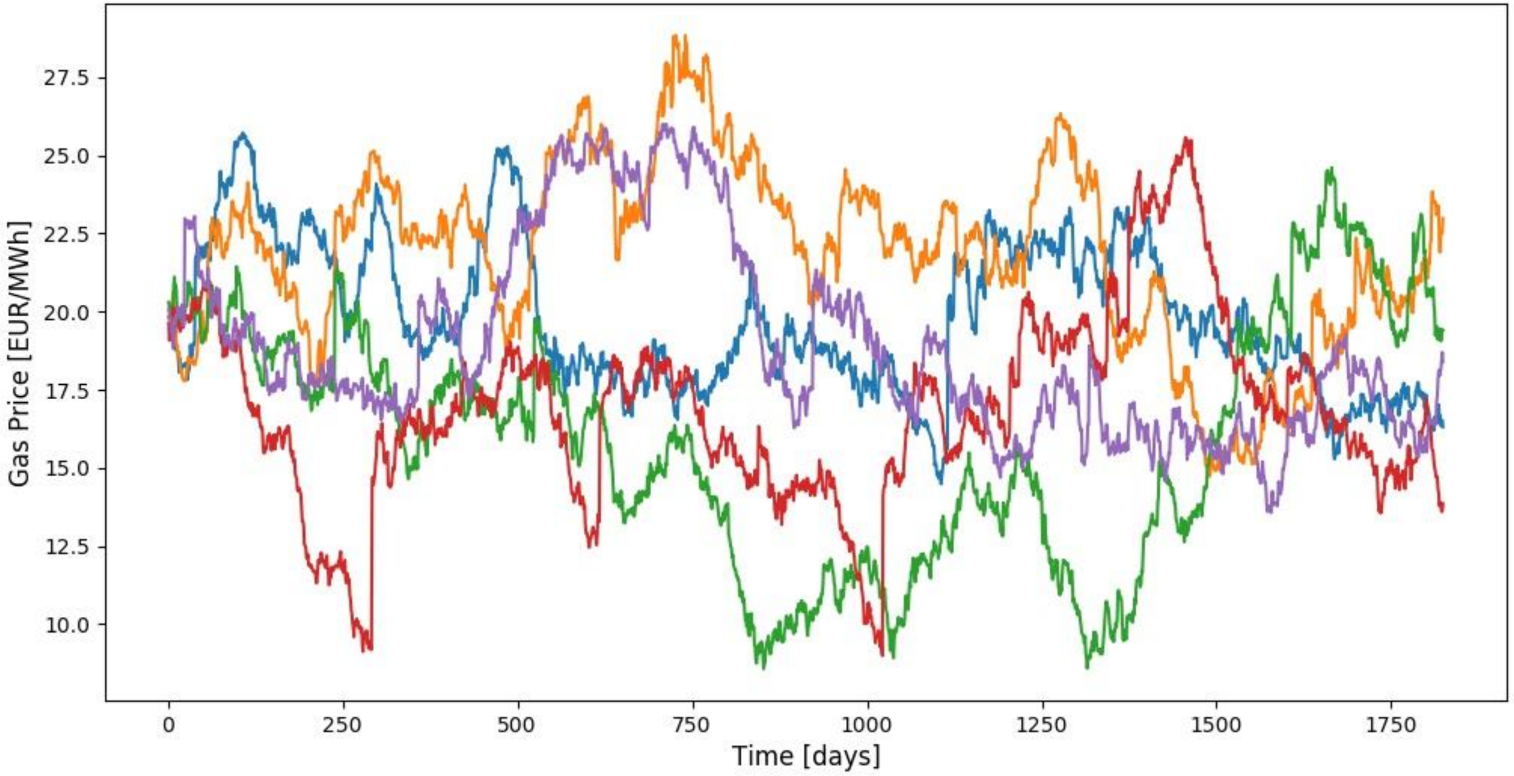
Scenario sampling

$$P_t = P_{t-1} + \overline{\Delta P_{P_t}}$$



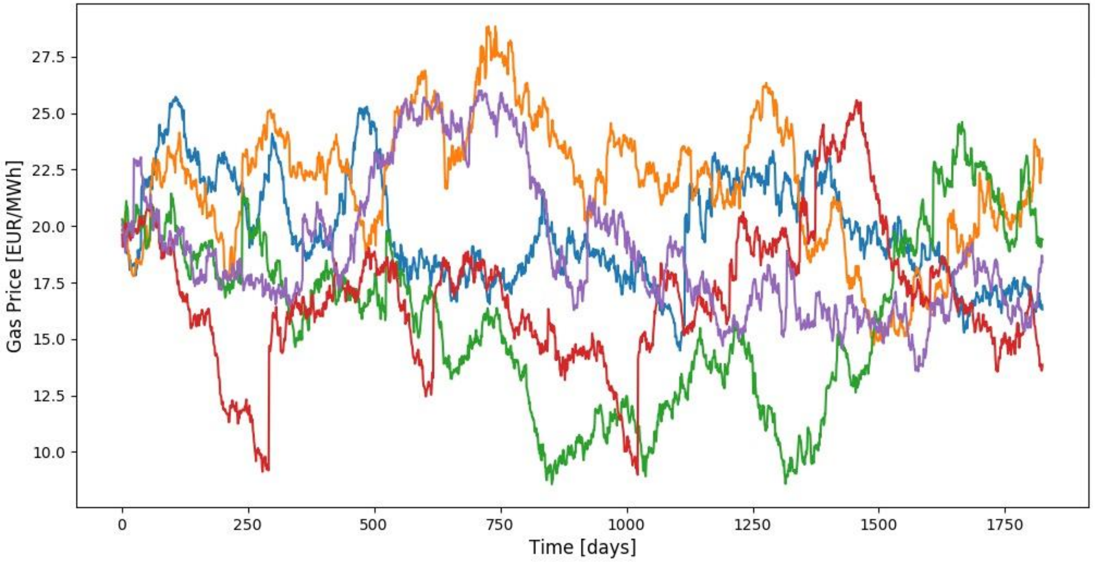
Methodology – Scenario Generation

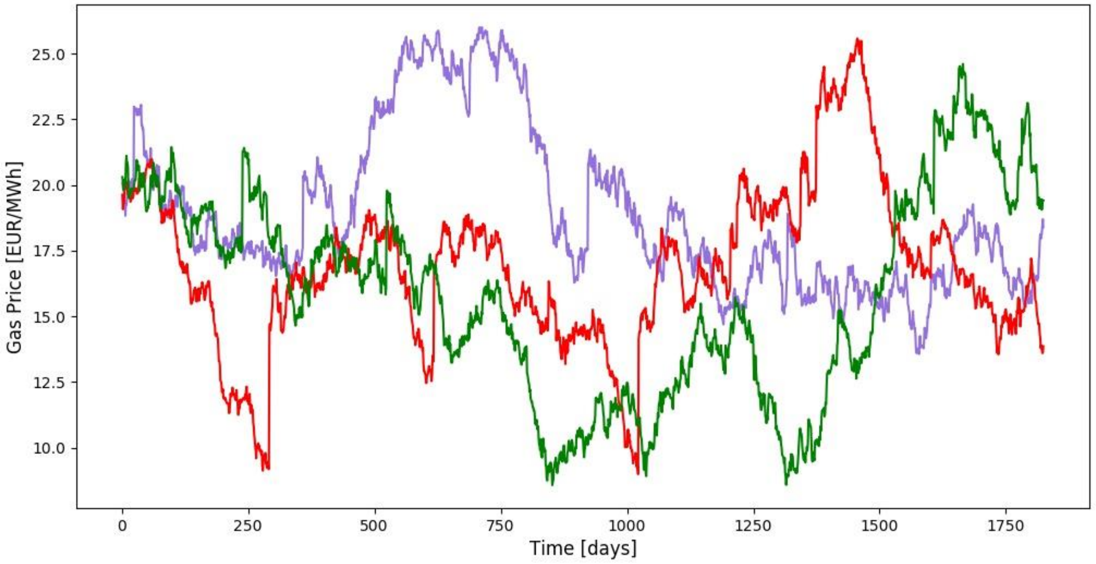
- Example: 5 Scenarios …



Methodology - Scenario Reduction

- Select N scenarios from original set by minimizing the Kantorovich distance between the original set and reduced set of scenarios.





Methodology - Scenario Reduction

- Select first scenario

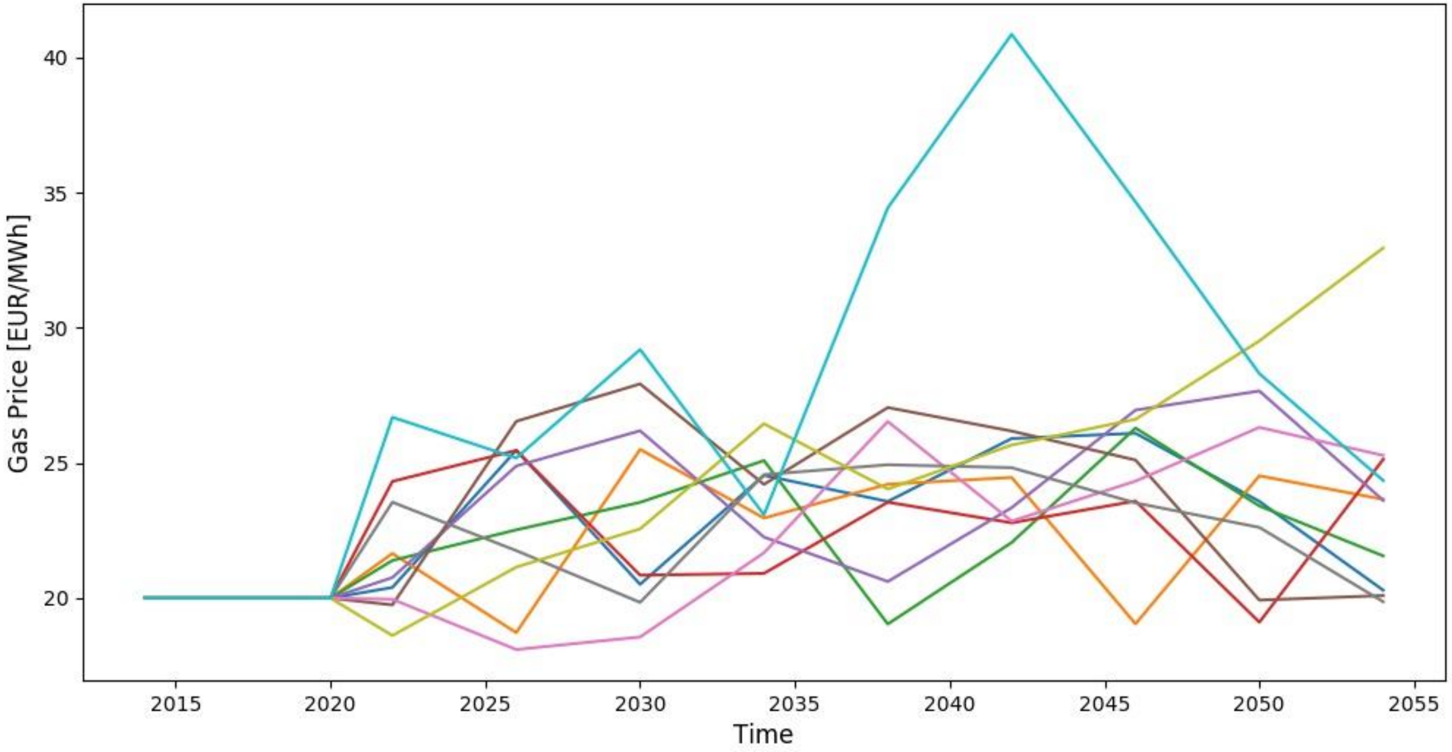
$$\omega_1 = argmin_{\omega'} \sum_{\omega \in \Omega} \pi_\omega c(\omega, \omega')$$

- Select N-1 scenarios according to the Kantorovich distance:

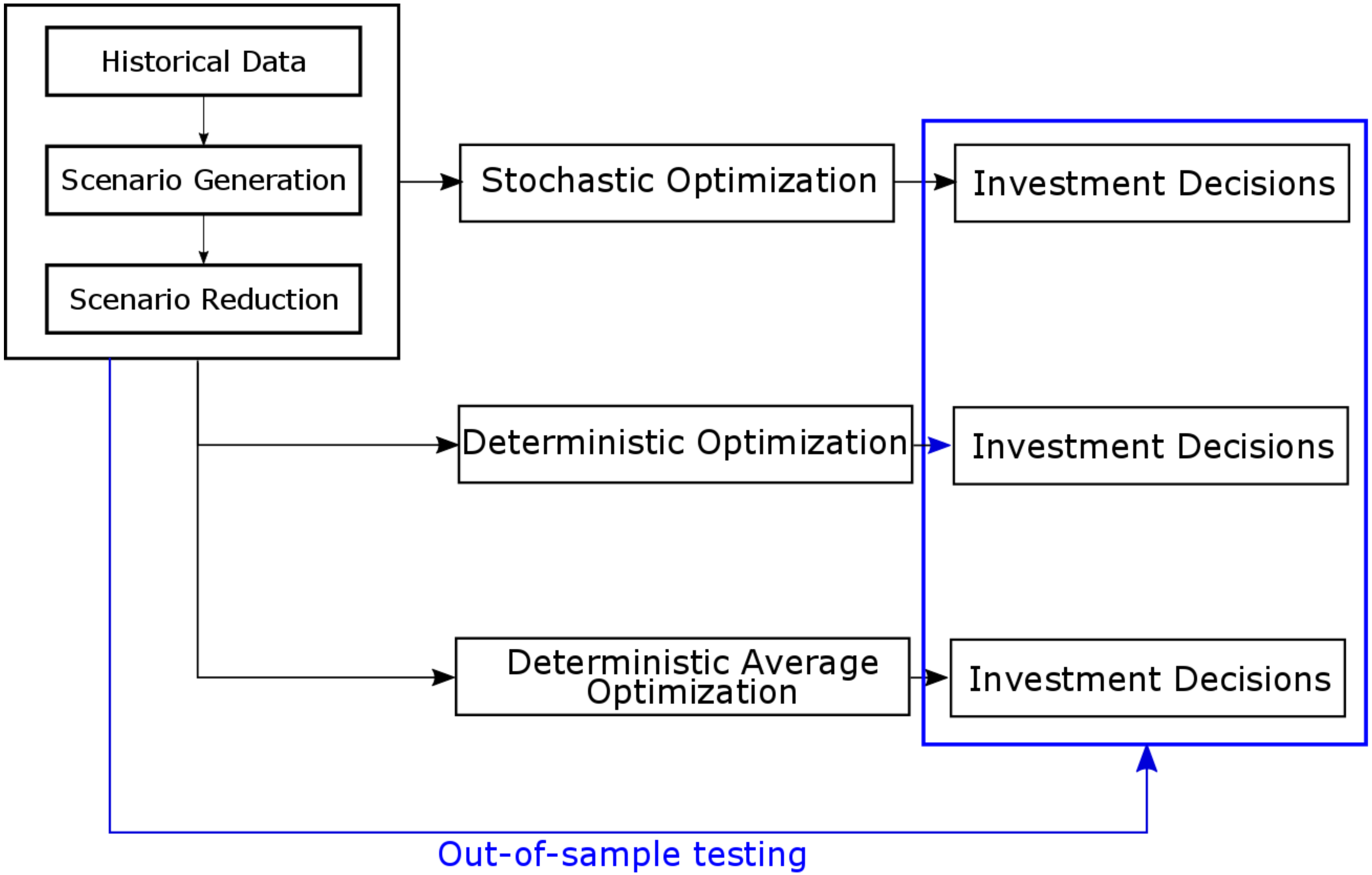
- Redistribute probabilities of not selected scenarios to the scenario that is most alike.

Methodology – Scenarios

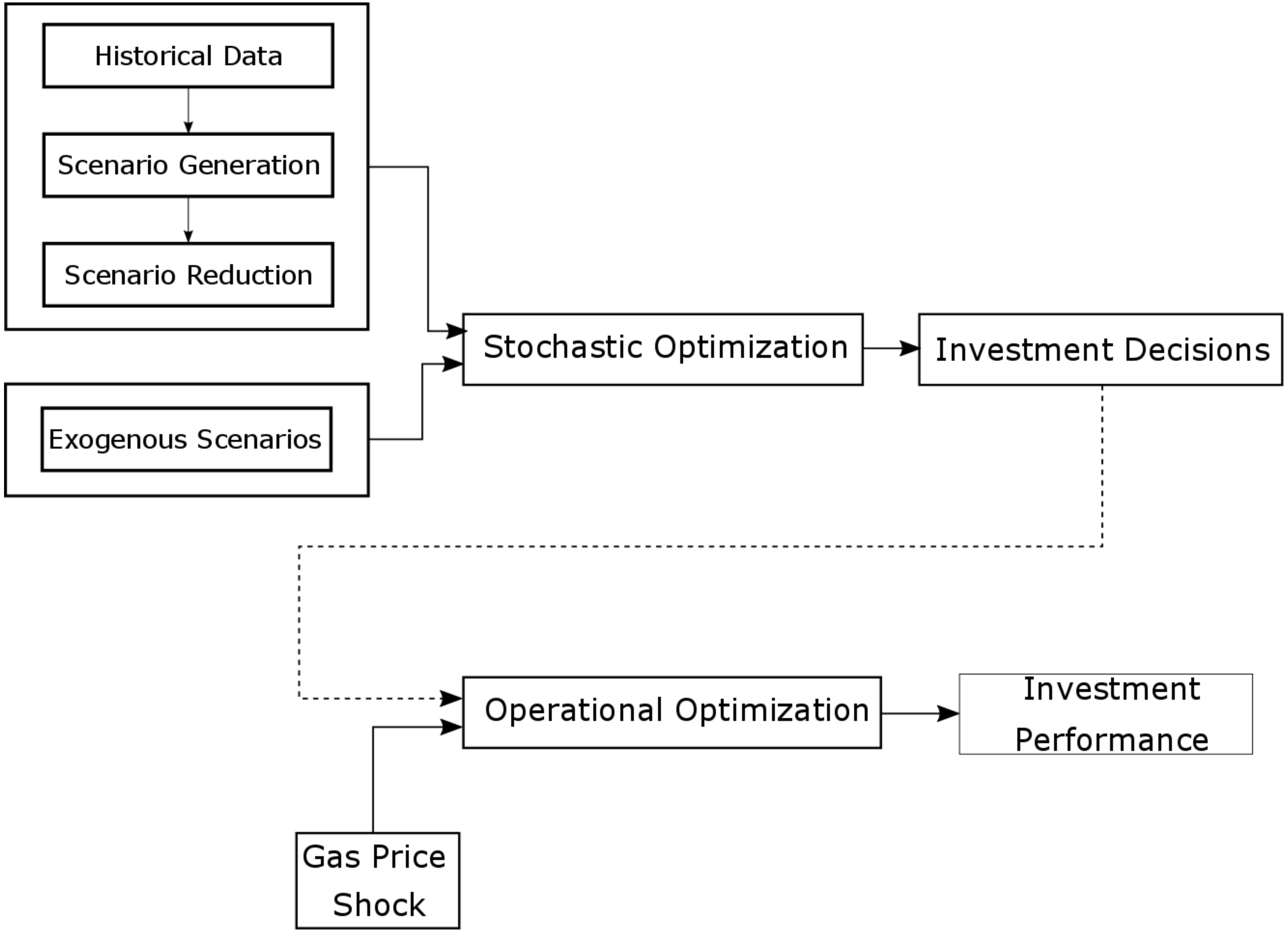
- Example - 10 selected scenarios



Methodology - Overview

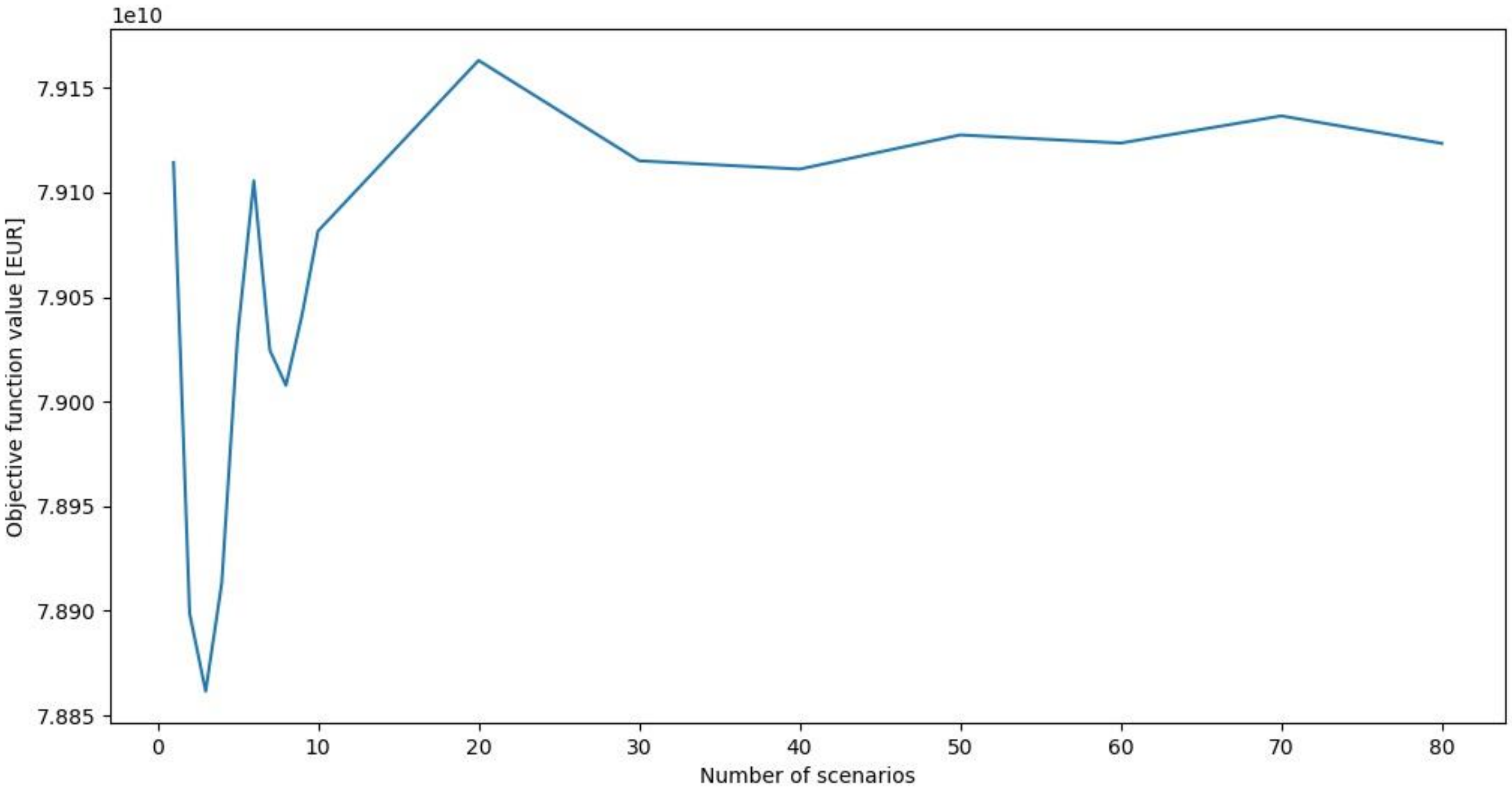


Methodology - Overview



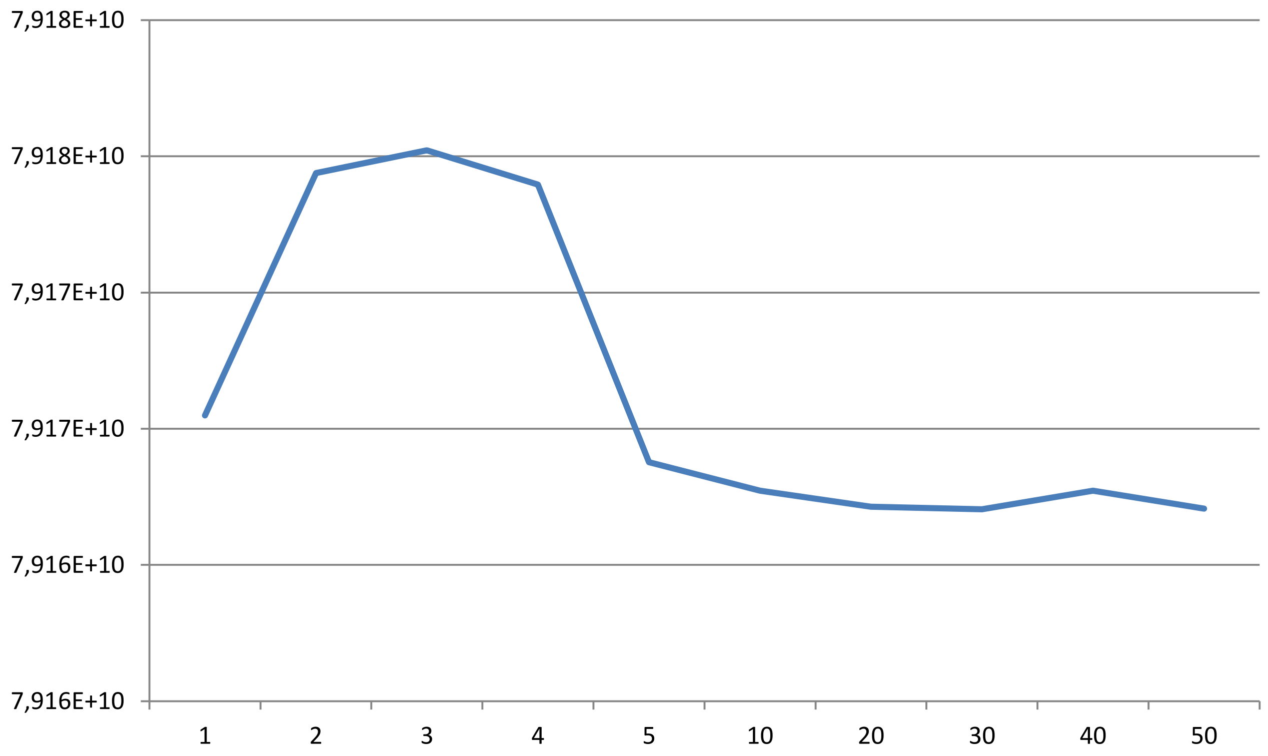
Gas price uncertainty – In-sample stability

- Compare objective values of scenario trees with increasing cardinality.



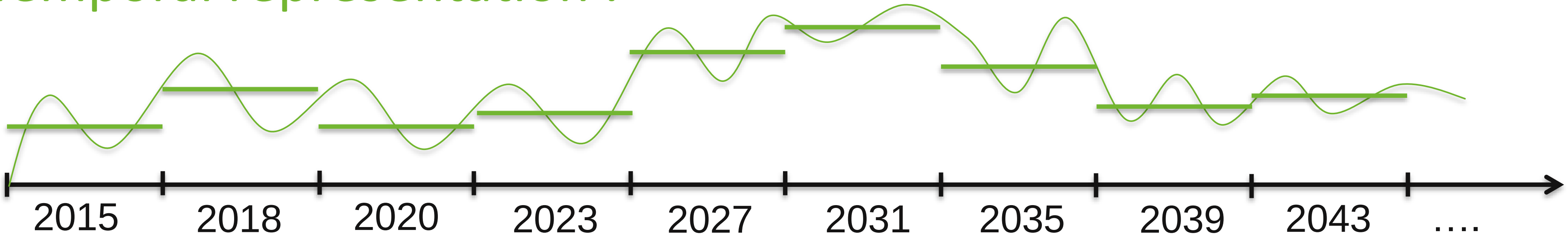
Gas price uncertainty – Out-of-sample stability

- Test first stage investment decisions on a large set of generated scenarios.



Stochastic Programming – Model Settings

- Temporal representation .



- Reduced set of scenarios is averaged in accordance with temporal structure.