A Data-driven approach for robust operation of energy storage systems

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Work package 4.3

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Overview

Introduction

Industrial Cluster

- Surplus Energy producers
- Energy consumers

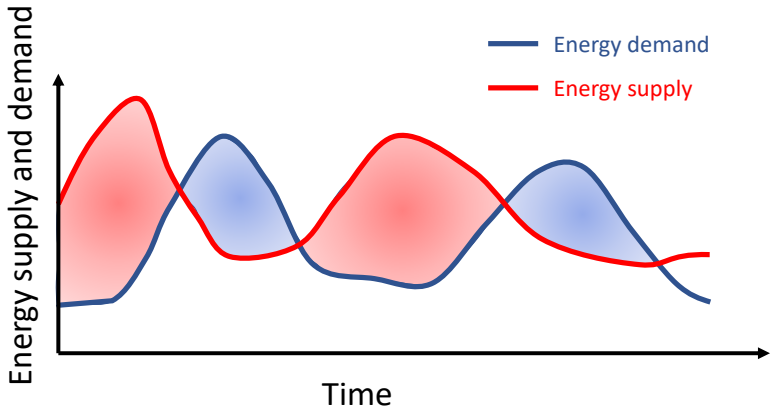
Problem:

- Production and consumption at different times

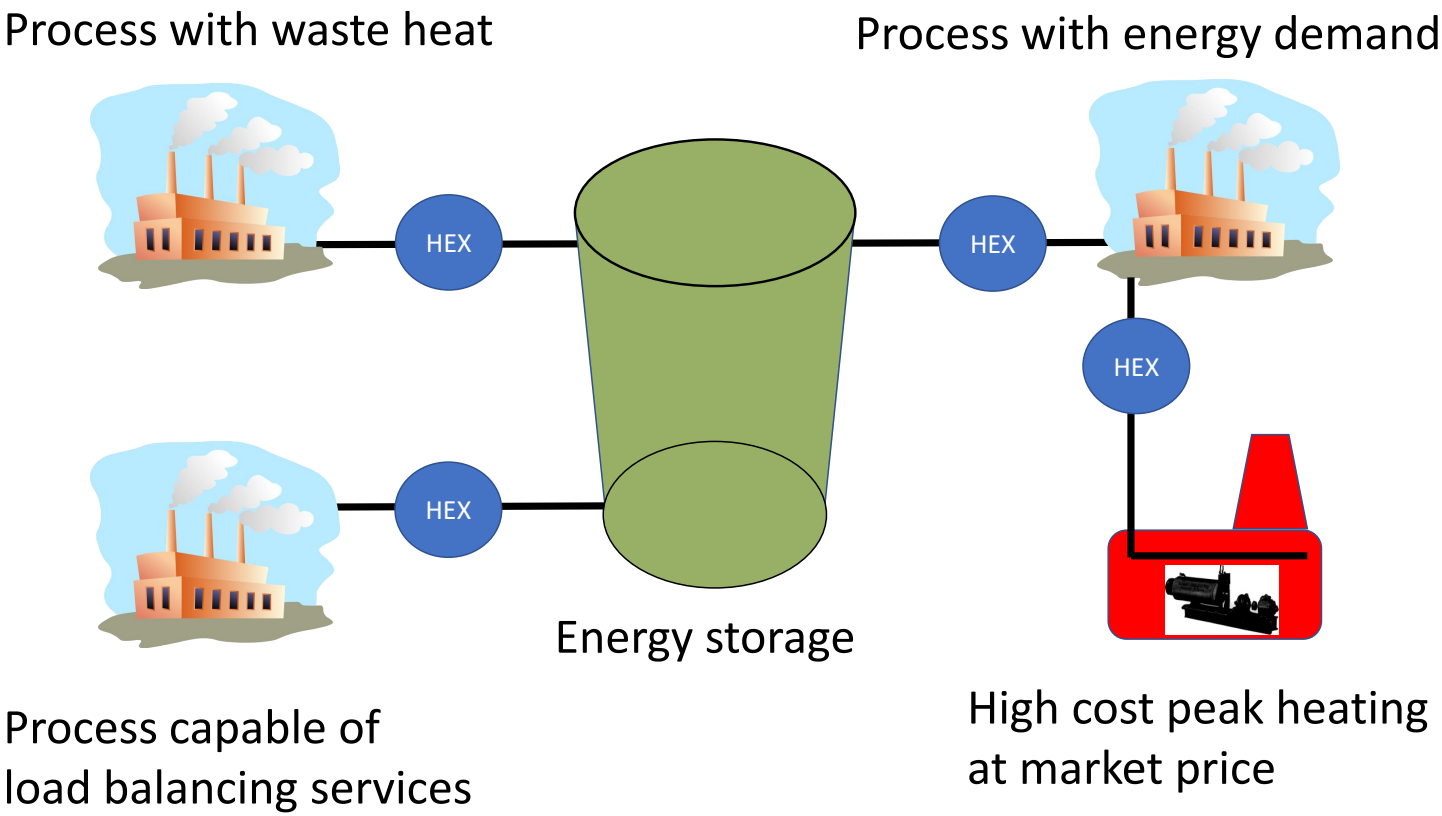
Solution

- Energy storage

Mo industry park



Operation of Thermal Energy Storage



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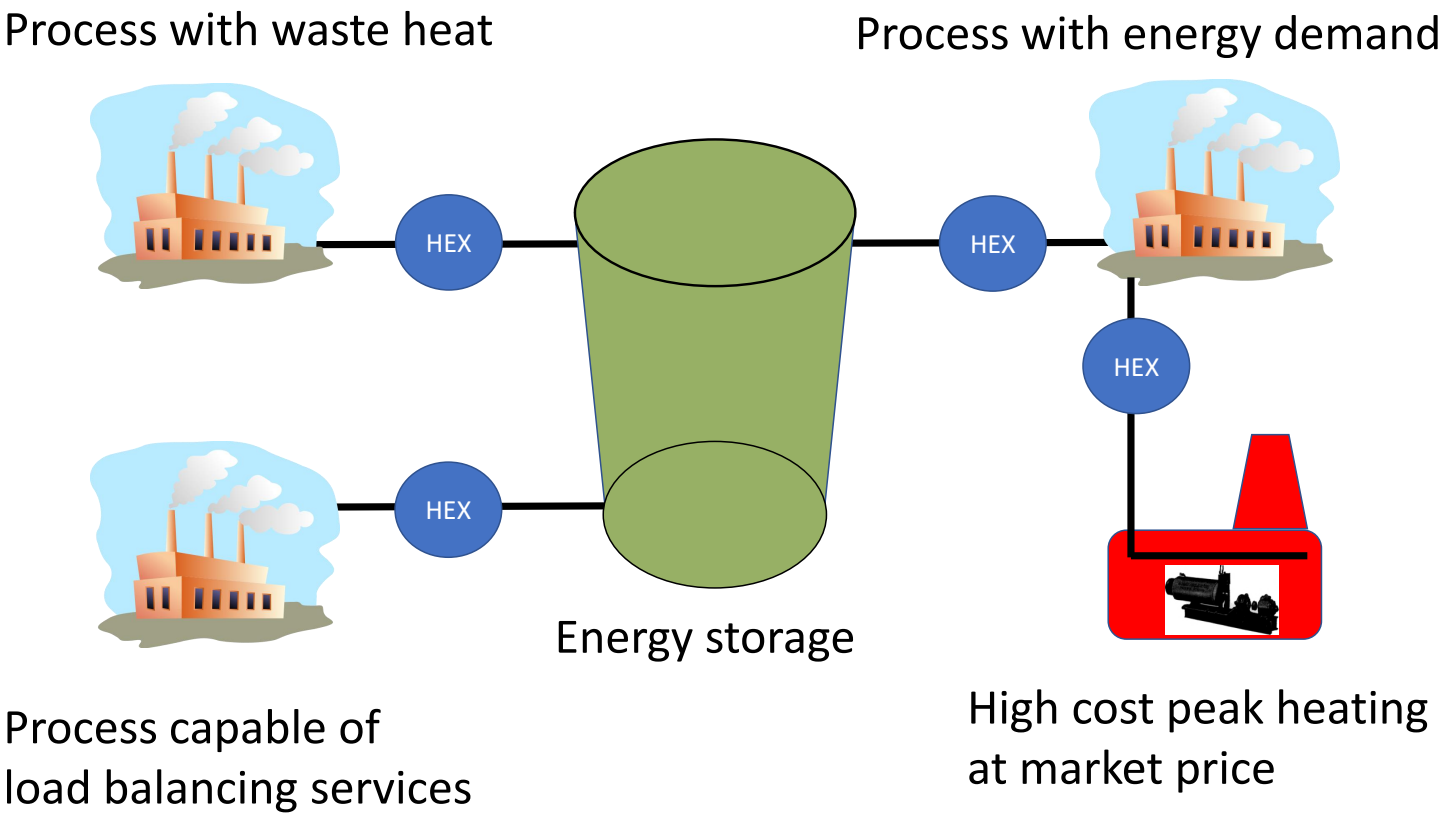
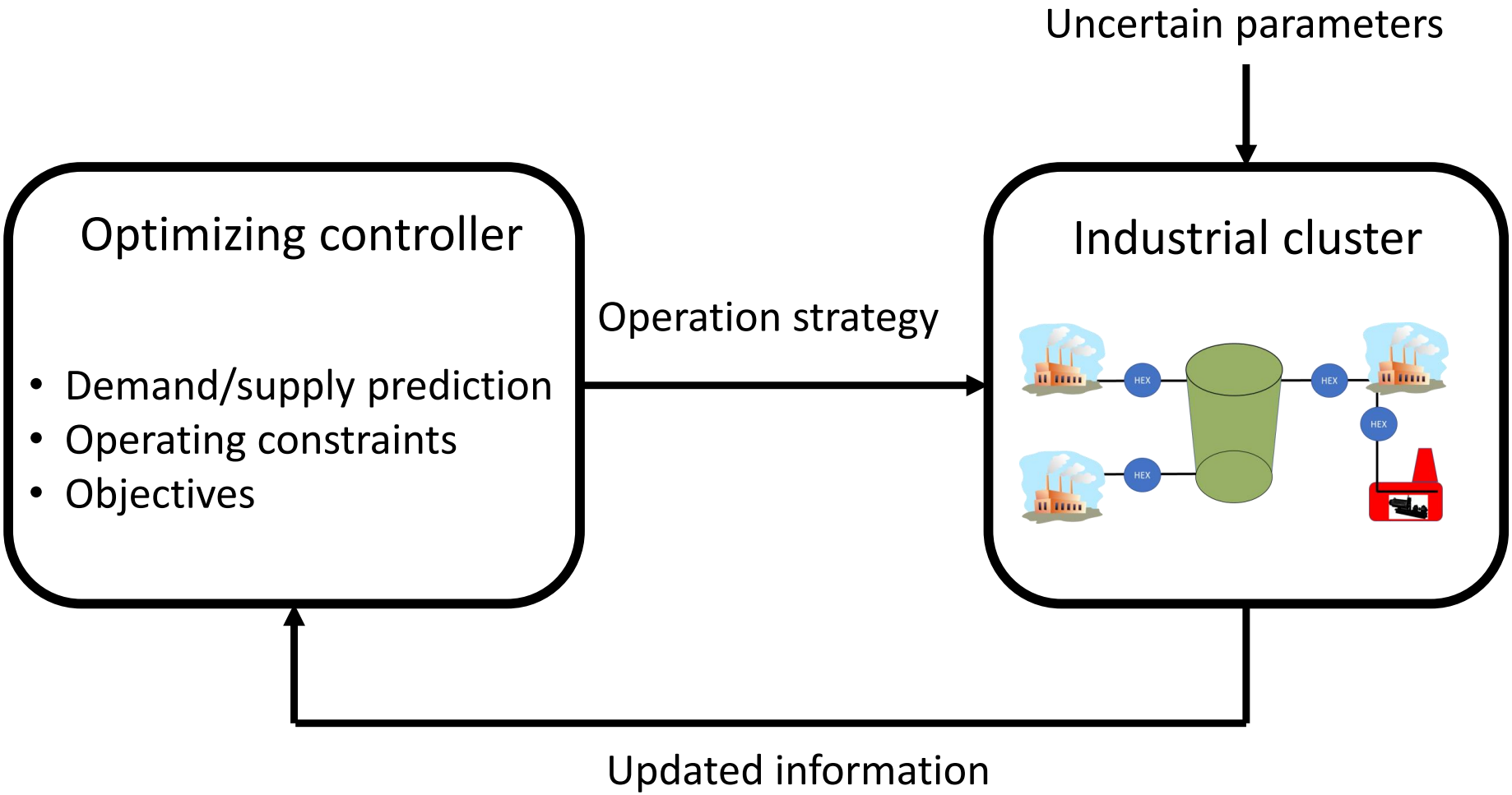


Challenges:

- Need to predict demand and supply
- Need operating strategy based on prediction

Operation of Thermal Energy Storage



Handling Uncertainty in Prediction - Scenario Tree

Discretize uncertain parameter (e.g: high demand - low demand)

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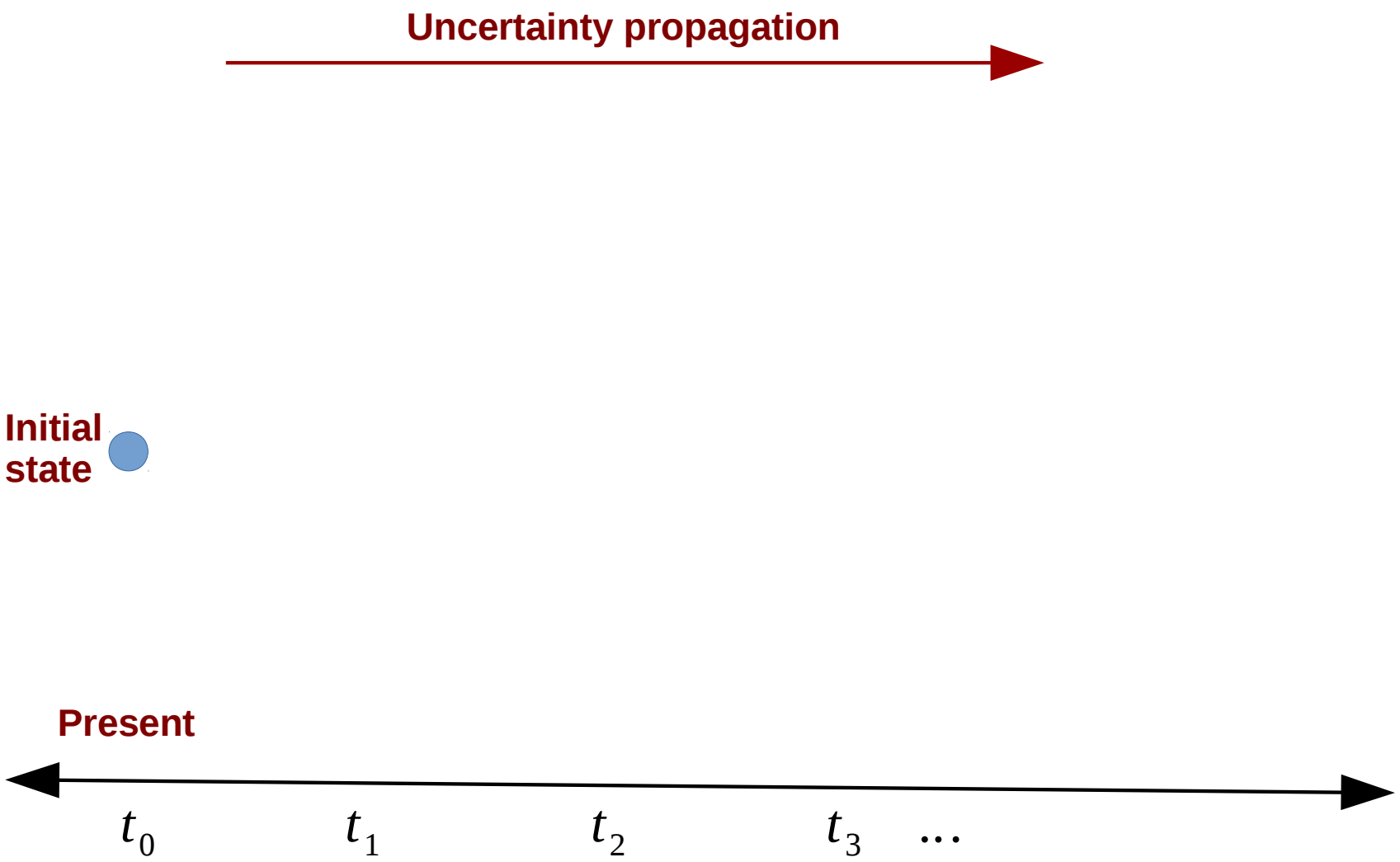

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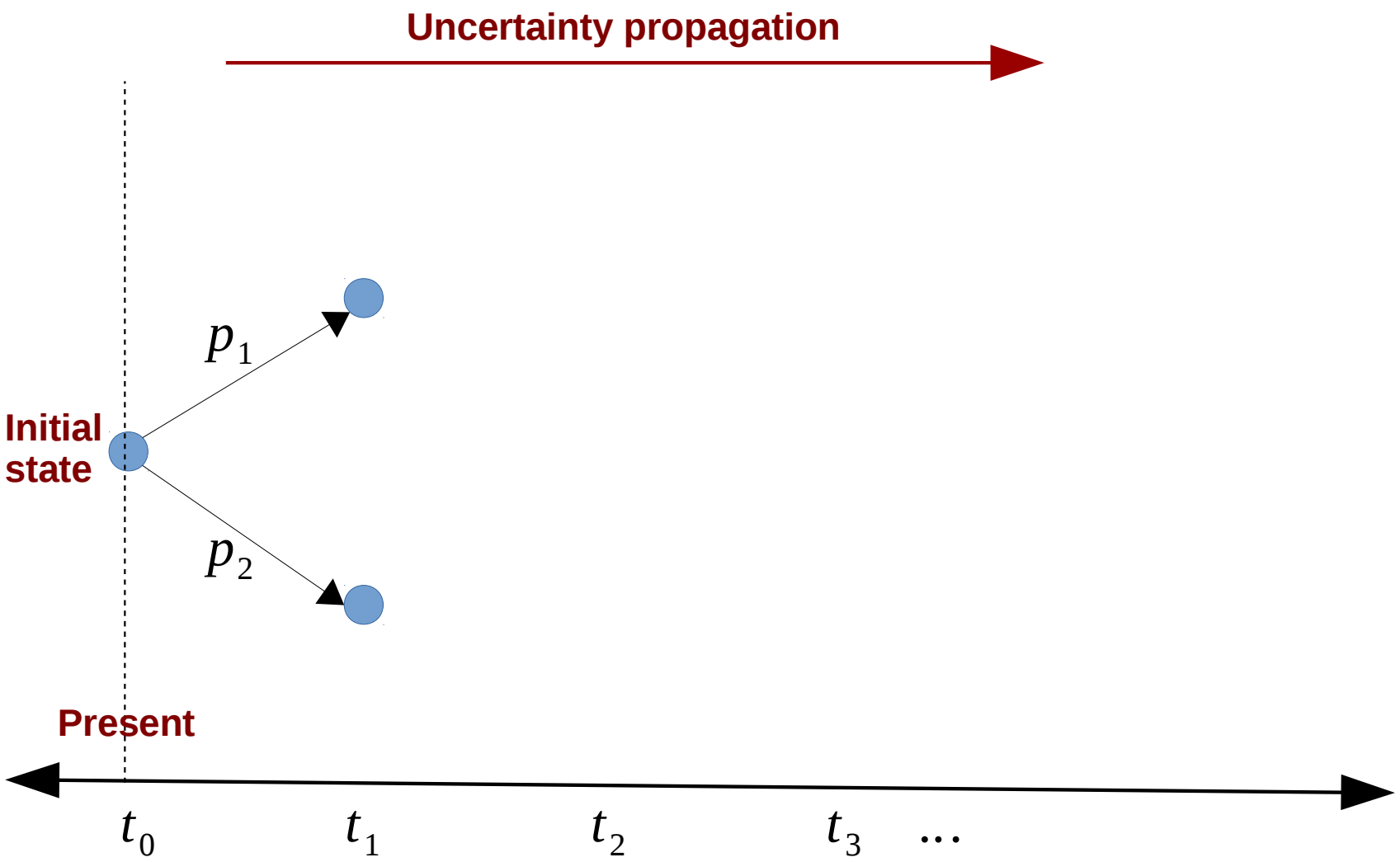

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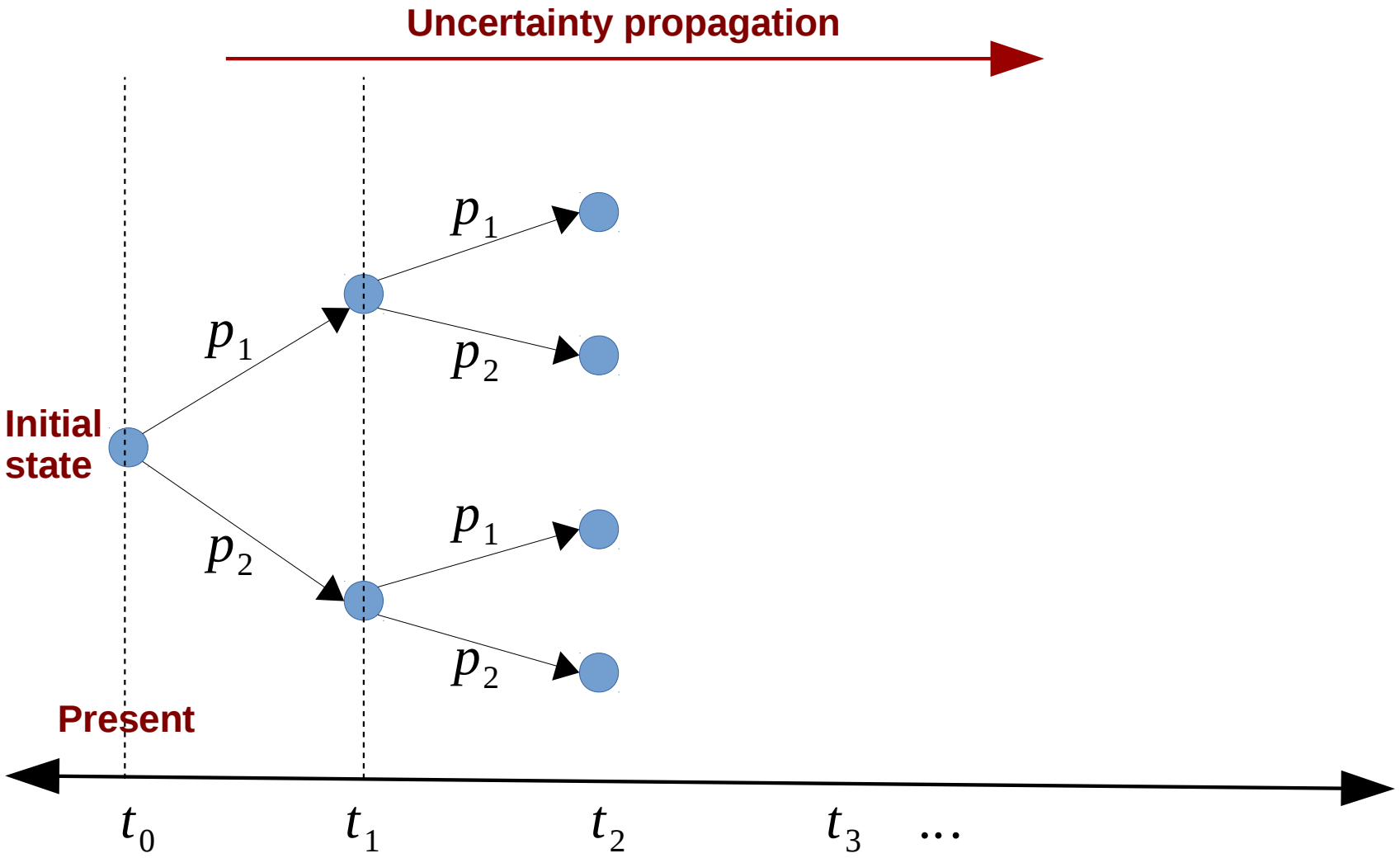

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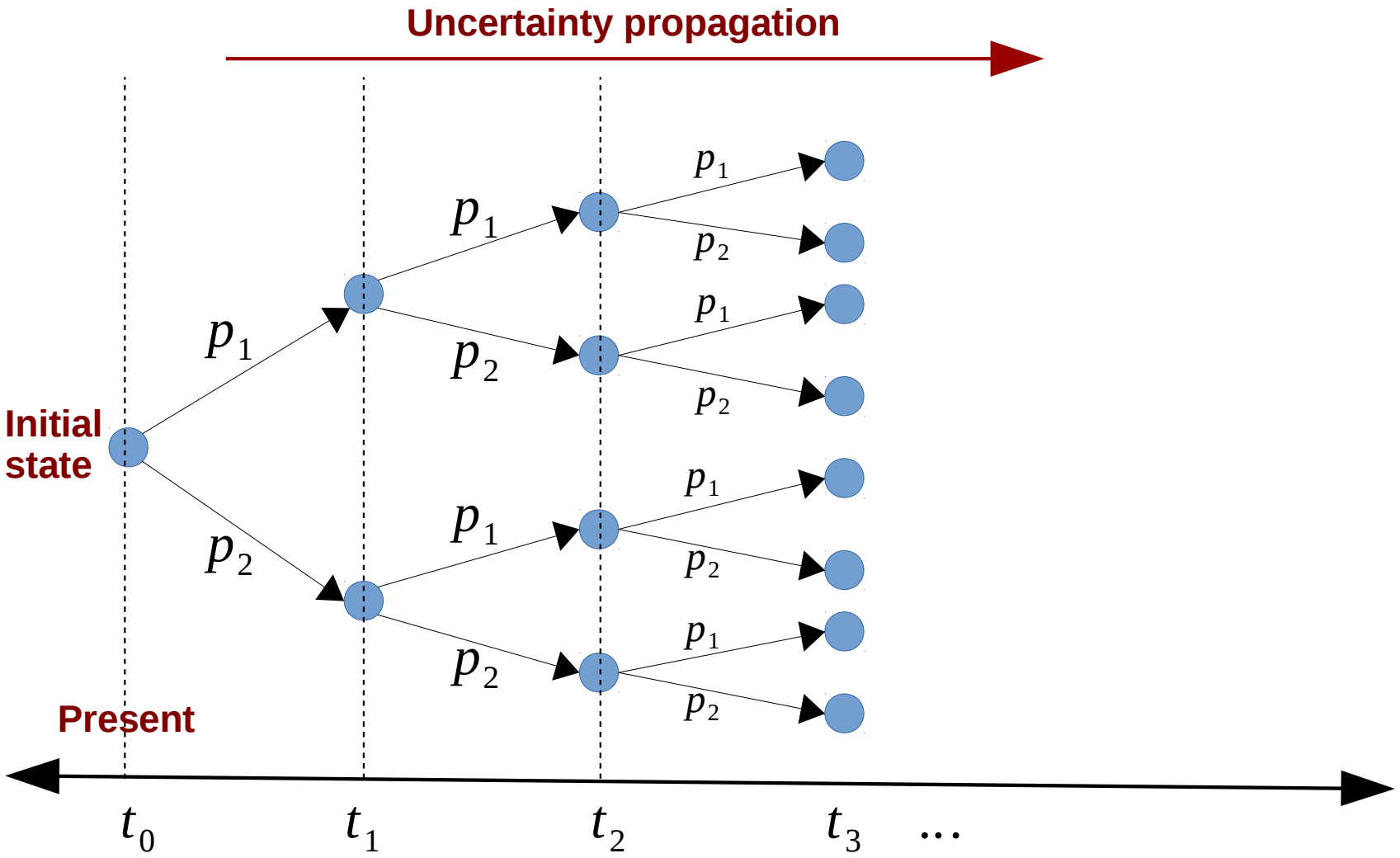

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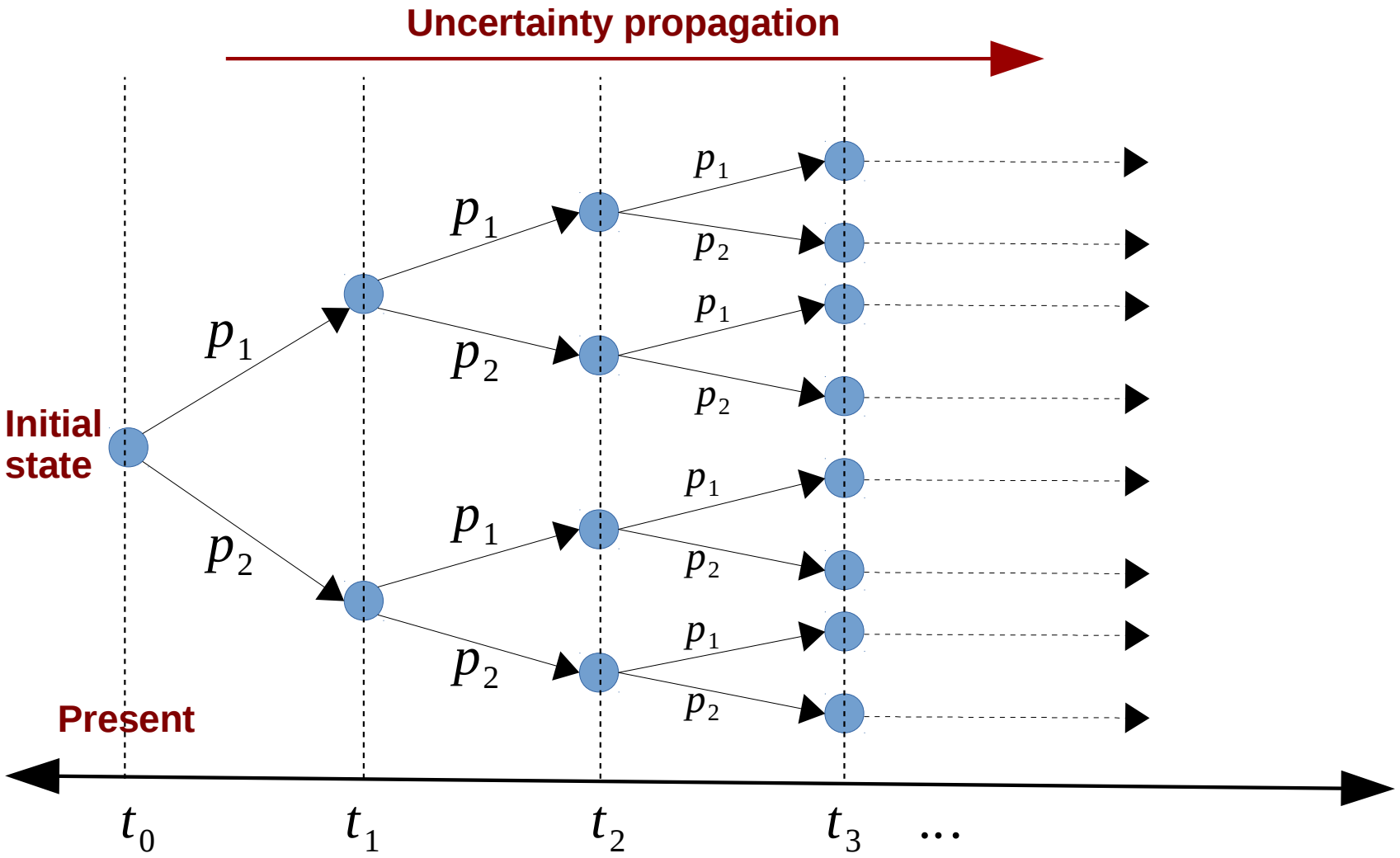
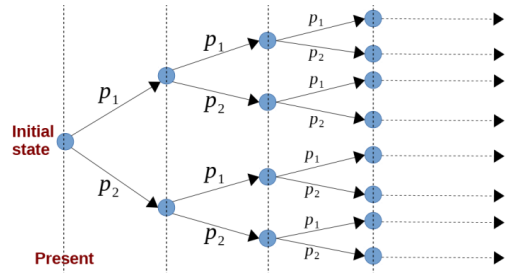


Robust operation of Thermal Energy storage

Uncertain parameters

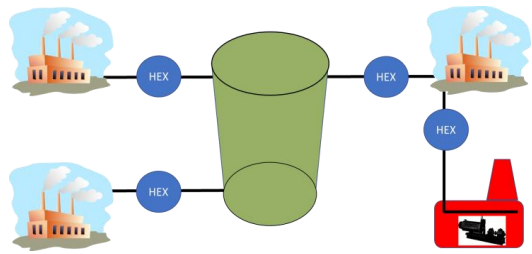
Optimizing controller

- Demand/supply prediction
- Operating constraints
- Objectives
- Scenarios



Operation strategy

Industrial cluster



Updated information

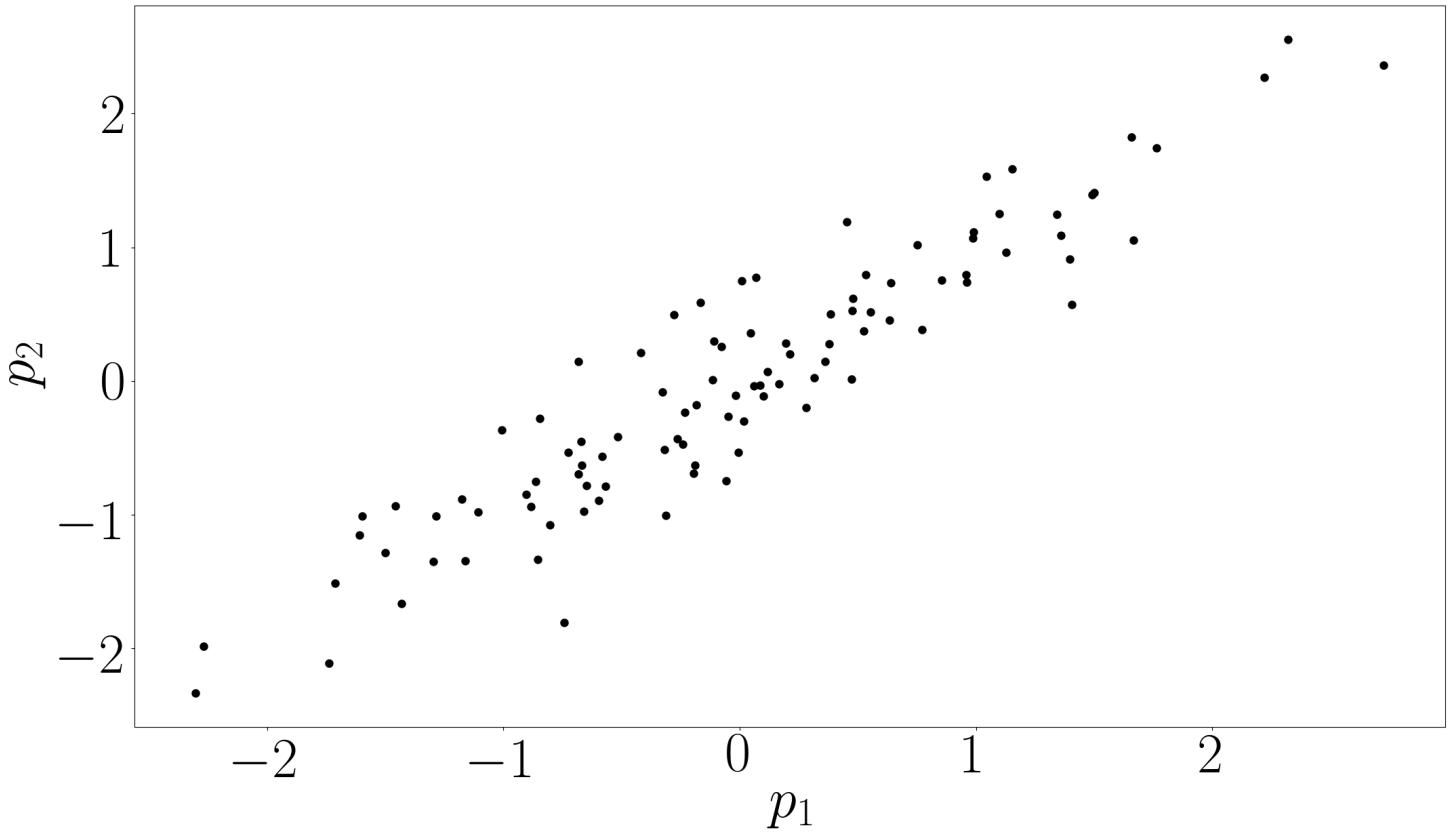
How to select Scenarios

How should the scenarios be selected?

- Expert knowledge and process insight
- Process design parameters
- Process data

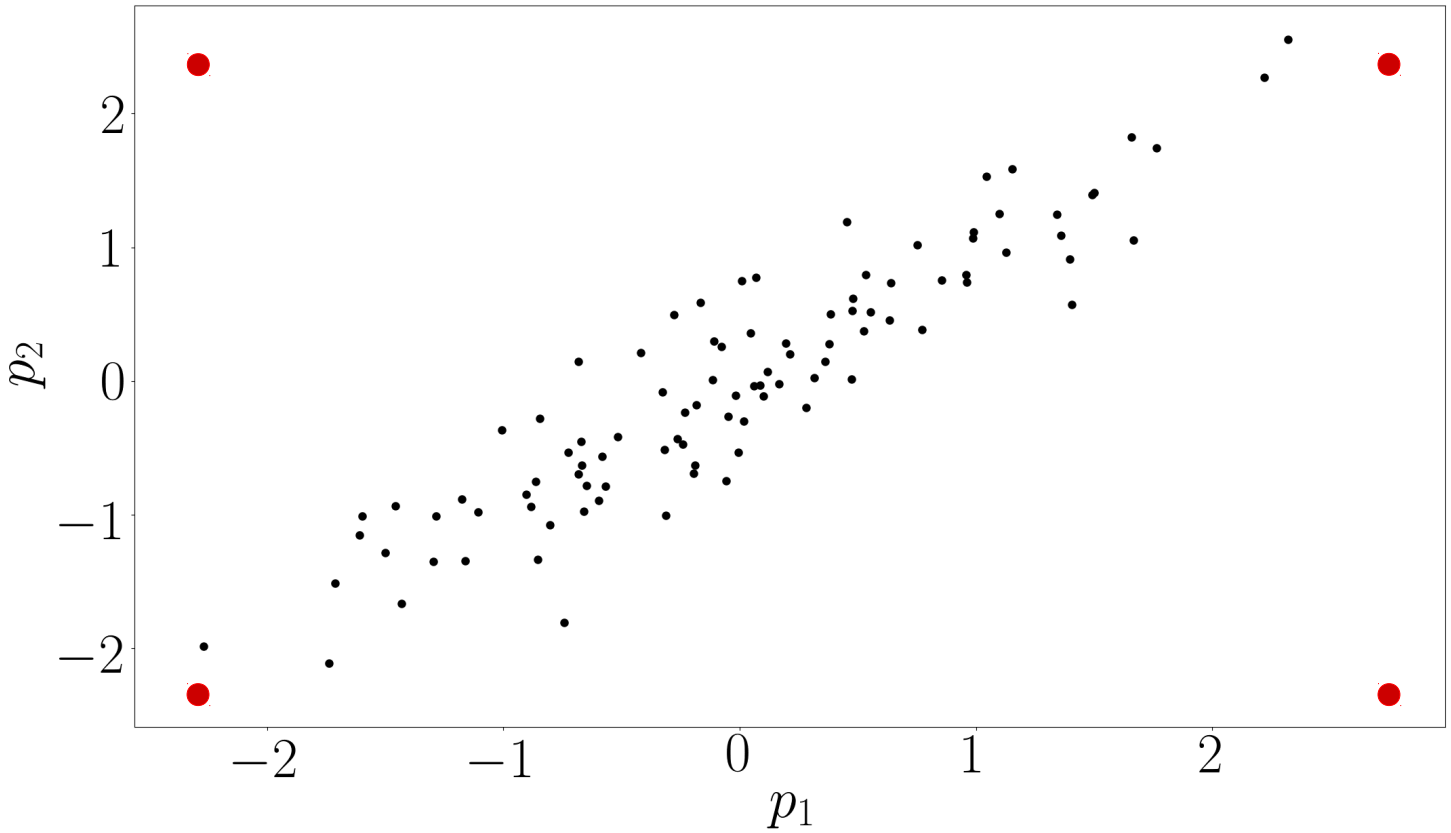
Scenario Selection using Data

- How to select scenarios from data representing uncertain parameters?



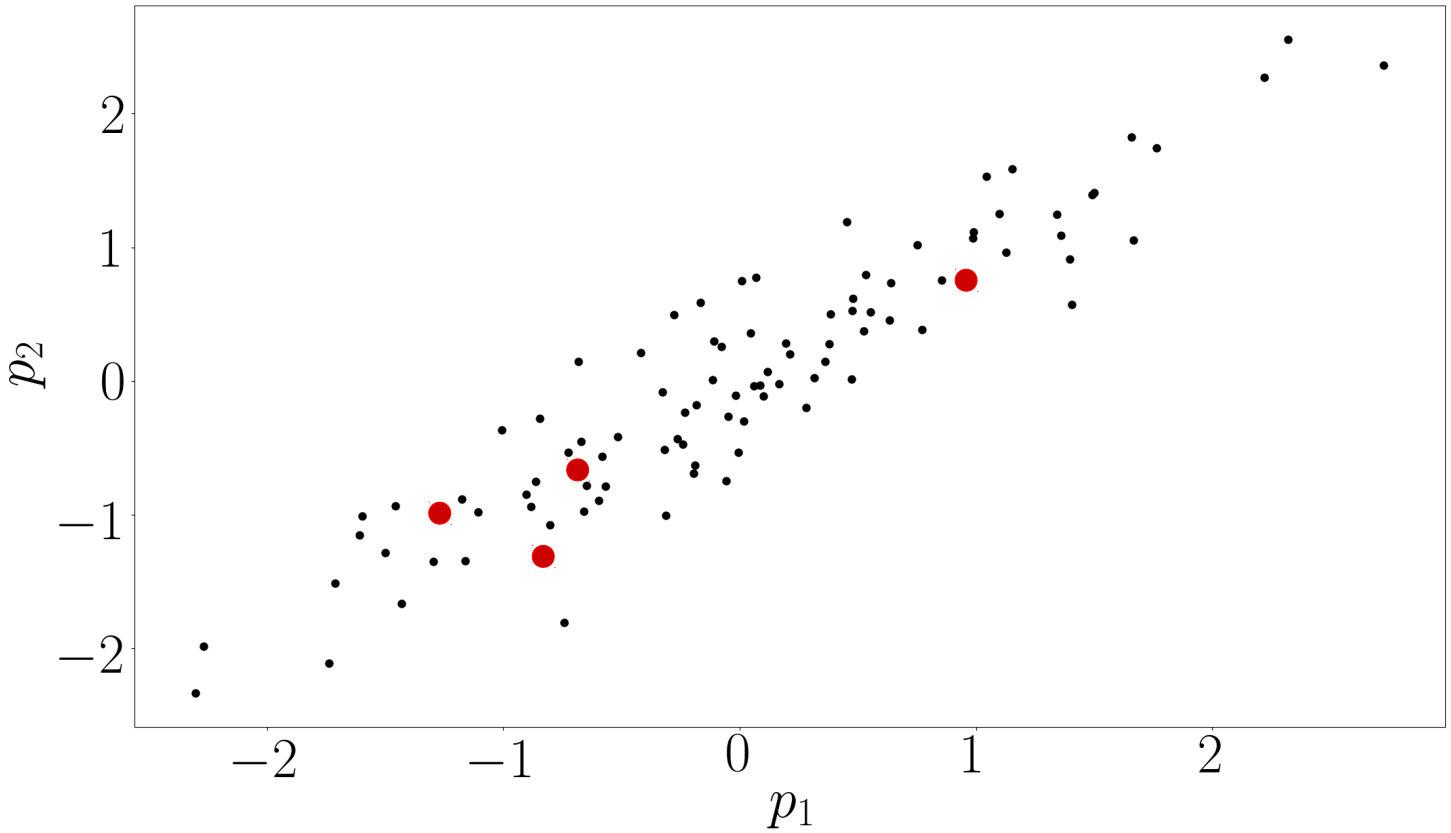
Scenario Selection using Data

- Naive approach: box sampling, Max-Min.



Scenario Selection using Data

- Random approach: radndom sampling - latin hypercube, etc.



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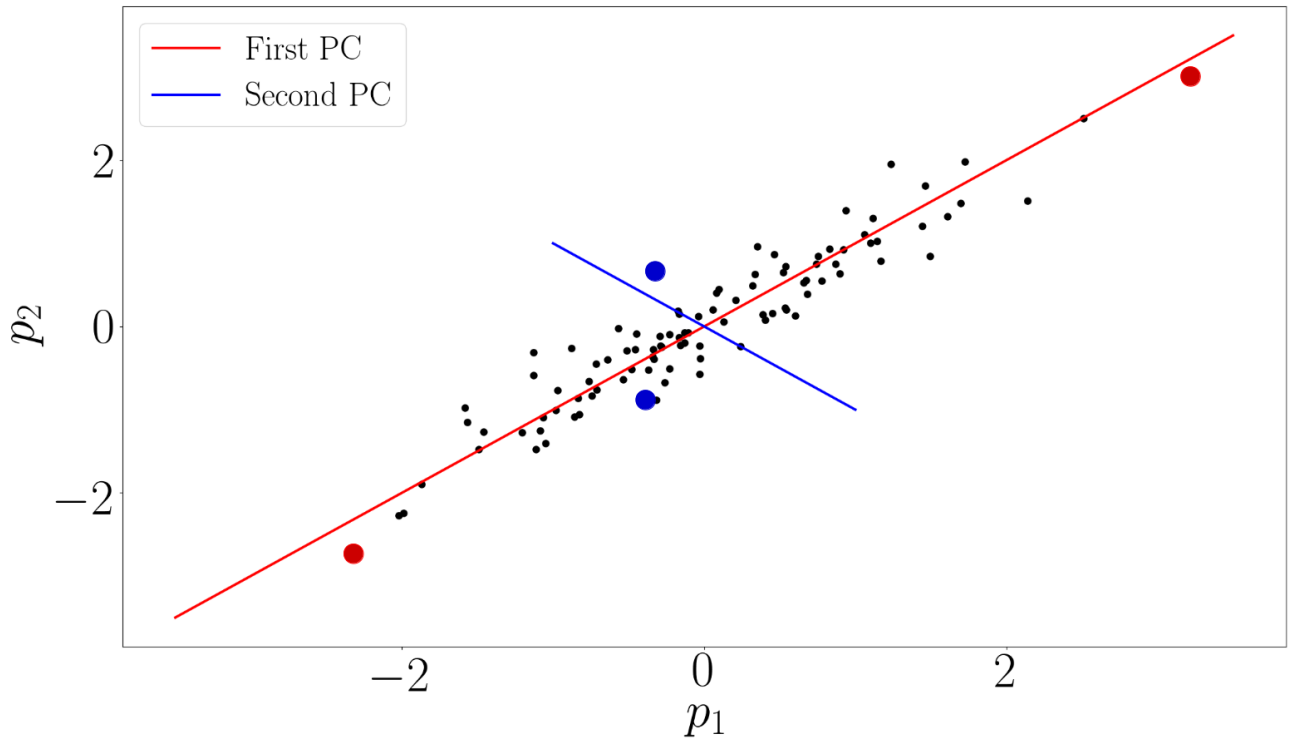

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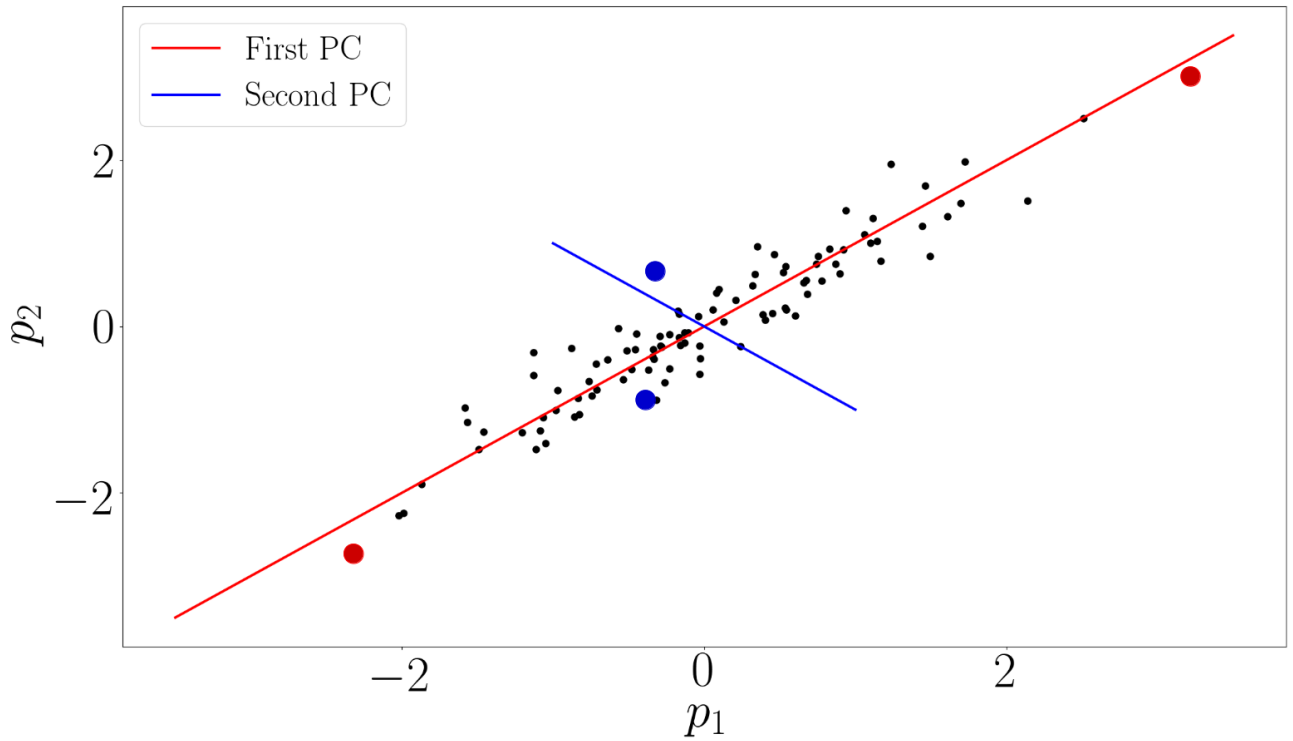

- Select scenarios as extreme values on the largest principal components

Dynamically Adjusting Scenario-Tree

Challenge

- Range of uncertain parameters changes with time
- How to take this into account?

Solution

Update scenario tree dynamically when new uncertainty information is available:

1. Adjusting the scenarios
2. Adjusting the length of the robust horizon, for anticipated changes (e.g. when going from off-peak to peak periods)

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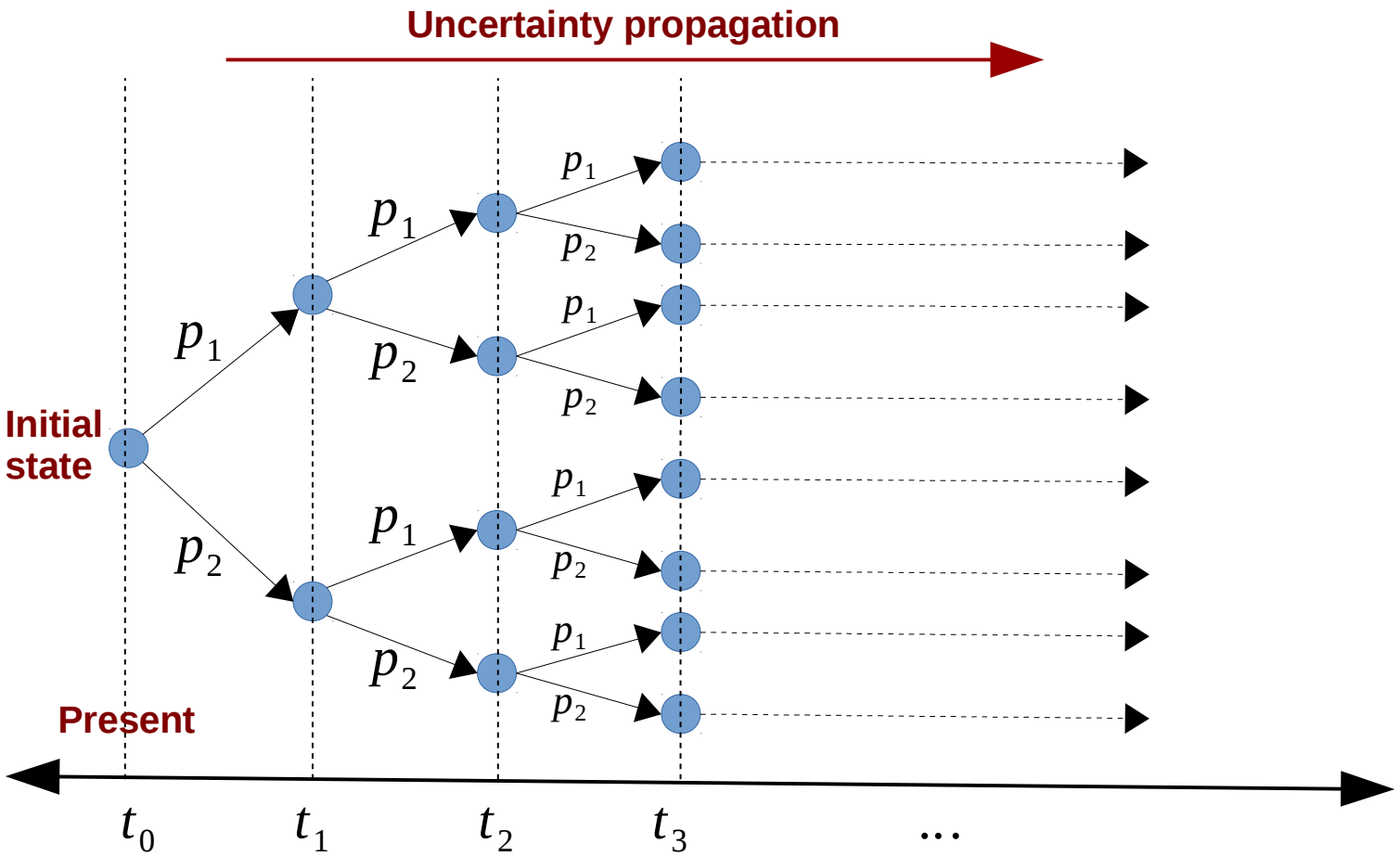

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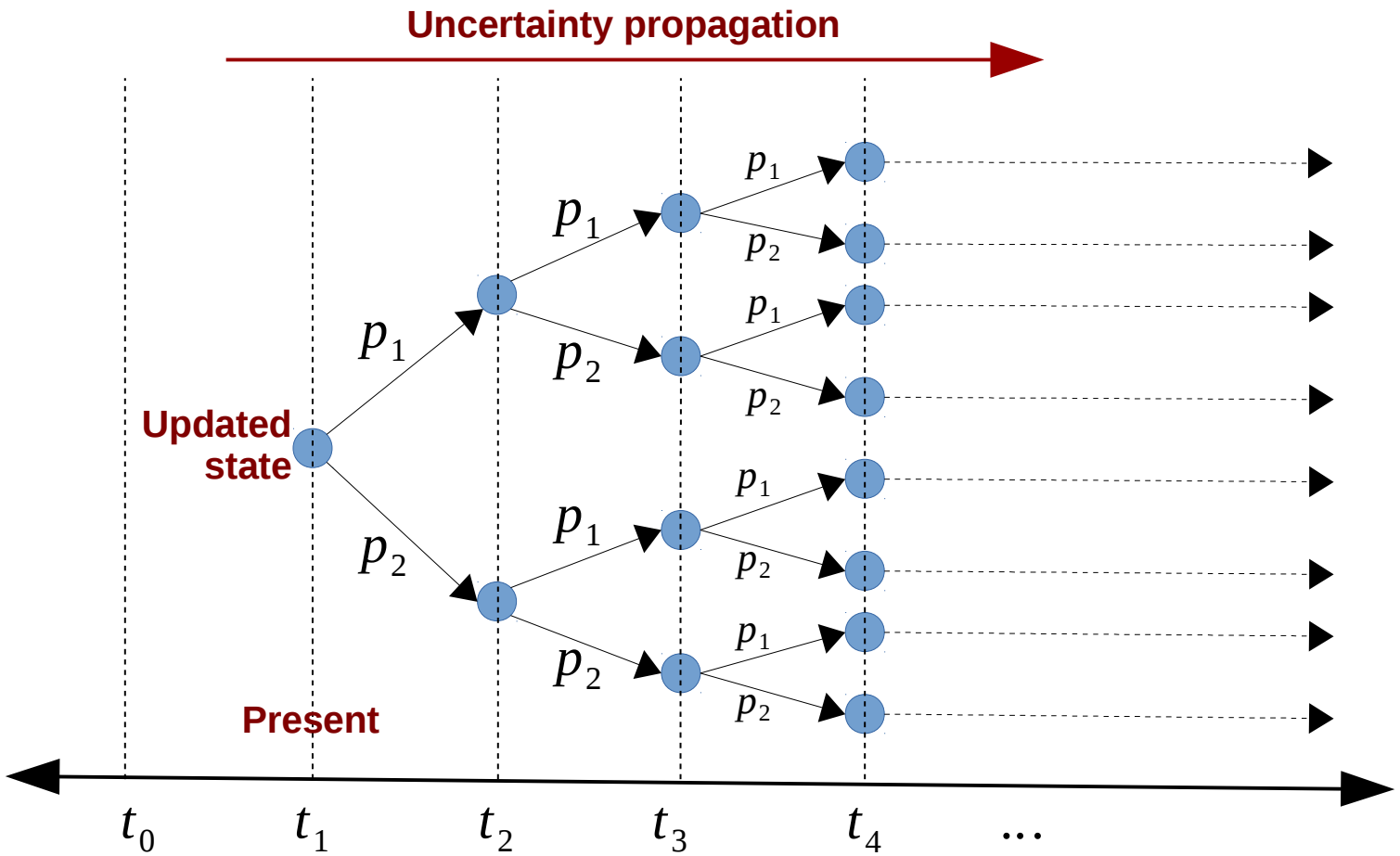

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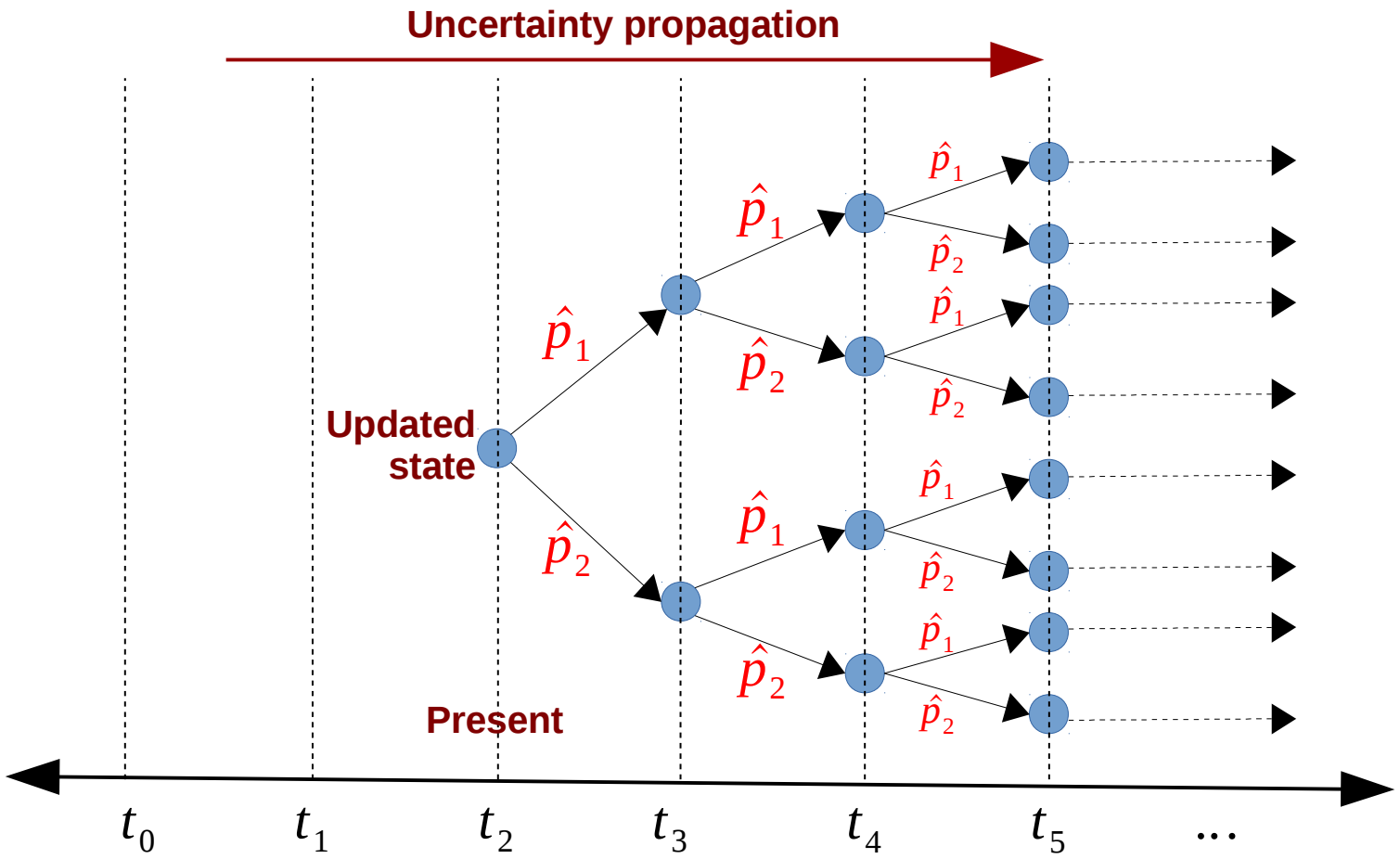
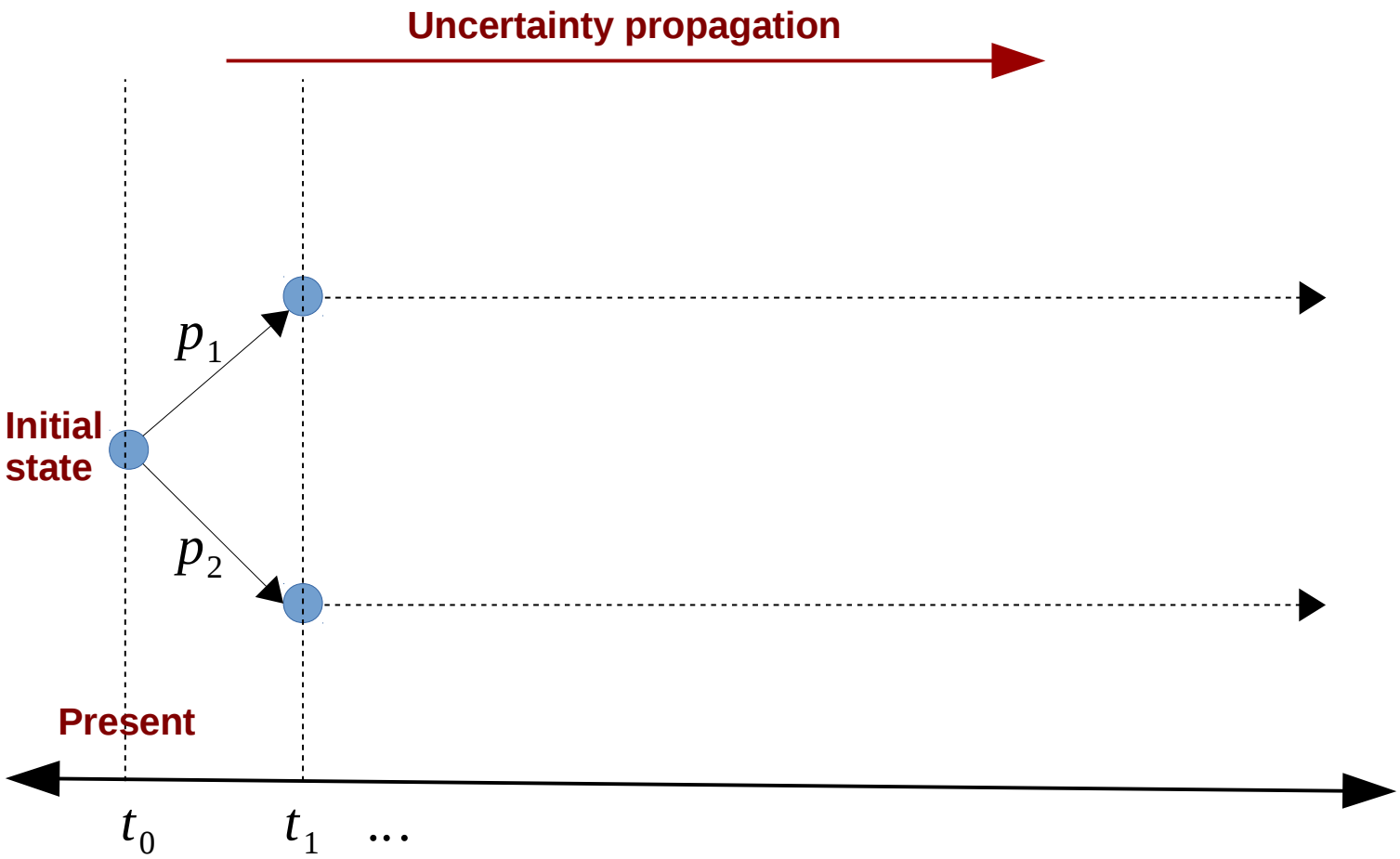


- New uncertainty information at t_2

Dynamically Adjusting Scenario-Tree

2. Adjusting the robust horizon



- Robust horizon $= 1$

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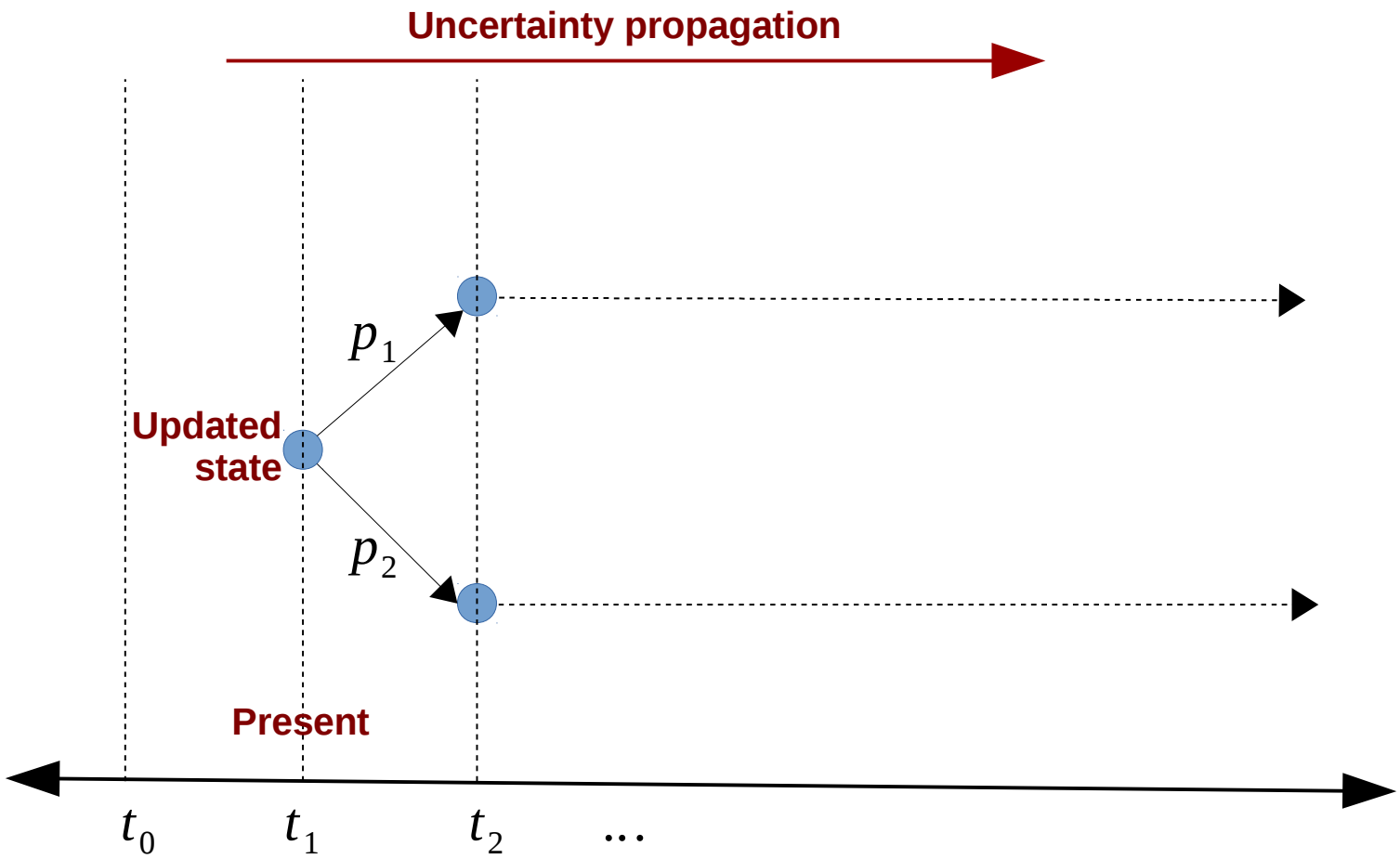

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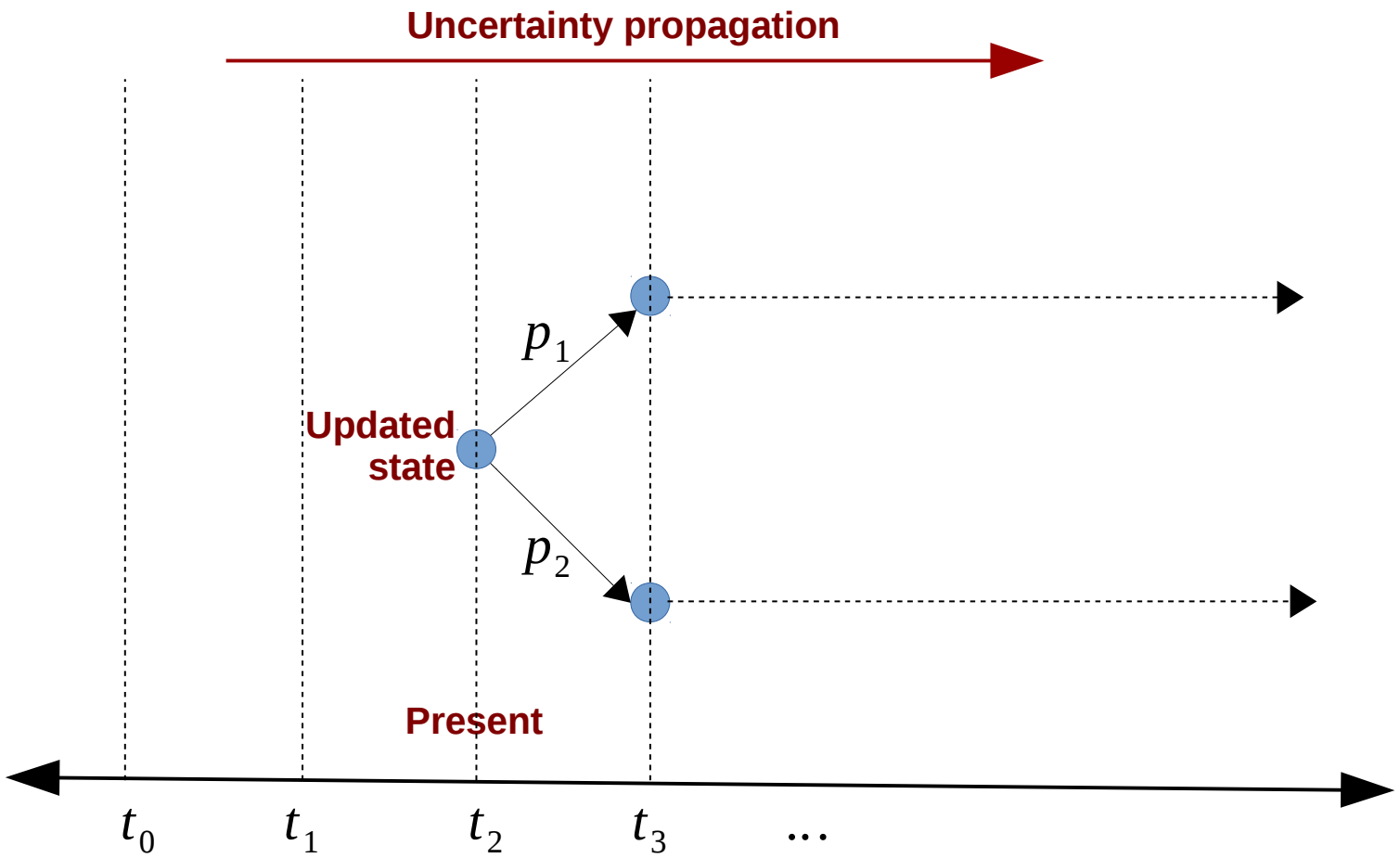

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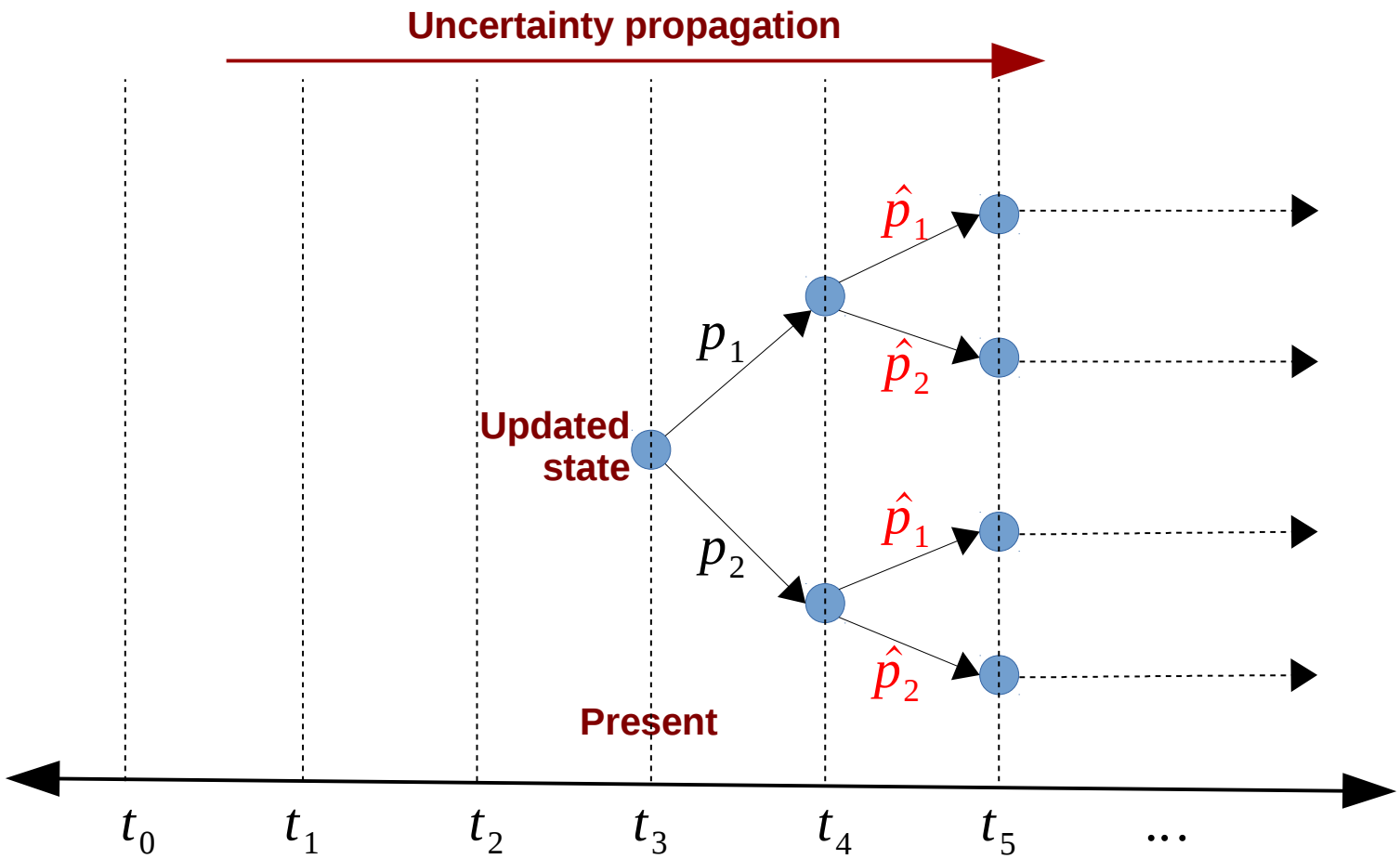
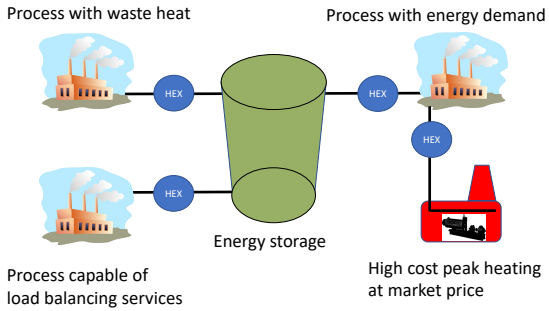


- Robust horizon $= 2$
- New uncertainty information at t_3 about t_4

Case Study - Thermal Energy Storage



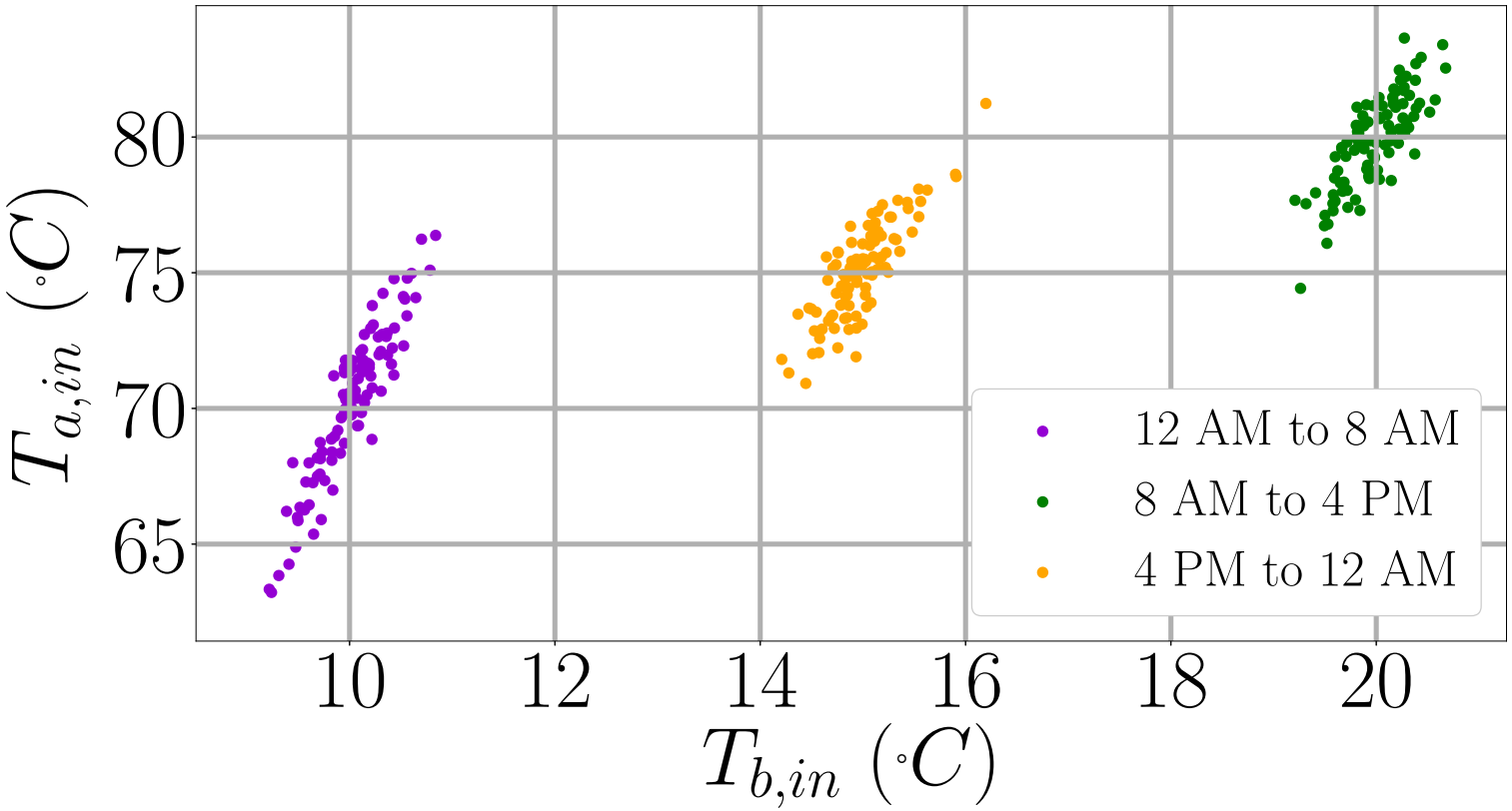
- For a given energy demand profile for plant B, the economic objective is to minimize the cost of energy:

$$P_{tank}(Q_{tank}) + P_{market}(Q_{market})$$

- Given uncertainties in:
  - Heat supply temperature of Plant A
  - Heat demand temperature of Plant B

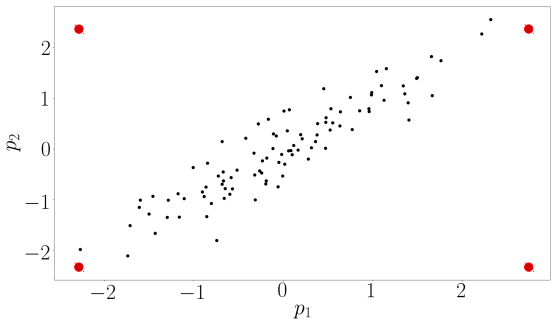
Uncertainty Description

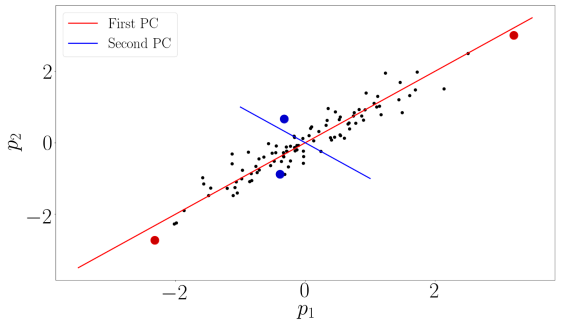
- Uncertainties are considered in the process temperatures of Plant A and Plant B.



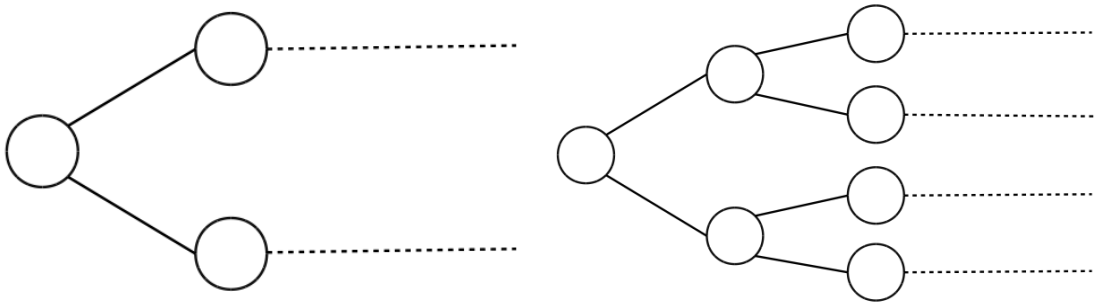
Results

1. Adjusting the scenarios: PCA vs Box selection
   - PCA: 3 scenarios
   - Box : 5 scenarios

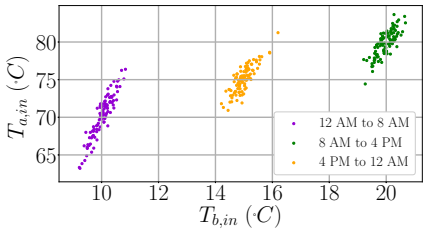




2. Adjusting the robust horizon: 1 vs 2
   - Case 1: Robust horizon 1
   - Case 2: Dynamically adjust robust horizon at 7 AM and 3 PM



Results - Scenario Selection: PCA vs BOX



- Peak demand 10,000 kW from (7:00-9:00) and (15:00-17:00),
- Off-peak demand 5000 kW

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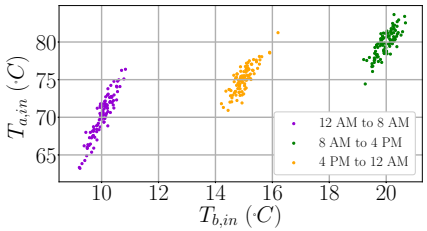

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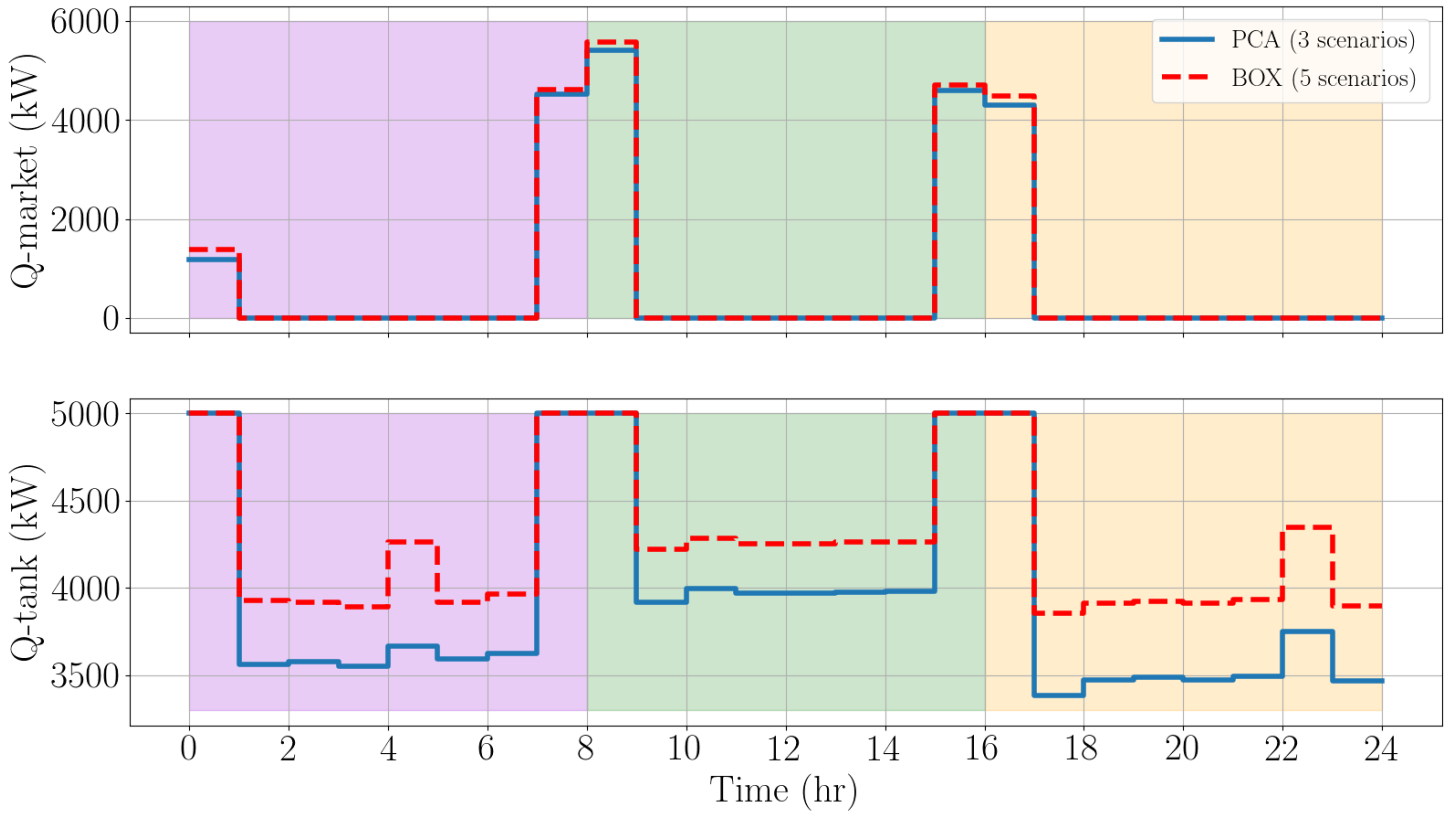

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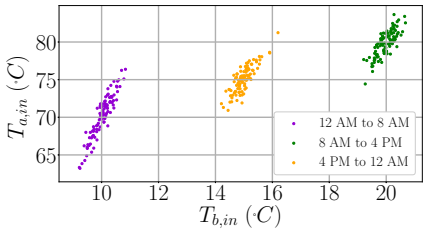

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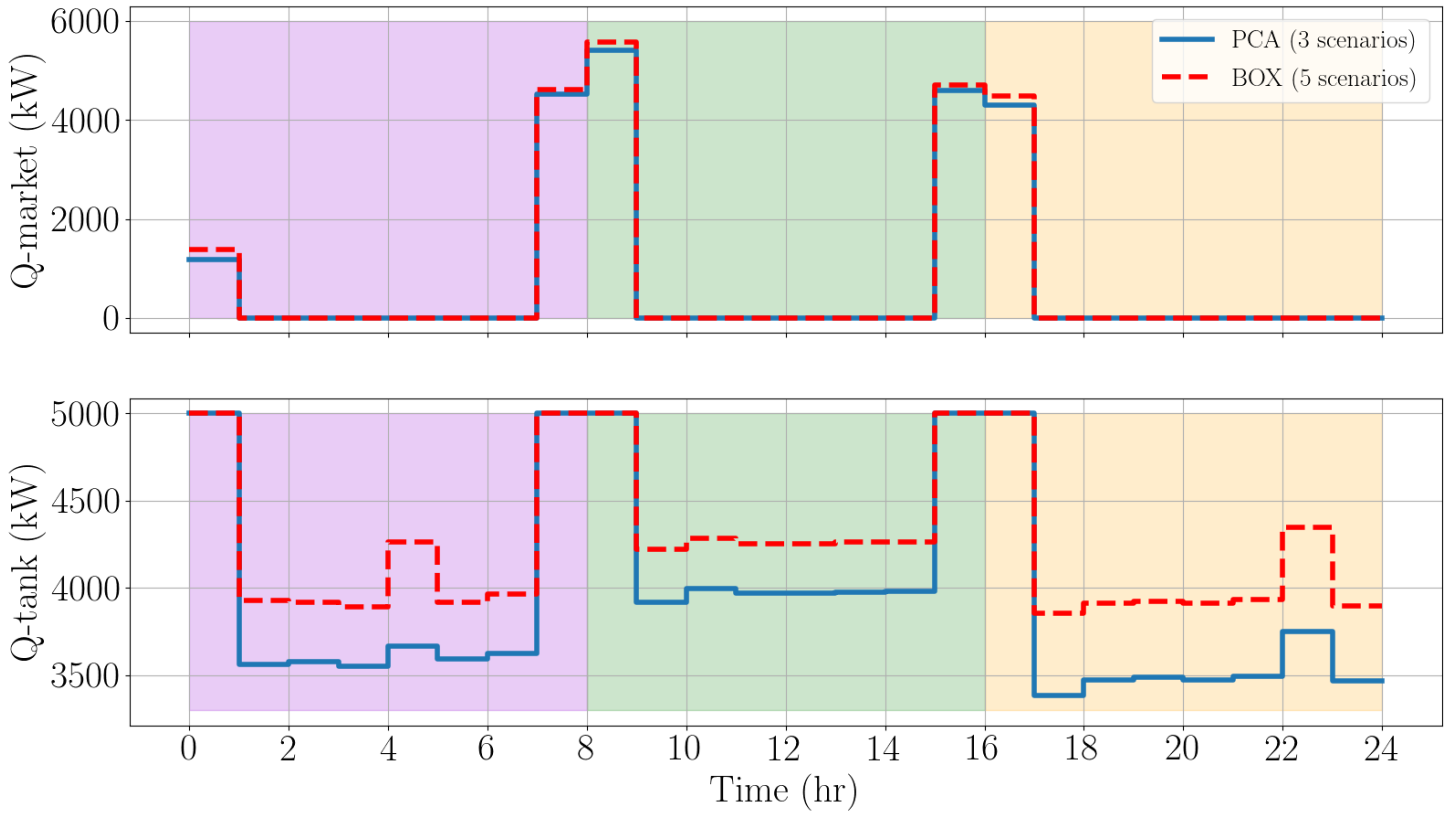
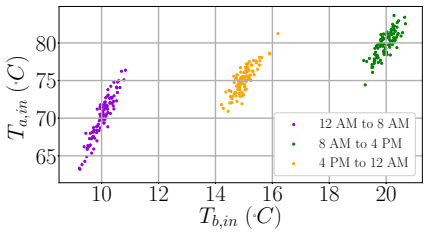


- **PCA uses fewer scenarios, and is less conservative!**

Results - Robust Horizon: 1 vs 2



- $N_r = 1 \rightarrow 2$ one hour before transition (at 7:00 and 15:00)
- Demand constant at 5000 kW

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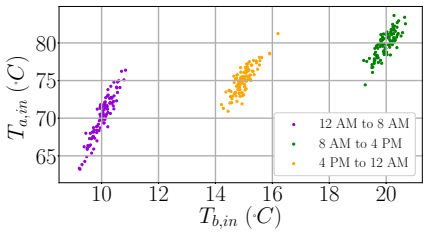

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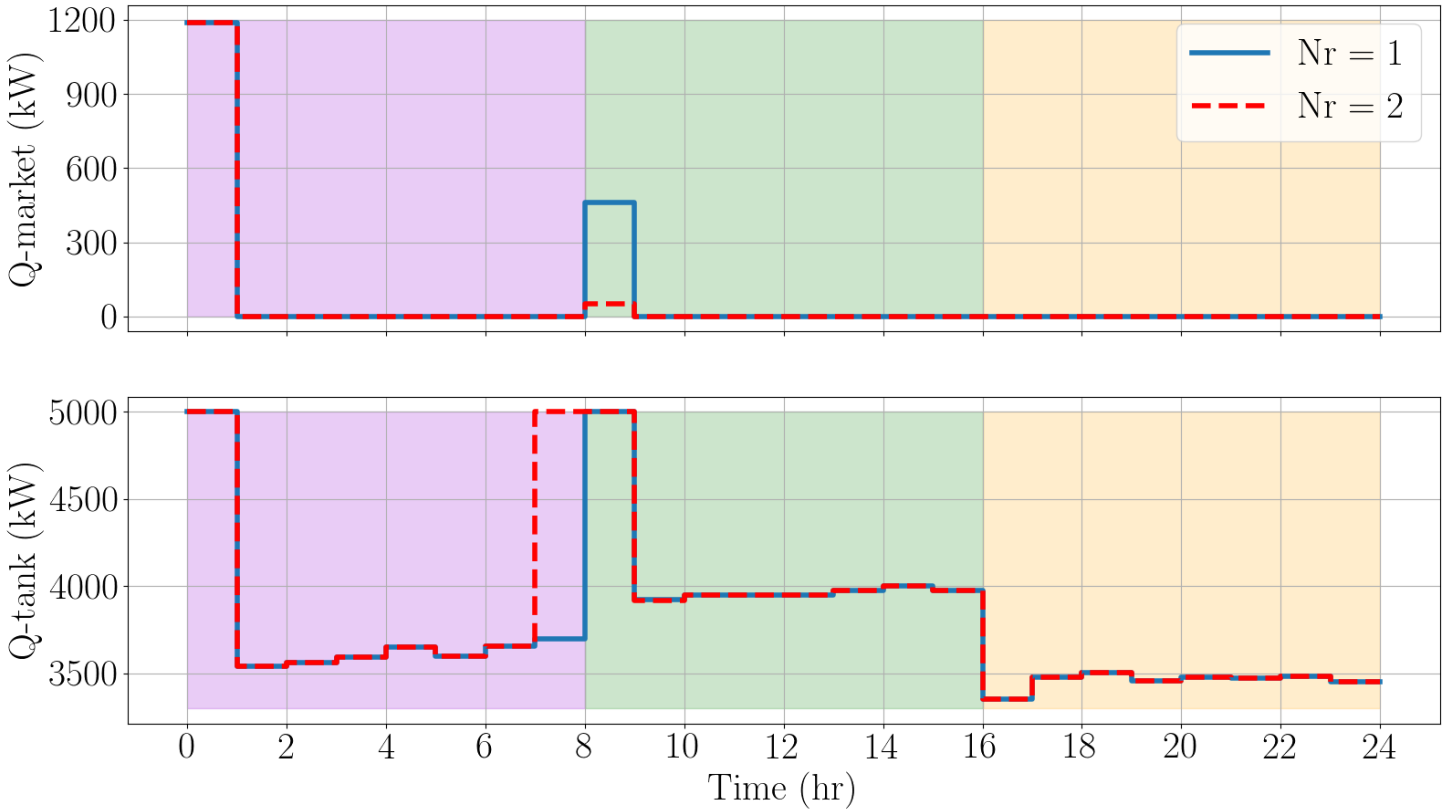

- **Adjusting N_r gives lower energy consumption!**

Conclusion

General conclusion

- Value added by energy storage is closely linked to operation strategy
- Accounting systematically for uncertainty reduces cost and increases efficiency (while satisfying requirements)

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Leverage data for maximum efficiency

- PCA based data-driven scenario selection
  - Smaller scenario trees, without sacrificing information
- Dynamically update scenarios
  - Account online for latest uncertainty information
- Dynamically adjust robust horizon
  - Preemptive control action – reduced operating cost