

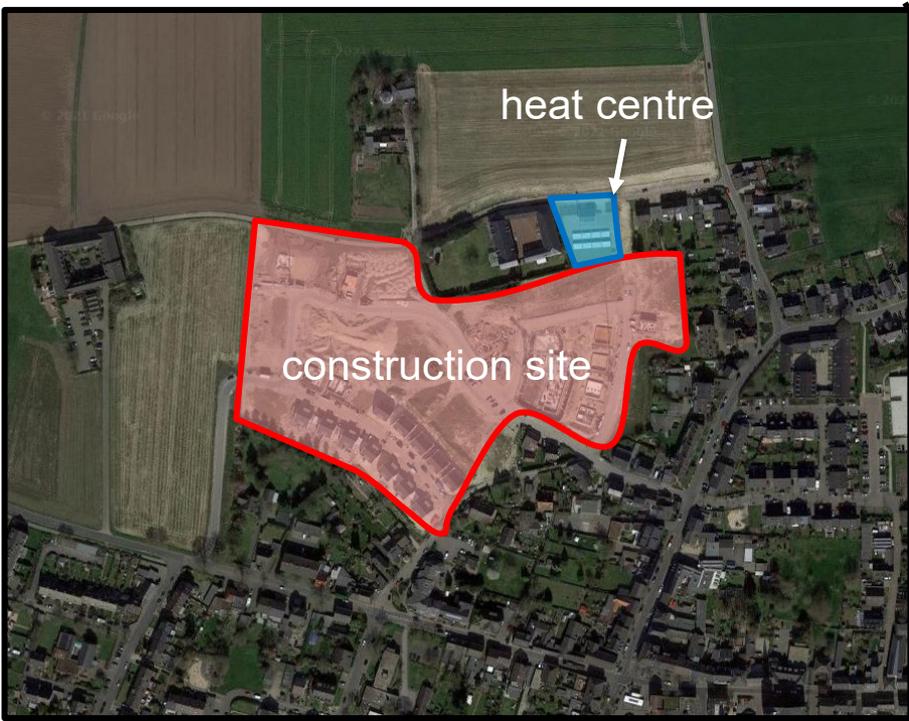
Data-Driven Model Predictive Control of a District Heating Network

Jonas Gottschald

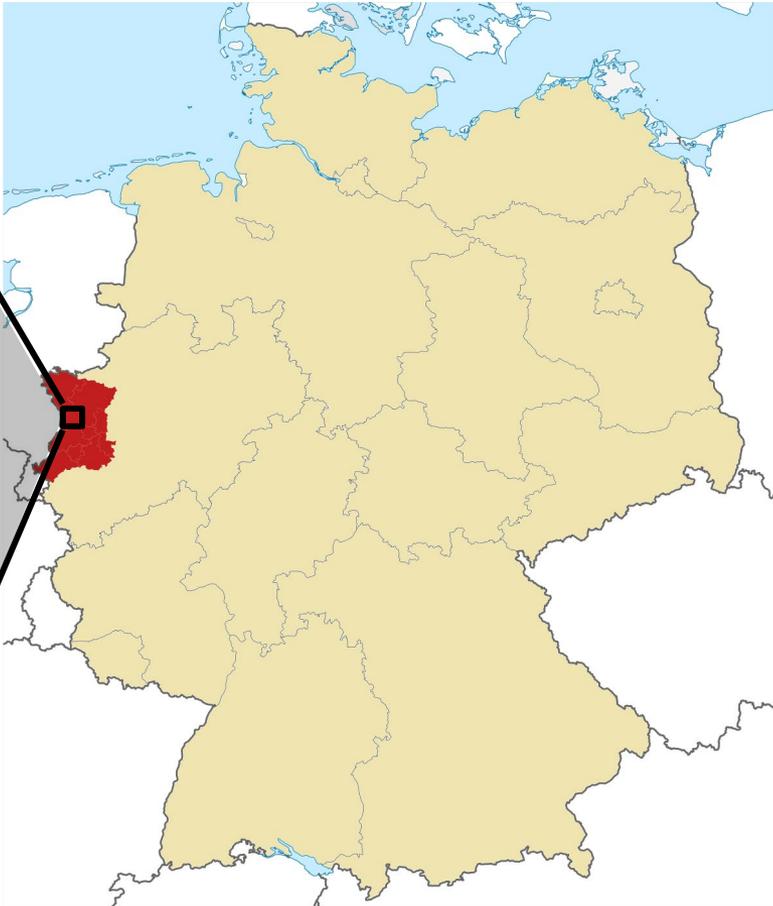
21.09.2021,
Smart Energy Systems
International Conference 2021

INTRODUCTION

New housing development in North Rhine-Westphalia, Germany,
120 residential units, 1 GWh annual heat demand



Source: www.google.de/maps/ (2021)



Source: [https://de.wikipedia.org/wiki/Niederrhein_\(Region\)](https://de.wikipedia.org/wiki/Niederrhein_(Region)) (2021)

INTRODUCTION

4th generation heating network (flow 55°C, return 35°C)

Heat generator for storage tank charging

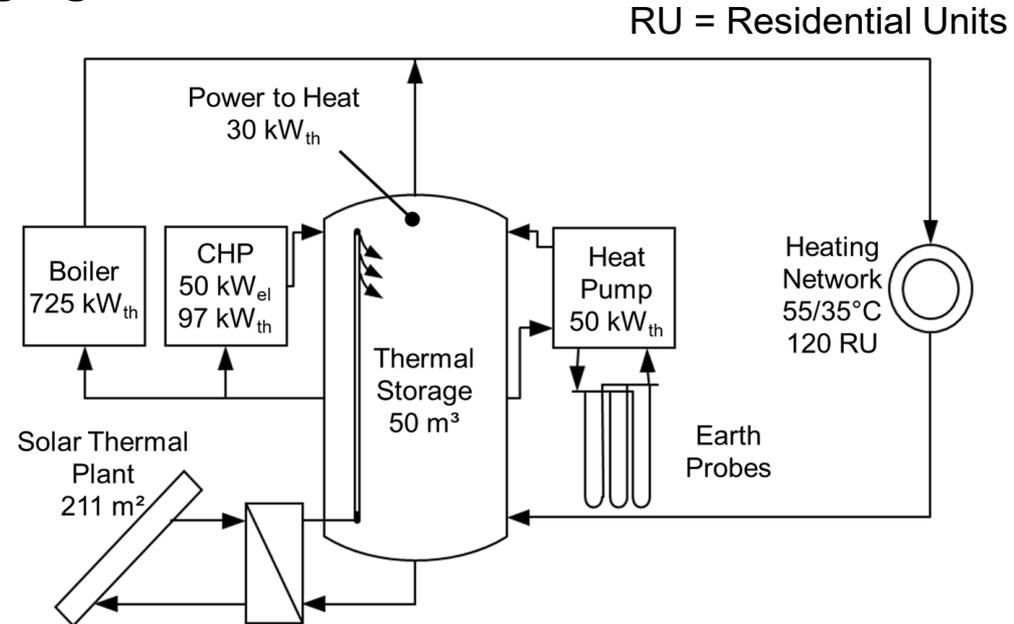
- Combined Heat & Power (CHP)
- Electric Heat Pump (HP)
- Solar Thermal Plant (STP)
- Heating rod

Securities

- Gas boiler secures supply
- System ensures device operation

Natural gas: Costs from purchase (incl. taxes)

Electricity: Costs/revenues from purchase/sale + state subsidies

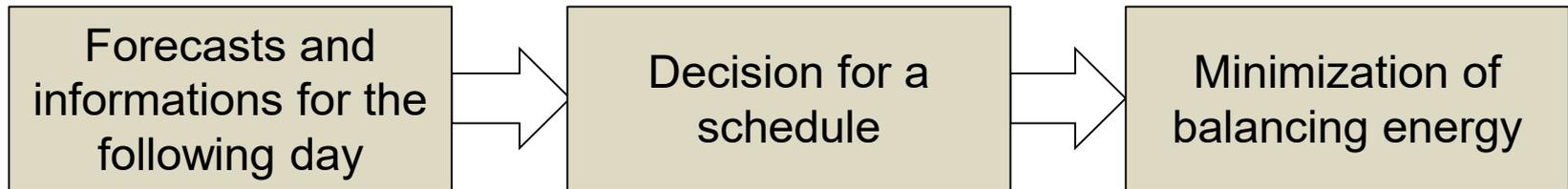


Optimal operation + connection to (electricity) market?

CHALLENGE I

Transmission system operator ensures a balanced power grid

- Market participants must declare planned energy quantities for the following day
- Energy quantities result from planned operation (➤ Schedule)
- Deviations from planned energy quantities (results in balancing energies) can lead to high costs



Challenge

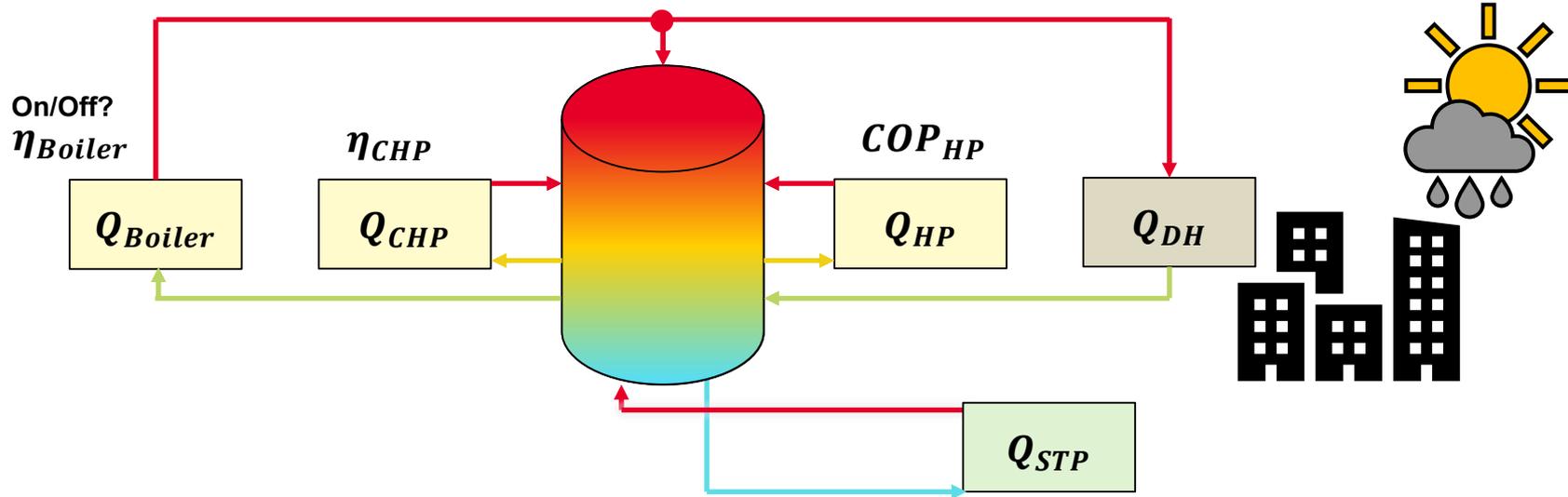
Creation of an optimized schedule and compliance with the declared energy quantities

CHALLENGE II

Thermal storage allows decoupling of heat demand and heat generation

Possible case: Exclusively electricity price-led operation of CHP + HP?

➤ Operation of CHP + HP "limited" by dependencies:



Challenge

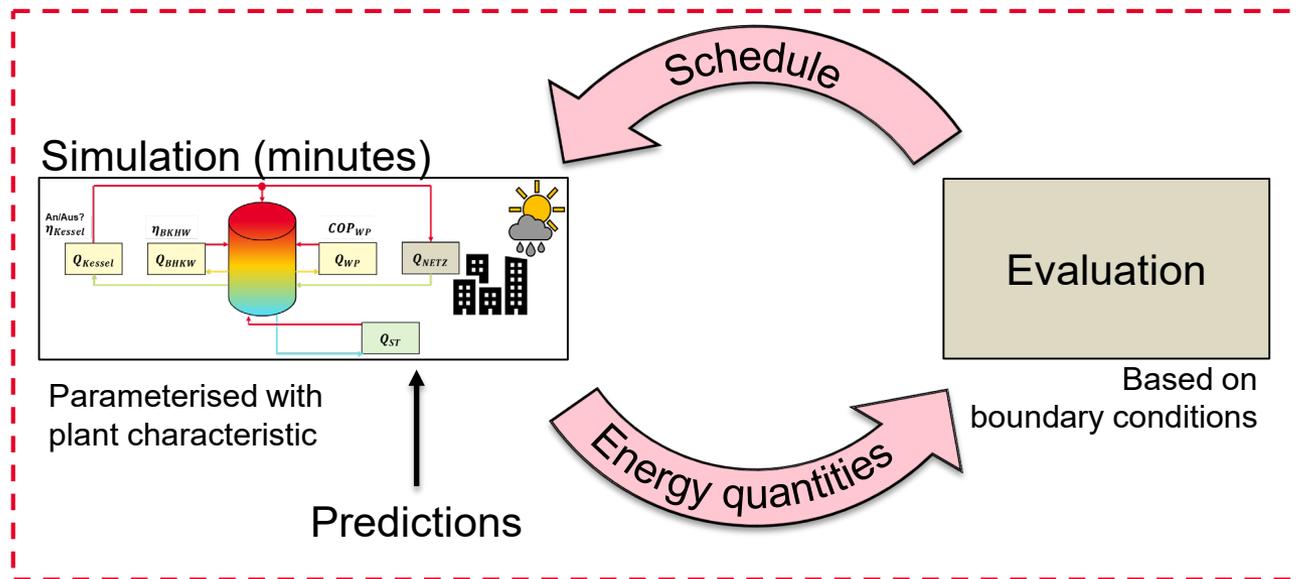
Prediction of boundary conditions **and** system response e.g. temperature distribution of the heat storage required

SOLUTION

Simulation of the system (e.g. using MATLAB/Simulink), embedding in optimization

- High computational effort
 - Few minutes for one simulation and evaluation (one Schedule)
 - 10000+ cycles (hours!) for optimal schedule
- Consideration of system changes? (fouling,...)

Optimization-Framework → Optimal schedule + corresponding energy quantities

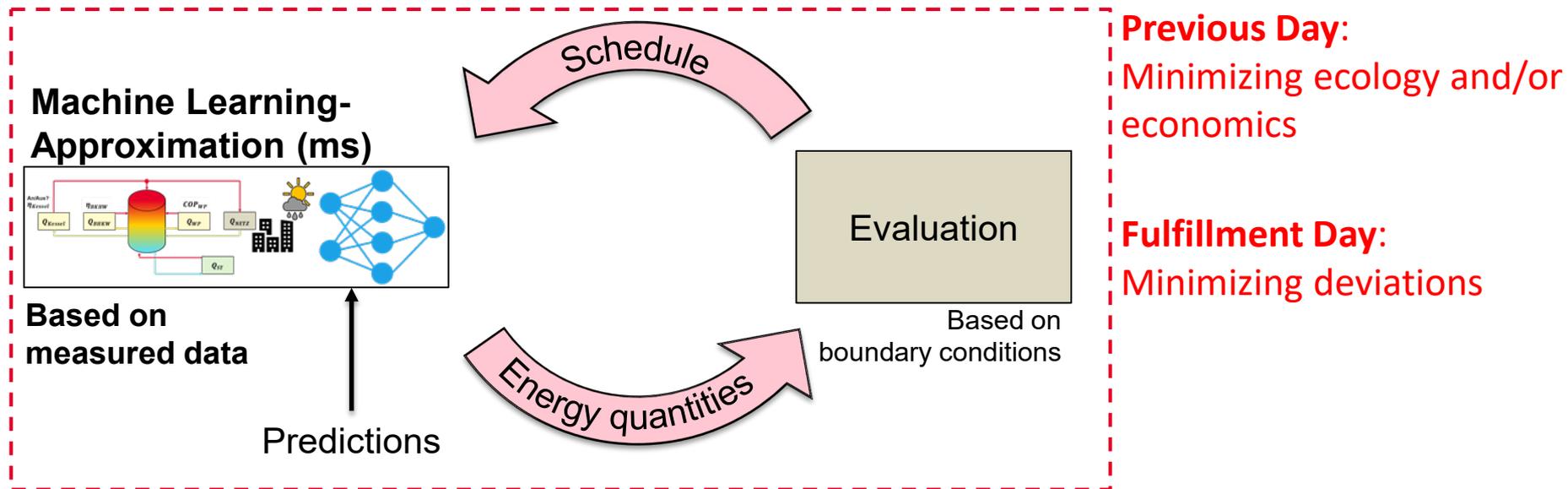


SOLUTION

Data-based approximation of thermal and electrical behavior

- Machine Learning (ML) for fast and accurate approximation
 - Only milliseconds incl. evaluation
 - Few minutes for optimal schedule
 - Approximates changes in system behaviour (based on measured data)

Optimization-Framework → Optimal schedule + corresponding energy quantities



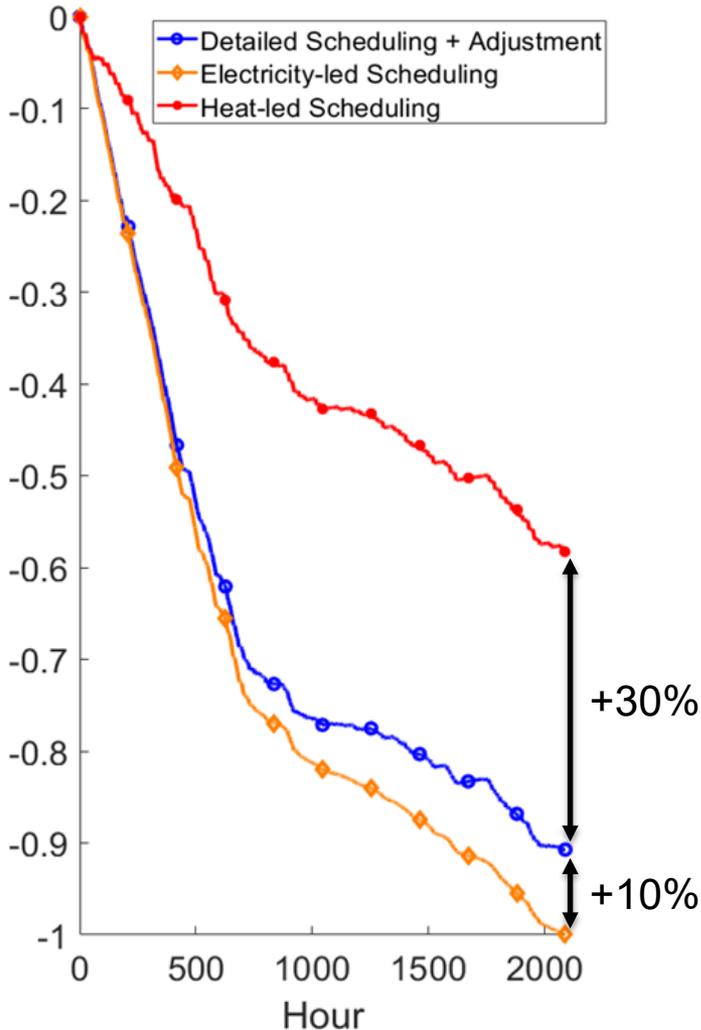
RESULTS

- Comparison of different approaches to **cost-optimal** control
- Scheduling in simulation-environment, 3 months (April-June)
- Boundary conditions (heat load, global radiation, etc.) with uncertainties
- Case 1: **Detailed Scheduling + Adjustment (DSA)**
 - Optimale scheduling using ML as described before
- Case 2: **Electricity-led Scheduling (ES)**
 - No prediction of systems state, optimized schedule to achieve highest revenue
- Case 3: **Heat-led Scheduling (HS)**
 - Rule-based (non-predictive), simple prediction based on energy balances

Case	Model predictive?	Reducing balancing energy?	Complexity	Cost-Stability
DSA	Yes	Yes	High	?
ES	No	No	Low	?
HS	Yes	No	Medium	?

RESULTS

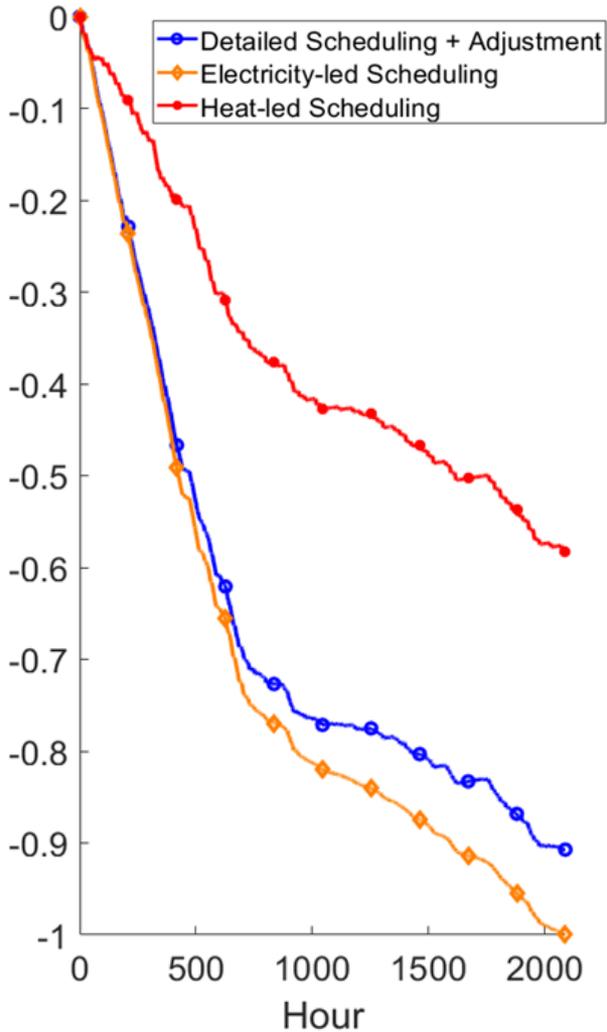
Cumulative Operating Costs



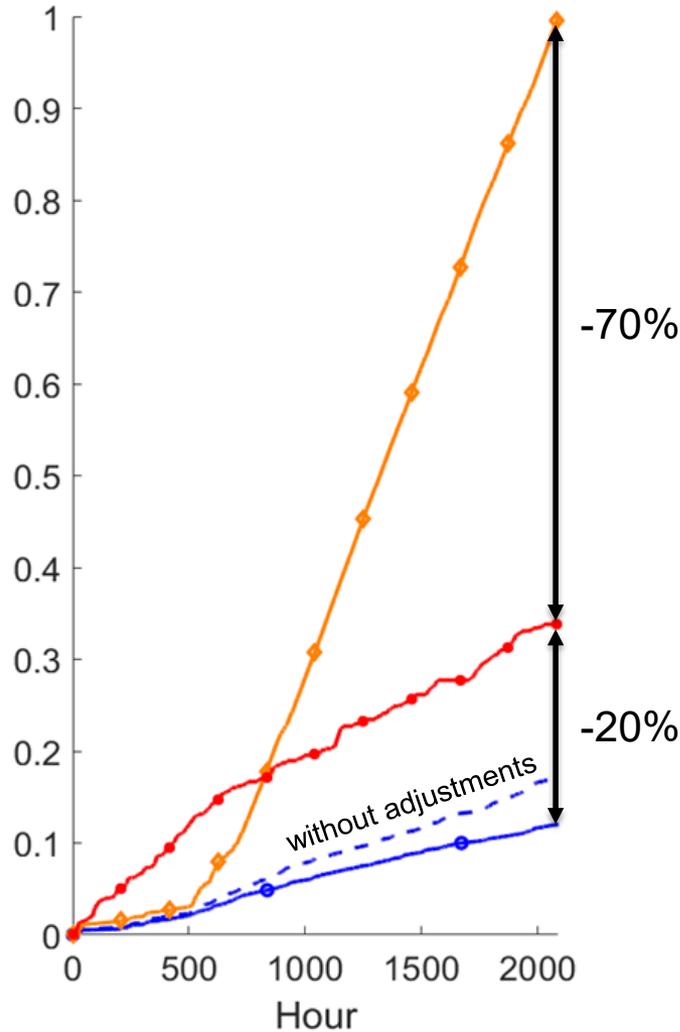
- In general: Revenues and subsidies for CHP electricity lead to negative operating costs
- Electricity price-led schedule:
 - Optimal operating costs by exhausting the CHP unit
- Storage temperatures influences CHP operation (efficiency + protection)
 - Deviations from schedule

RESULTS

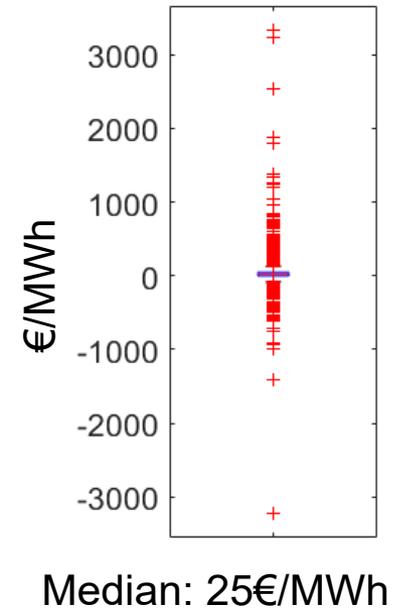
Cumulative Operating Costs



Cumulative Balancing Energies

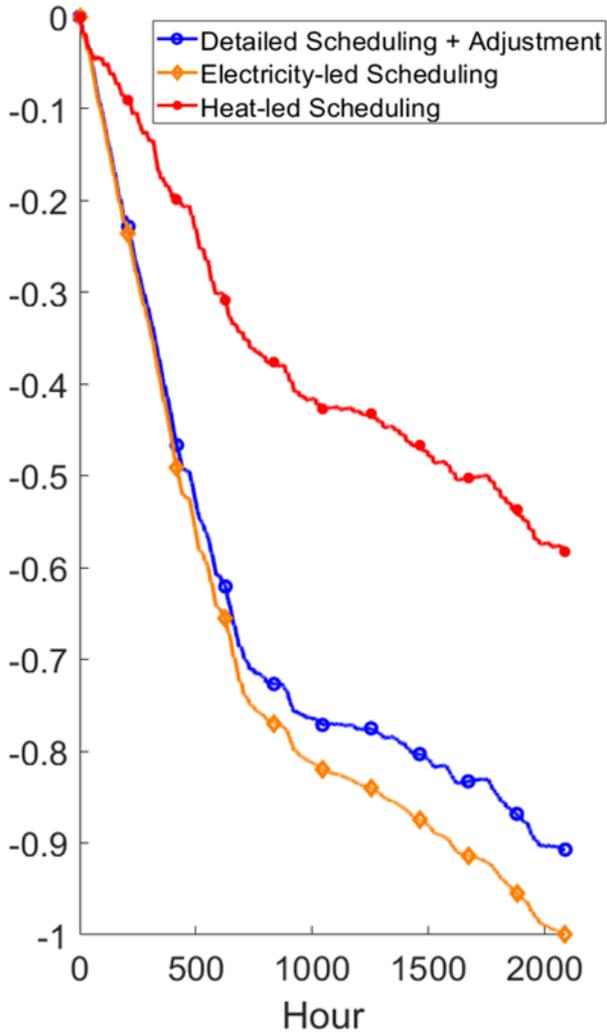


Costs for Balancing Energies:

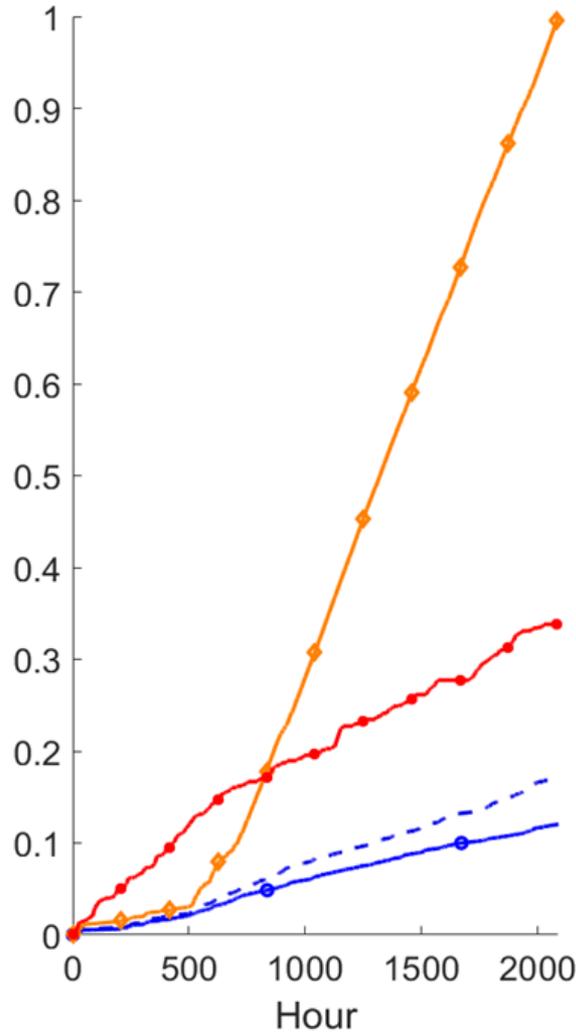


RESULTS

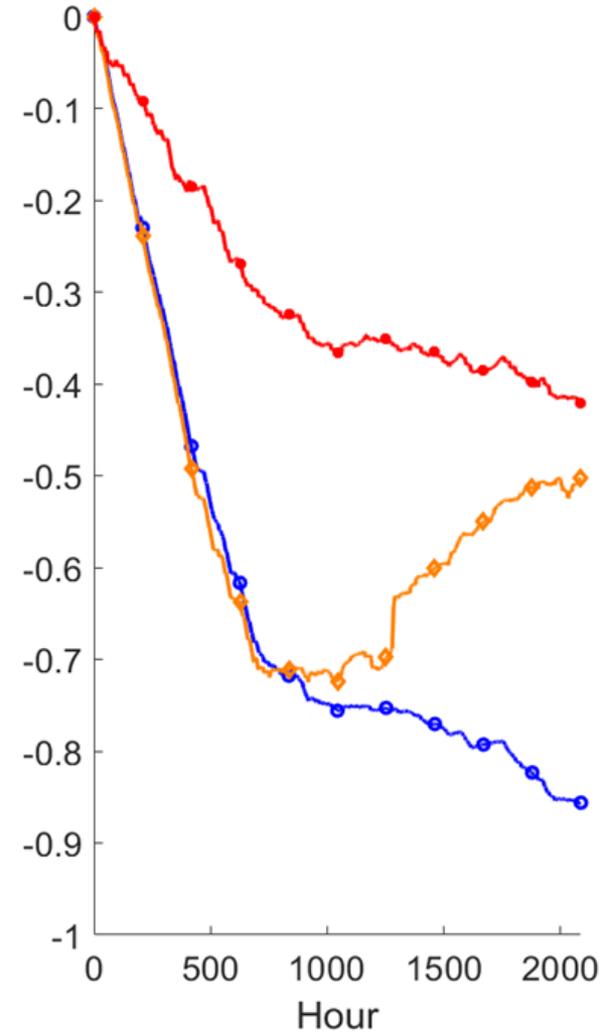
Cumulative Operating Costs



Cumulative Balancing Energies



Total Costs



SUMMARY

- Hybrid Systems require detailed prediction of future systems state for optimal control and scheduling
 - Machine Learning for detailed approximation better than simple models based on energy balance
- Cost stability increase with complexity of the method
- Adjustments on fulfillment day reduce balancing energies significantly (-30%)
- Outlook: Boundary conditions will change, emissions from natural gas will become more important to consider = Electricity-led operation won't be best choice

Case	Model predictive?	Reducing balancing energy?	Complexity	Cost-Stability
DSA	Yes	Yes	High	High
ES	No	No	Low	Low
HS	Yes	No	Medium	Medium

**THANK YOU FOR YOUR
INTEREST!**

IF YOU HAVE QUESTIONS

Jonas Gottschald

jonas.gottschald@hs-duesseldorf.de

Tel.: +49 211 4351 3575

Centre of Innovative Energy Systems

<https://zies.hs-duesseldorf.de>

