Design and Dispatch of Decentralized Energy Systems using Artificial Neural Networks

MODPROD 2024 – Lukas Koenemann, Astrid Bensmann, Richard Hanke-Rauschenbach

WETEC GROUP IfES Leibniz Universität Hannover

Motivation

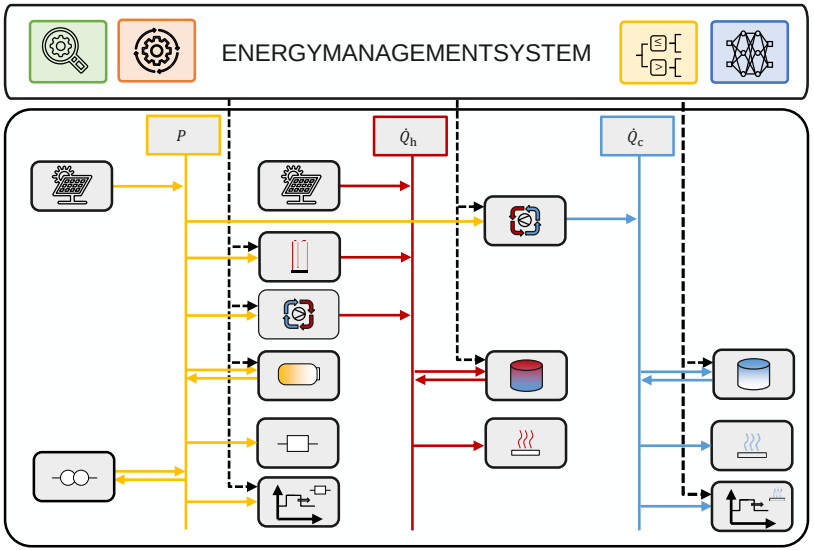
- Decentralized Energy Systems integrating renewable energy sources using dispatchable
  - Conversion components (e.g. heat pump, chiller)
  - Energy storage systems (e.g. li-ion battery)
  - Flexible energy demands (e.g. electro mobility)
- Energy management systems
  - Task: Dispatch flexible components
  - Aim: Cost-efficient and reliable energy supply
  - Methods:

Optimal dispatch
+ Optimal solution
- Perfect foresight

Heuristic Rules
+ Easy to apply
- Expert knowledge

Model Predictive Control
+ Performing well
- Need good forecast & model convexity

Artificial Neural Networks
- Training method?
- Performance?



Outline

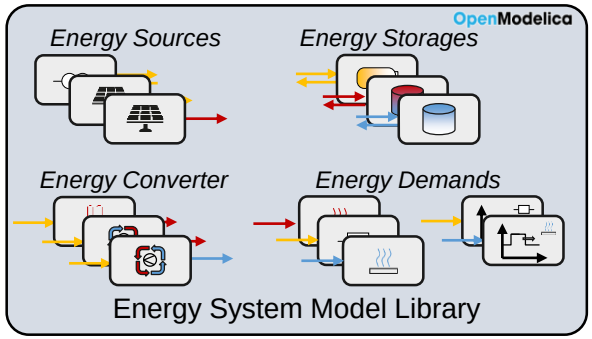
01 Framework for an Artificial Neural Network-based Dispatch Strategy

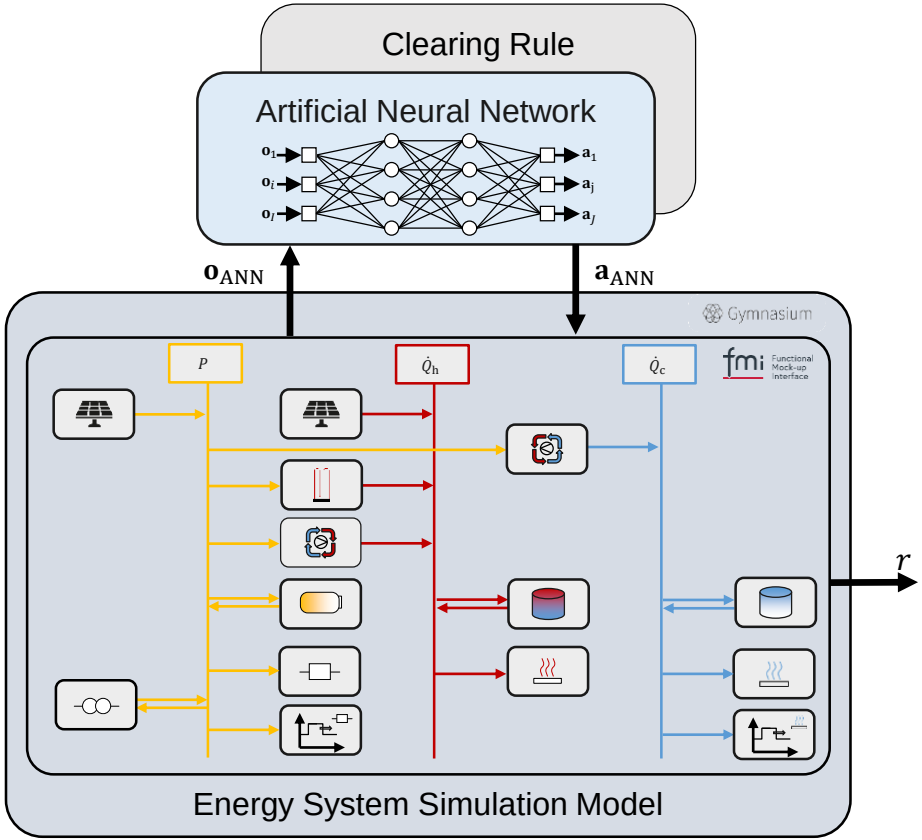
02 Comparative Analysis

03 Conclusion & Outlook

Modeling & Simulation Framework

- Component modeling using OpenModelica
- Energy system simulation using pyfmi
- Embedding in gymnasium framework
- Dispatch energy system using Artificial Neural Network
  - Observation ($\mathbf{o}_{\mathrm{ANN}}$): e.g. battery state of charge, photovoltaic power
  - Action ($\mathbf{a}_{\mathrm{ANN}}$): power set point for components
  - Reward (r): e.g. resulting operating cost
- Clearing Rule to ensure energy supply





Training methods for ANN-based dispatch strategy

Training method I: Predict optimal dispatch

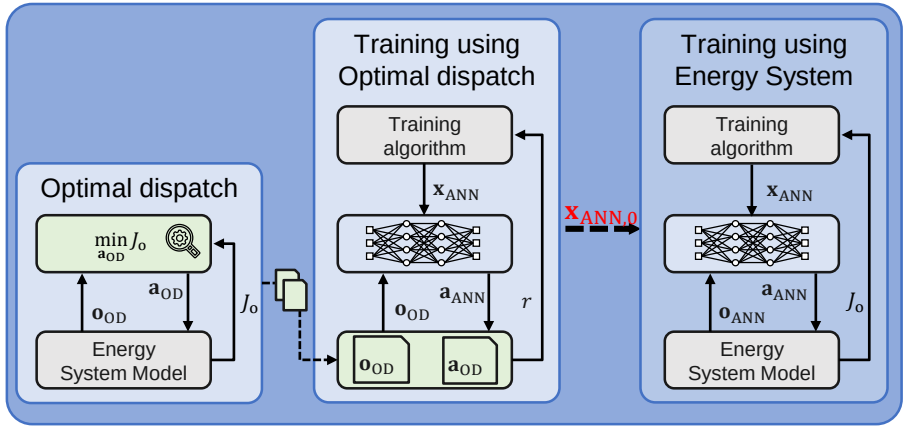
1. Solving optimal dispatch problem using NLP
2. Training using the optimal dispatch ($\mathbf{a}_{\mathrm{OD}}, \mathbf{o}_{\mathrm{OD}}$)
   - Observation: From pre-calculated OD ($\mathbf{o}_{\mathrm{OD}}$)
   - Action: Predict the optimal action ($\mathbf{a}_{\mathrm{OD}}$)
   - Reward: $r = |\mathbf{a}_{\mathrm{OD}} - \mathbf{a}_{\mathrm{ANN}}|$

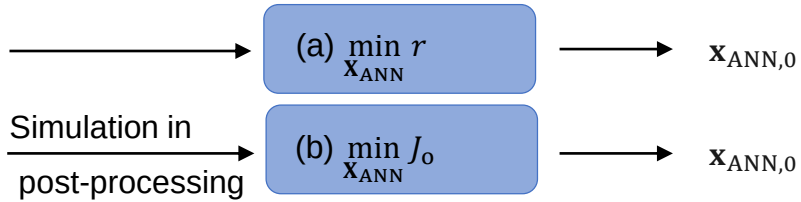
Training method II: Using Energy System Model

- Observation: From energy system model ($\mathbf{o}_{\mathrm{ANN}}$)
- Action: Power set-point for next time step ($\mathbf{a}_{\mathrm{ANN}}$)
- Reward: Simulated operating cost J_{o}

Training method III: Combination

1. Solving optimal dispatch problem
2. Training using the optimal dispatch
3. Training using the ESM with initial solution ($\mathbf{x}_{\mathrm{ANN},0}$)





Outline
Conclusion

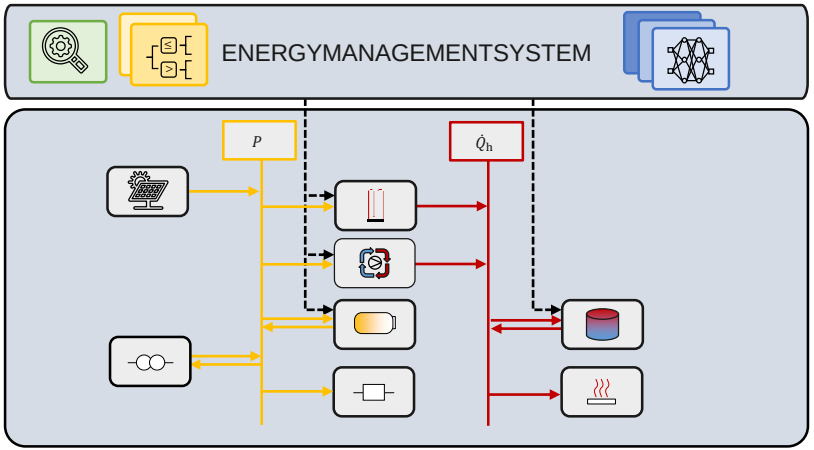
01 Framework for an Artificial Neural Network-based Dispatch Strategy

02 Comparative Analysis

03 Conclusion & Outlook

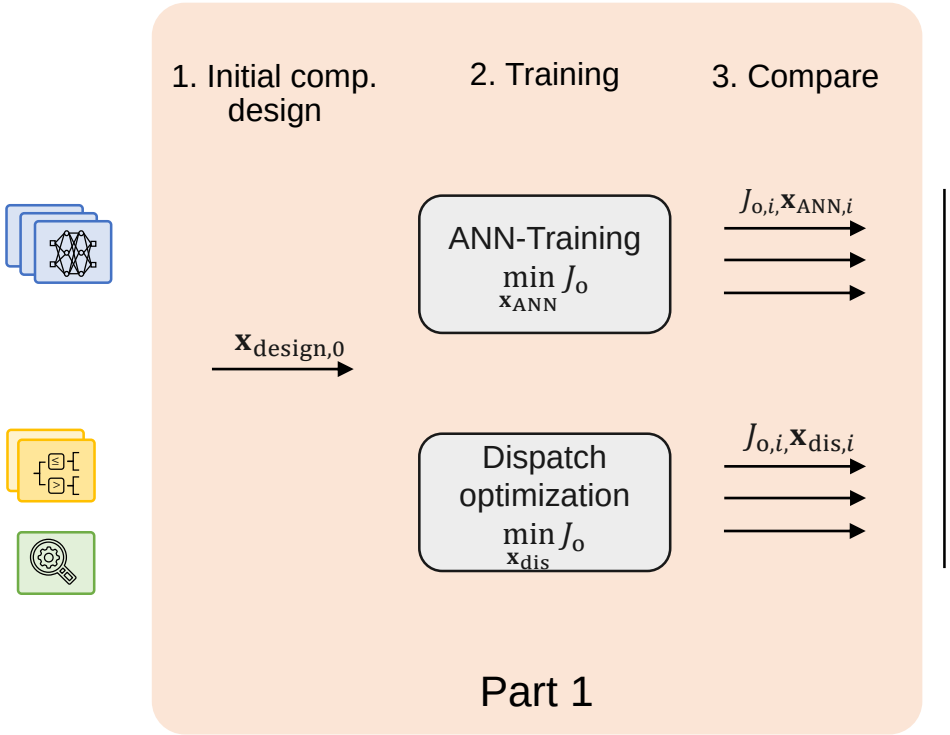
Case Description

- Electrical and Heating demand for a small district
- Electrical supply:
  - Photovoltaic system
  - Li-ion battery
  - Public grid connection
- Heating supply:
  - Air-source heat pump
  - Electric boiler
  - Hot water storage
- Dispatch strategies methods:
  - ANN-based dispatch (using Training method I-III)
  - Simple & advanced rule-based
  - Optimal dispatch



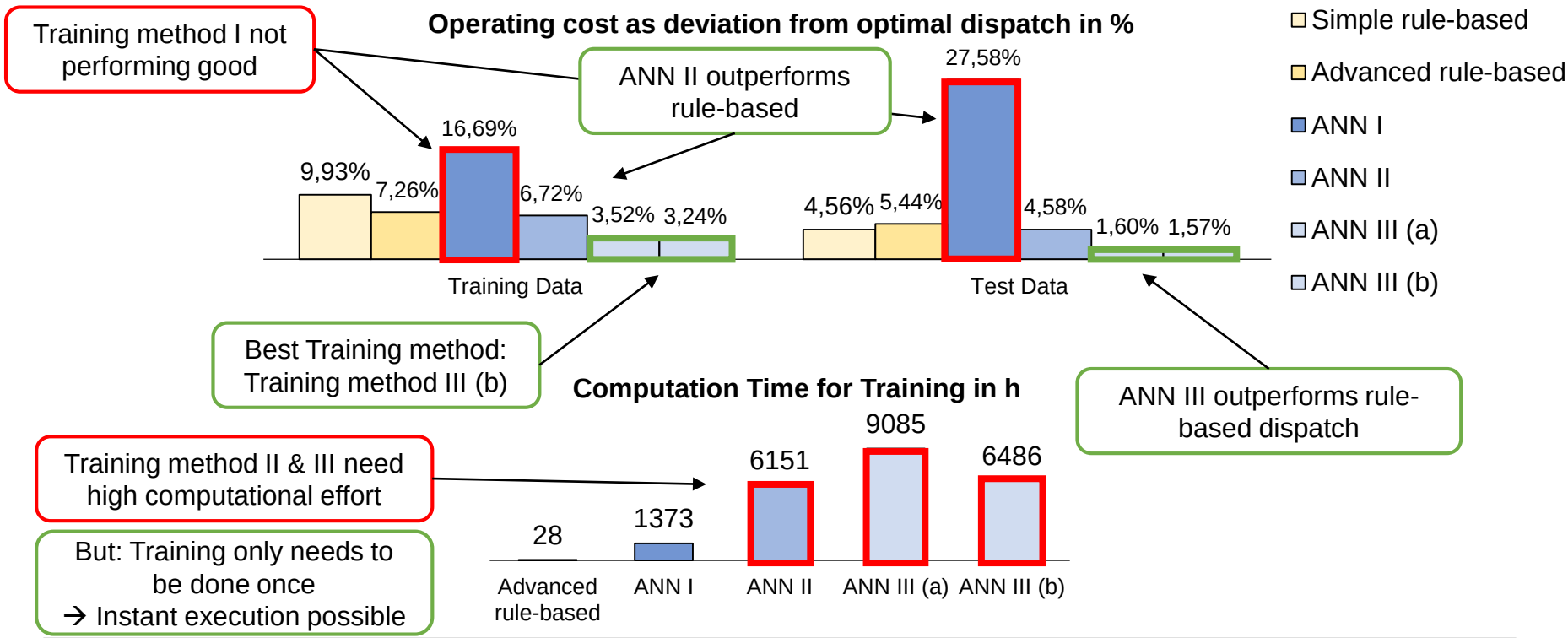
Analysis Part 1: Dispatch Strategies

Procedure



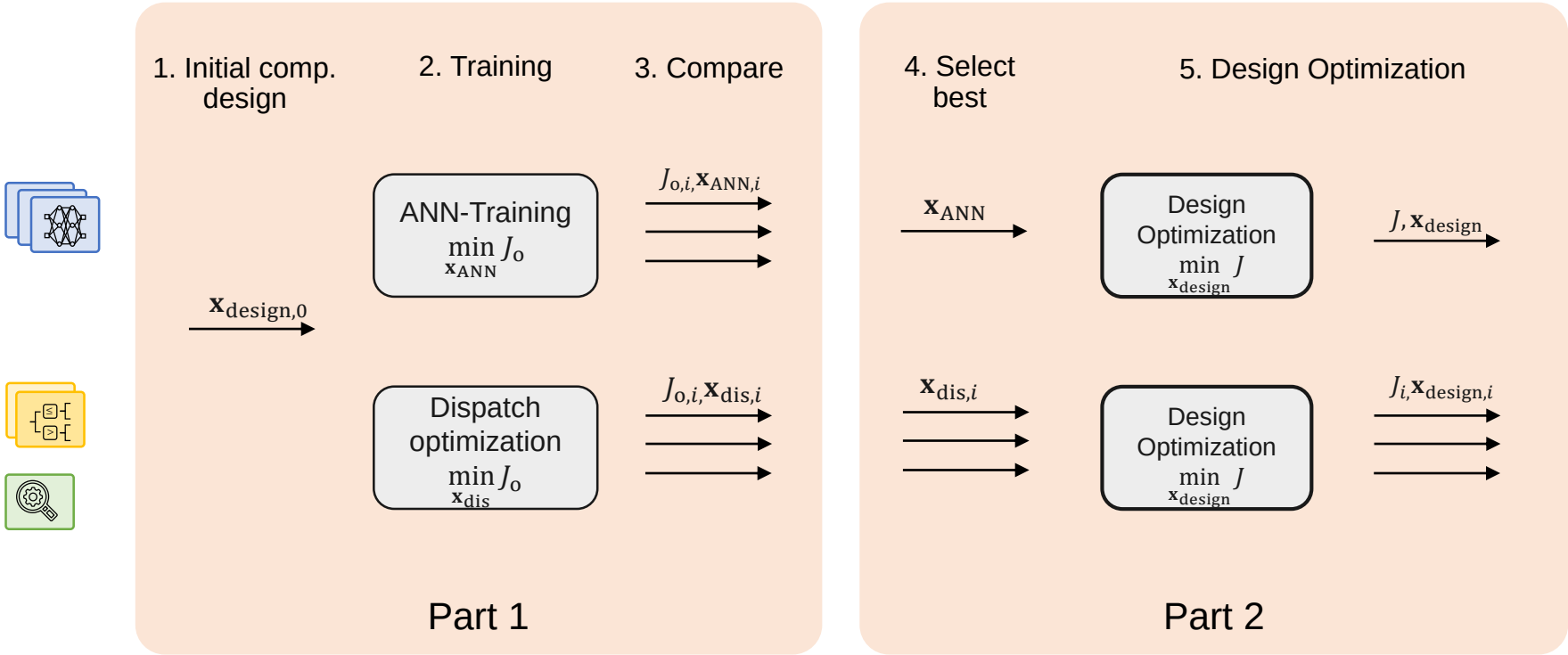
Analysis Part 1: Dispatch Optimization

Results



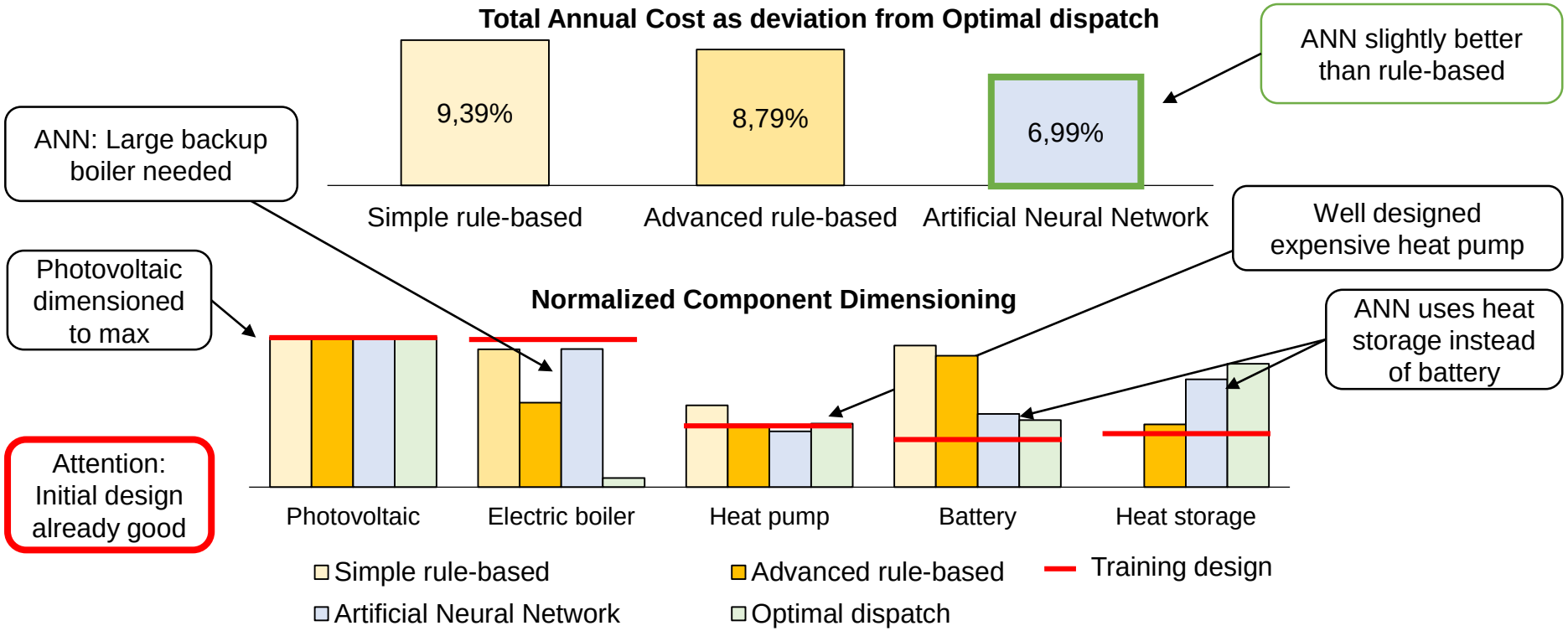
Analysis Part 2: Design Optimization

Procedure



Analysis Part 2: Design Optimization

Results



Outline
Conclusion

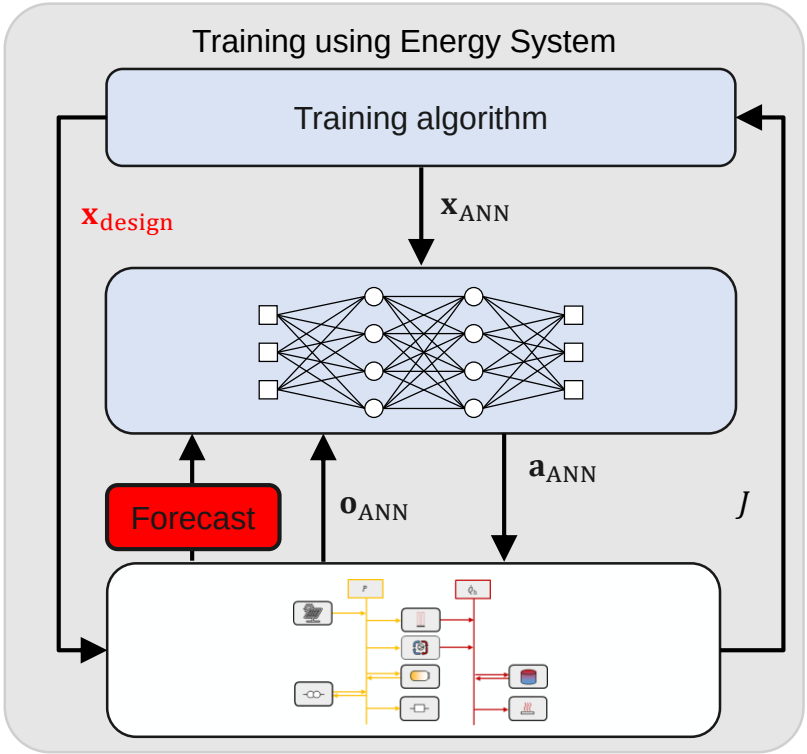
01 Framework for an Artificial Neural Network-based Dispatch Strategy

02 Comparative Analysis

03 Conclusion & Outlook

Conclusion and Outlook

- Training of ANN-based dispatch strategy
  - ↑ ANN-based dispatch outperform rule-based
  - ↓ High computing times for training required
- Design optimization with pre-trained ANN-based
  - ↑ Slightly better than rule-based
  - ↓ But: Training design must be carefully chosen
- Outlook
  - Considering an uncertain forecast
  - Coupled design optimization ($\mathbf{x}_{\text{design}}$) and training of neural networks



Thank you for your attention!