Power to Heat and Energy Storage Systems: System Layout and Operation Strategies for Process Heat based on Day-Ahead Market Pricing

Knowledge Sharing Workshop - CETP TRI 1 + 6 Flexibility in Industry
LoCoMoSa Project
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LoCoMoSa - Low Cost Molten Salt Thermal Energy Storage for Industrial Processes

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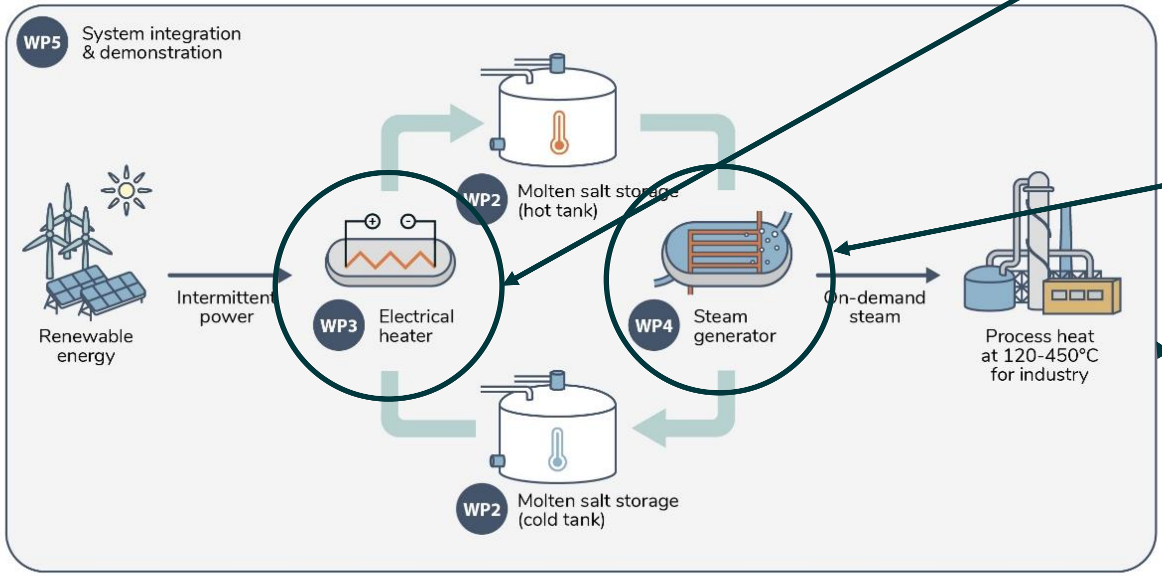
2.	Hyme Energy ApS	Denmark
3.	Fraunhofer Institute for Solar Energy Systems ISE	Germany
4.	Schniewindt GmbH & Co. KG	Germany
5.	National Institute for Nuclear Physics (INFN) Padua Division	Italy
6.	SEAMTHESIS Srl	Italy

Co-funded by the European Union

Our main objectives

Strategic Objective:

- Demonstrate a low-cost molten salt thermal energy storage system



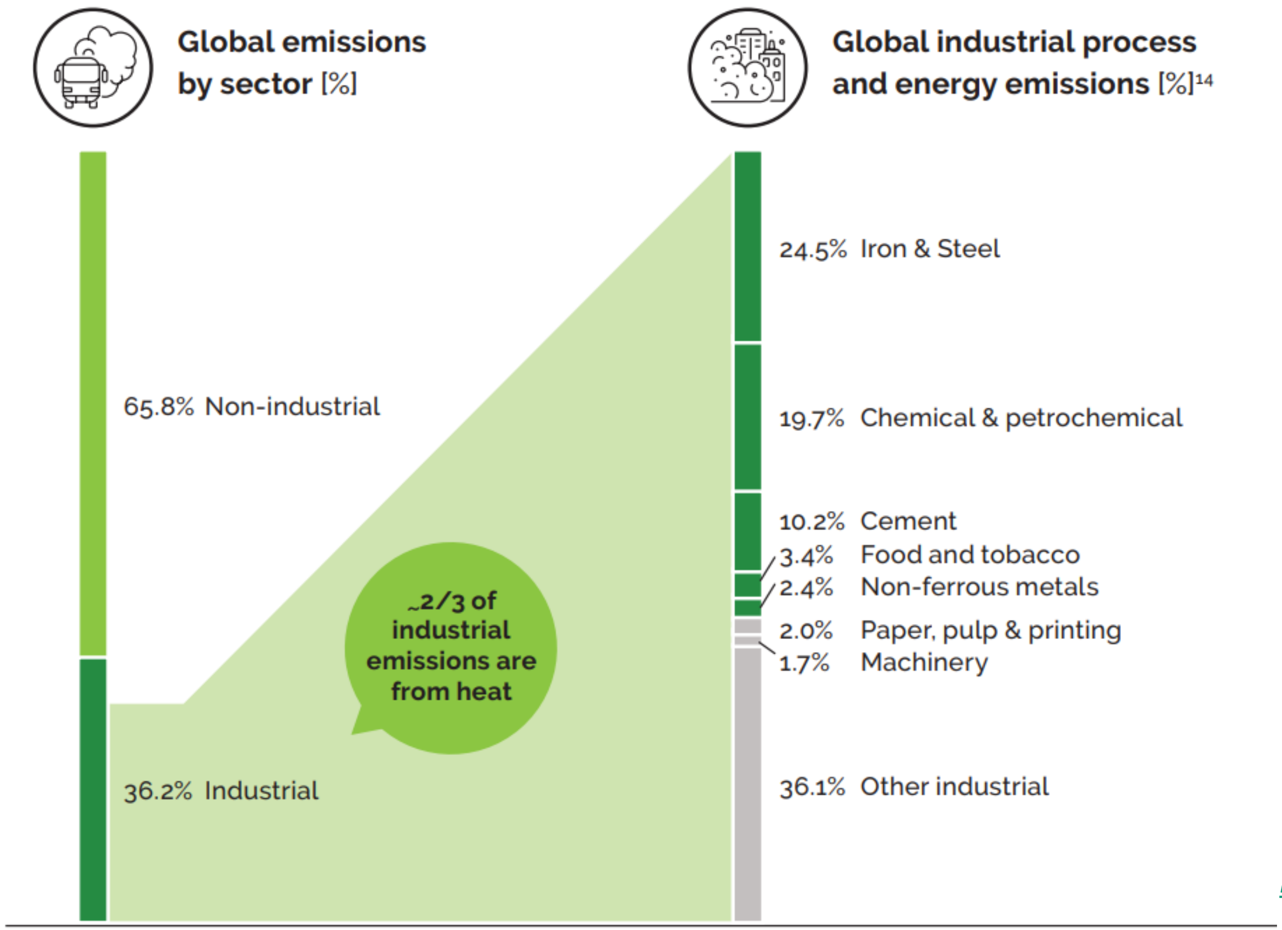
Specific Objectives:

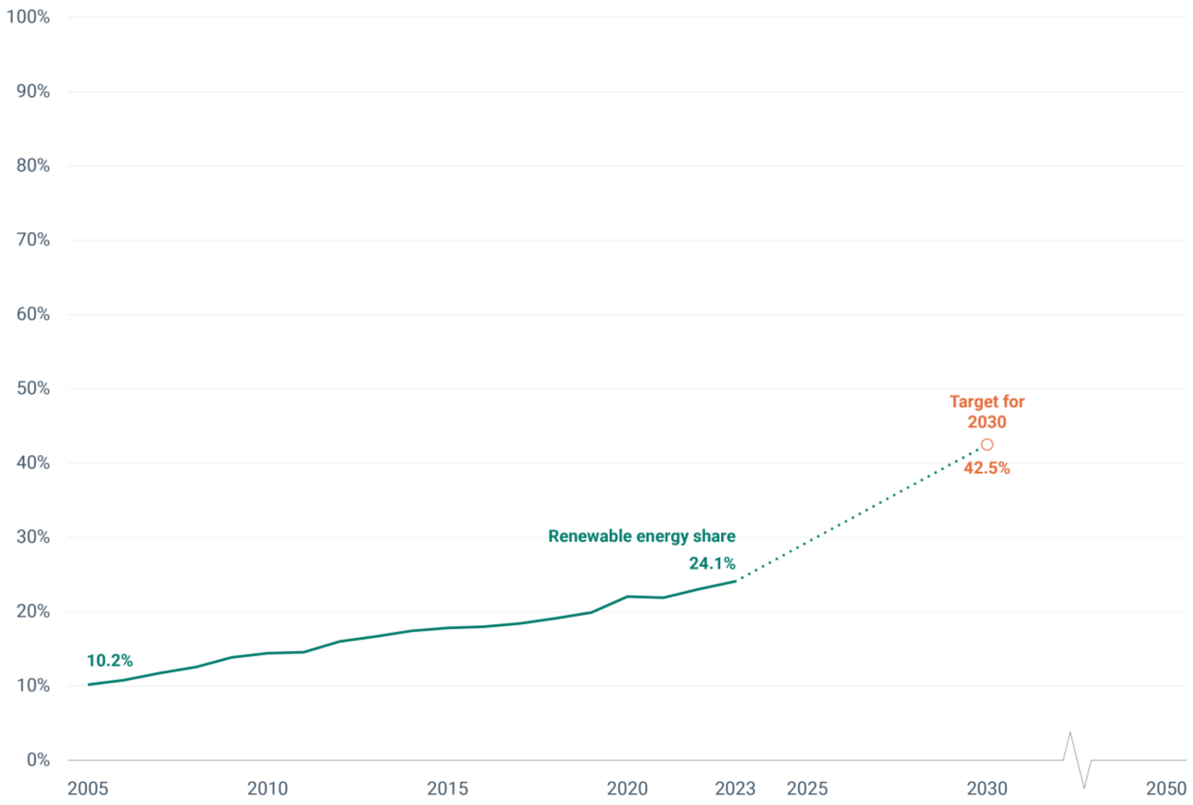
- Demonstrate a high electrical capacity medium voltage electrical heater for molten salt
- Demonstrate an additive manufactured heat exchanger with a novel heat transfer geometry
- Reduce system CAPEX and OPEX costs through system-level optimization

Why thermal storages for high temperatures?

Need for fast and affordable energy transition in industry

Global greenhouse gas emissions by sector and industrial segment, 2016





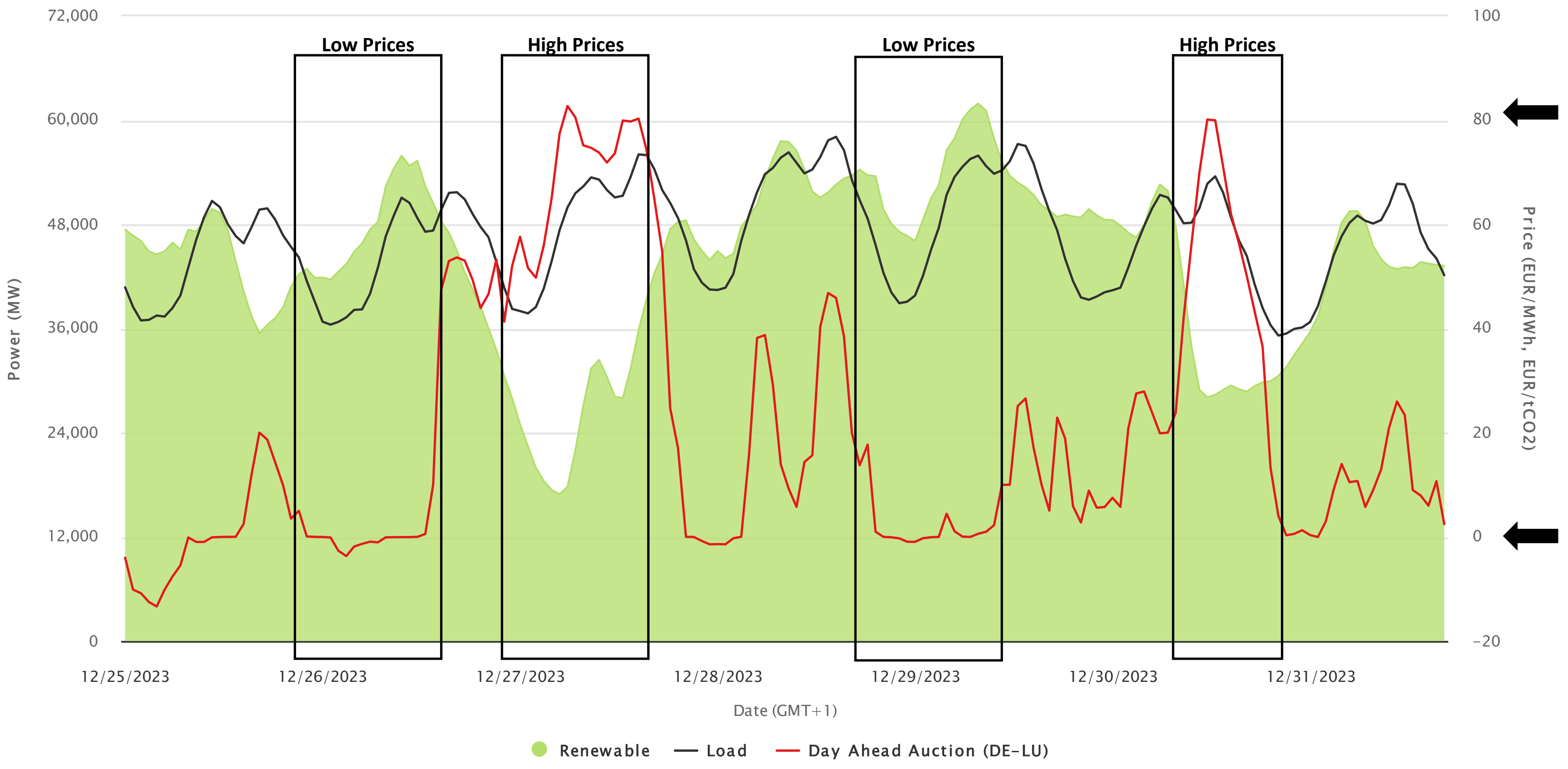
https://www.eea.europa.eu/en/analysis/indicators/share-of-energy-consumption-from

14 Data center emissions are not included in global industrial process emissions

Source: LDES/Roland Berger 2023

Why thermal storages for high temperatures?

Constant demand vs. volatile prices and availibility



Source: energy-charts.info

- 100 MWh of electricity for 30 Mio Euro
  10 Years Lifetime

Europe's largest energy storage facility begins operations in Belgium

Source: euronews.com

- Cost of molten salt storage in CSP:
  →100 MWh storage for 1.5-8 Mio Euro

Source: Thomas Bauer et al. 2021

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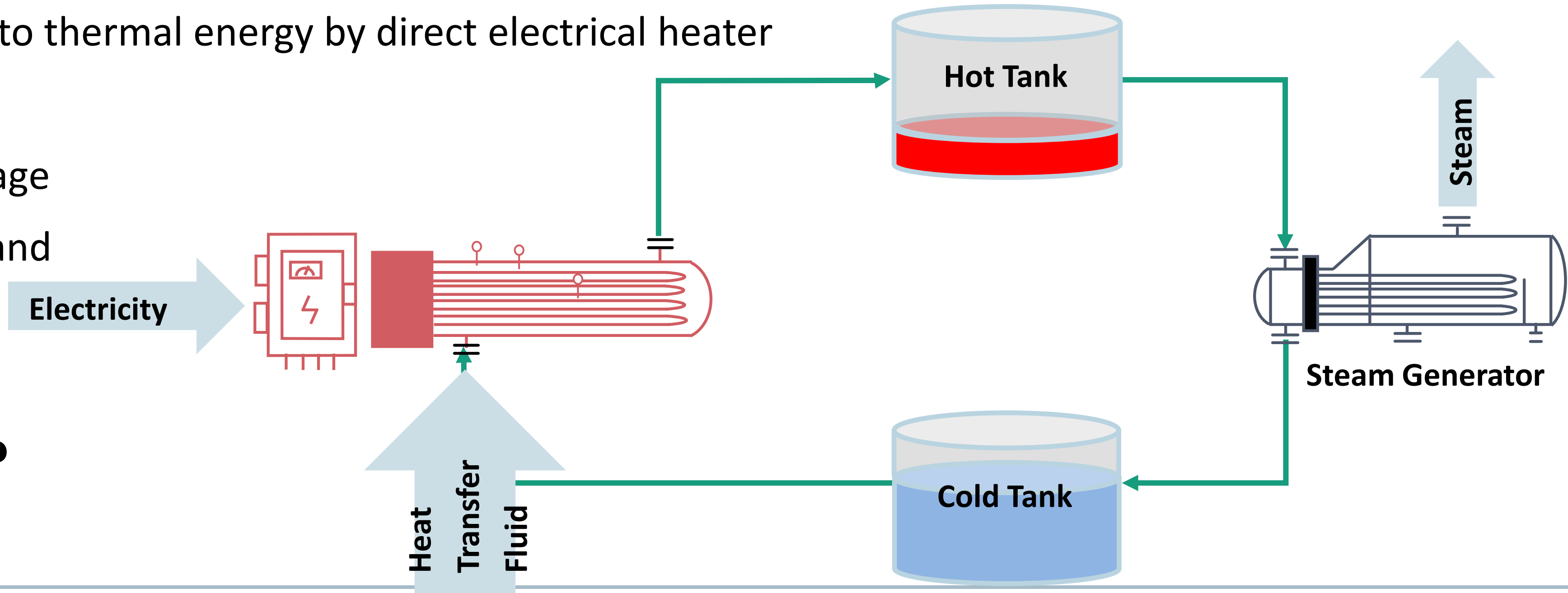
Motivation

Power-to-Heat + Energy Storage

- Economic opportunity with low-cost renewables
  - Electricity can be utilized for heat generation
- Power-to-heat (PtH) Technology
  - Efficient conversion of electricity to thermal energy by direct electrical heater
- Importance of thermal energy storage
  - Essential for balancing heat demand in industrial applications

How to Integrate???



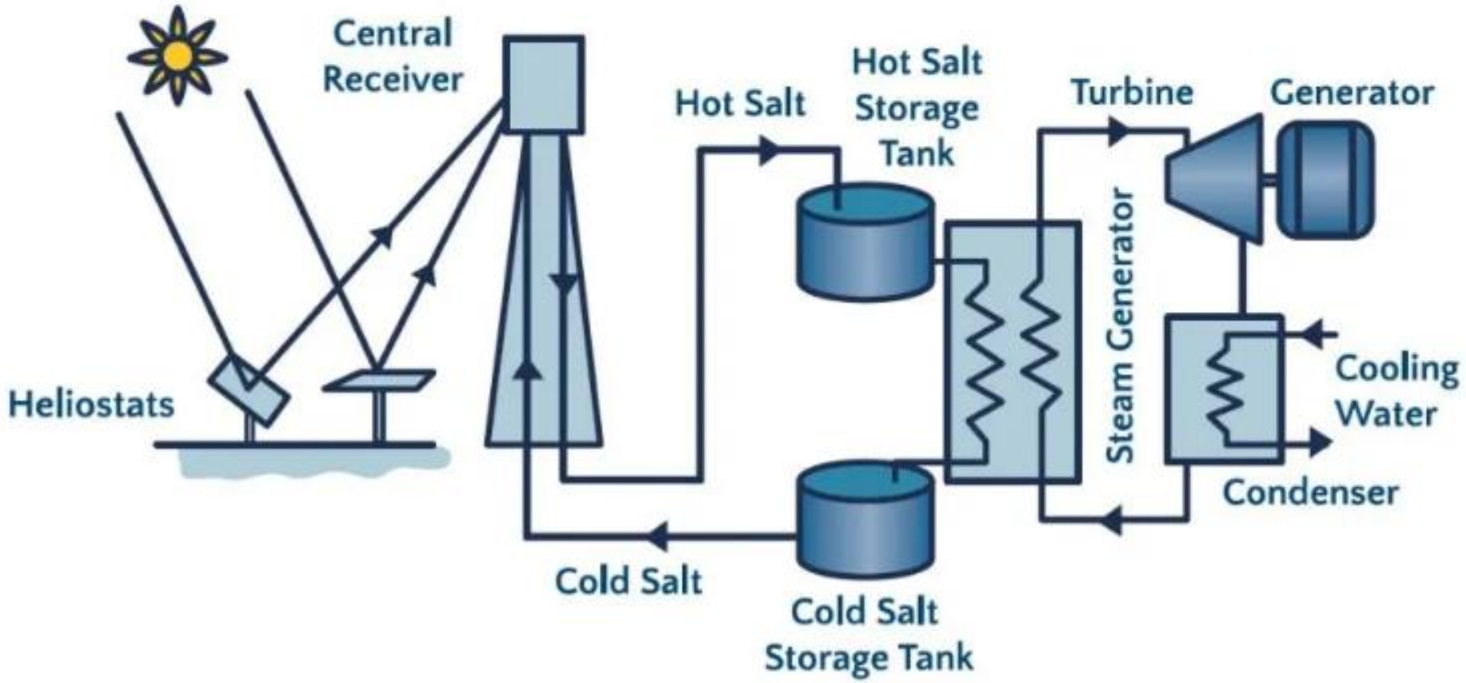
Main Research Questions

- How to size a PtH + storage system?
- What is the influence of the location on the storage system?
- How can a backup auxiliary gas boiler influence the levelized cost of heat?
- How does an electricity price forecaster influence the levelized cost of heat?

Background

Sensible Thermal Energy Storage

- Applications
  - Heating water
  - Space heating
  - Industrial processes
  - Solar thermal plants
- Most common HTF
  - Solar Salt
    - Implemented in many projects
    - Relevant share of TES cost and corrosive



[Molten Salt Storage Tank Design | Dandk Organizer (alquilercastilloshinchables.info)]

[1] Trevisan, S.; Buchbjerg, B.; Guedez, R. Power-to-heat for the industrial sector: Techno-economic assessment of a molten salt-based solution. Energ Convers Manage, 2022, 272, 116362

[2] Klasing, Freerk, et al. "Techno-economic assessment for large scale thermocline filler TES systems in a molten salt parabolic trough plant." AIP Conference Proceedings. Vol. 2033. No. 1. AIP Publishing, 2018.

[3] 2016 13th International Conference on the European Energy Market (EEM); IEEE, 2016.

Background

Levelized Cost of Heat (LCoH)

- Use to compare cost-effectiveness of different heating technologies
- Consider the initial capital cost (CAPEX) and the operational expenses (OPEX)
- Calculated from this equation [1]

$$\mathrm{LCoH} = \frac{(1-\gamma_{\mathrm{CAPEX}})\cdot \mathrm{CAPEX} + \sum_{n=1}^{n_{op}}\left(\frac{\alpha_{\mathrm{EOH},n}\cdot \mathrm{OPEX}}{(1+d_{eco})^{n}}\right) + \frac{\mathrm{DECOMM}}{(1+d_{eco})^{n_{op}+1}}}{\sum_{n=1}^{n_{op}}\left(\frac{\alpha_{\mathrm{EOH},n}\cdot E_{TES,Net}}{(1+d_{tech})^{n}}\right)}$$

γ_{CAPEX}: External Financing Factor (50%)

n_{op}: Operational lifetime (25Y)

$\alpha_{\mathrm{EOH},n}$: Equivalent operating hours factor (98%)

d_{eco}: Economical discount rate (5%)

DECOMM: Cost incurred by decommissioning (2%)

d_{tech}: Technology Degradation rate (1.5%)

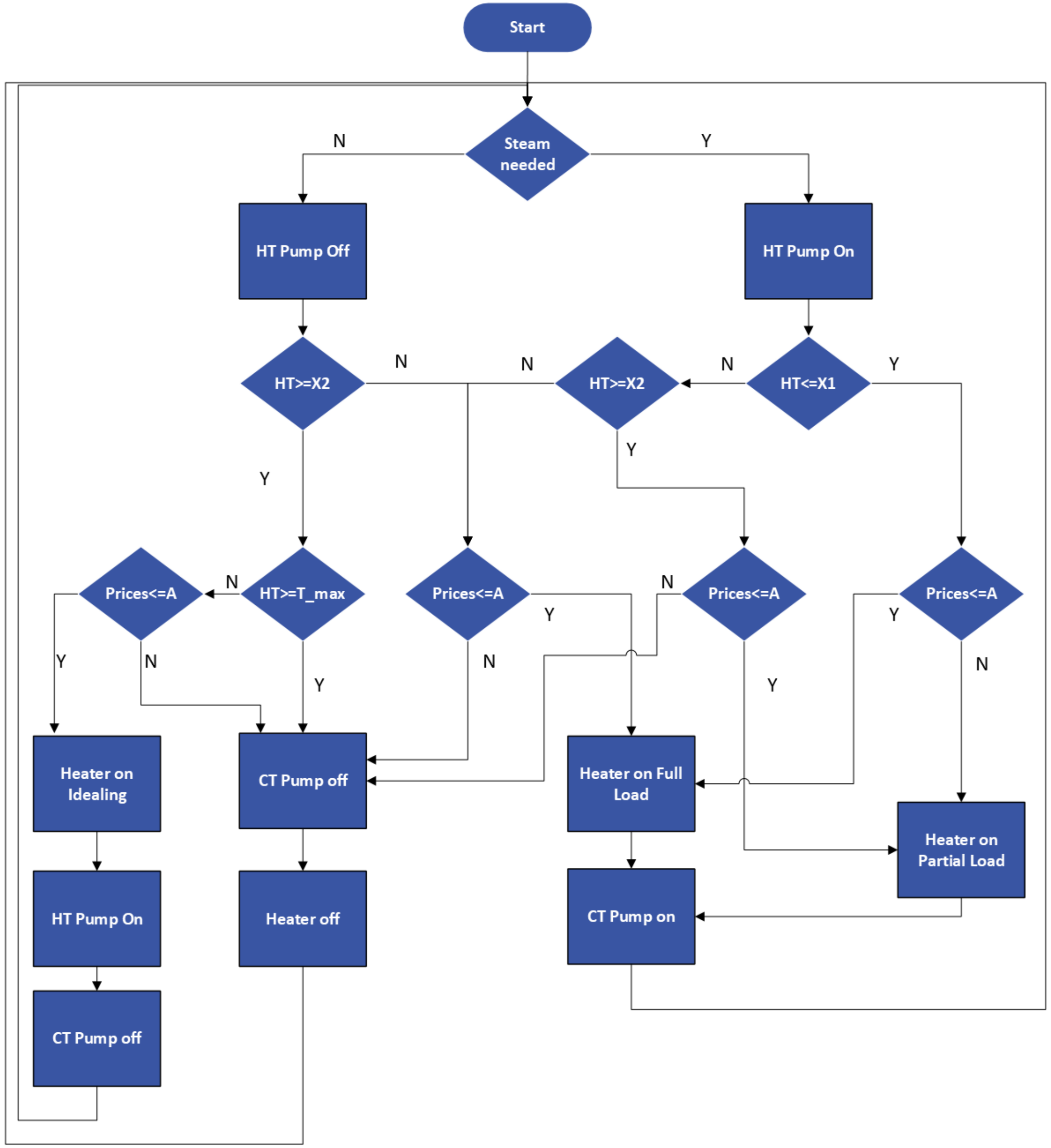
$E_{TES,Net}$: TES capacity

Component	Value	Unit	Reference
Transformer	30	EUR/kW_e	[1]
Electric Heater	100	EUR/kW_e	[2]
Steam Generator	90	EUR/kW_{th}	[2]
Tanks*	30	EUR/kWh_{th}	[2]
BMS**	100,000	EUR	[3]
Site Preparation	150,000	EUR	[1]
Resources	150,000	EUR	[1]

LCoH as the main performance indicator

Control Strategy

- Inputs
  - Electricity market prices (Year 2023)
  - Thermal demand profile (40MW @180°C/10bar)
  - Charging price threshold (50€/MWh)
- Signals
  - State of charge (SoC)
  - Hot tank temperature
- Outputs
  - Power to the electrical heater
  - Mass flow rate in the system



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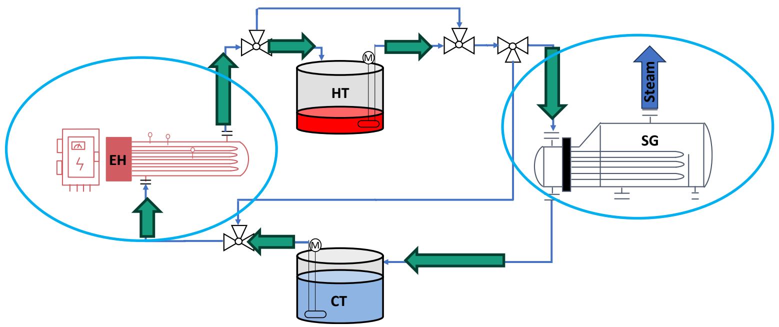
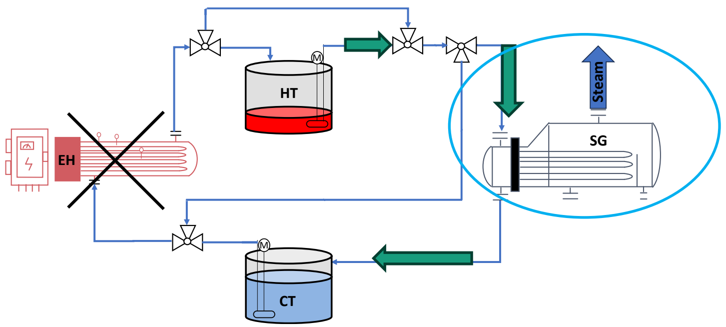
Operation Modes

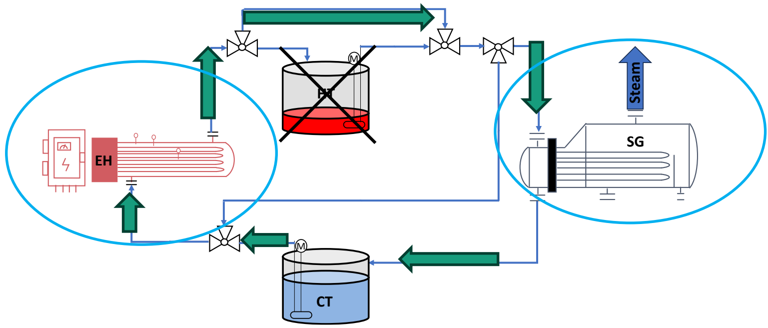
Steam Demand



Charging + Steam Demand

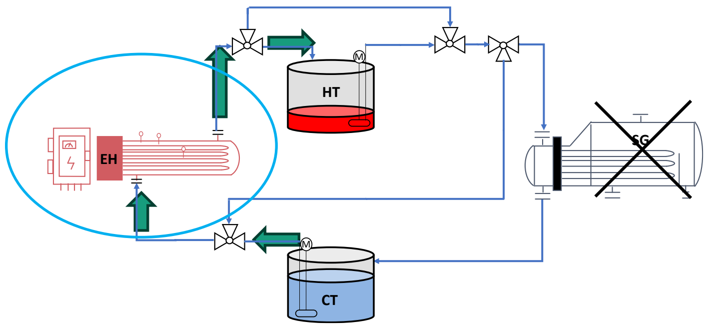


Discharging

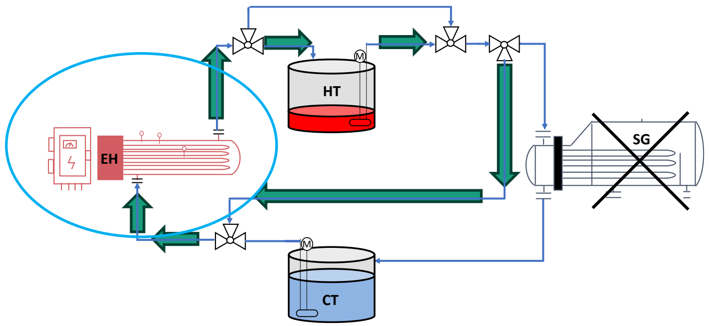


Baseload

No Steam Demand



Charging + No Steam Demand



Bypass

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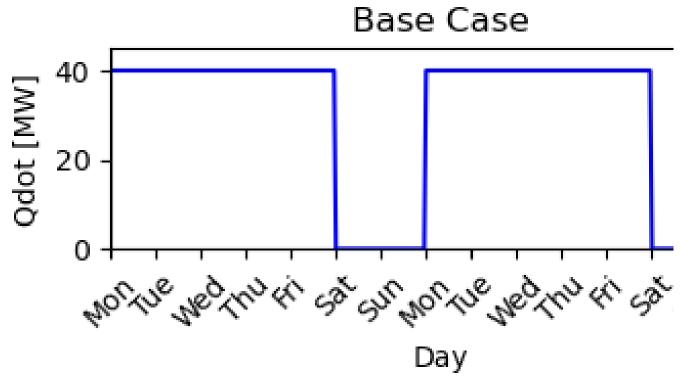
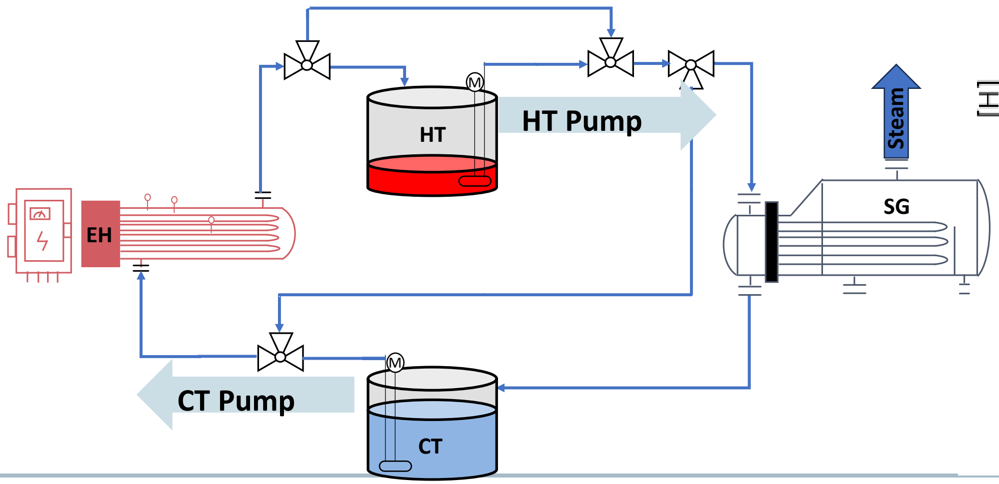
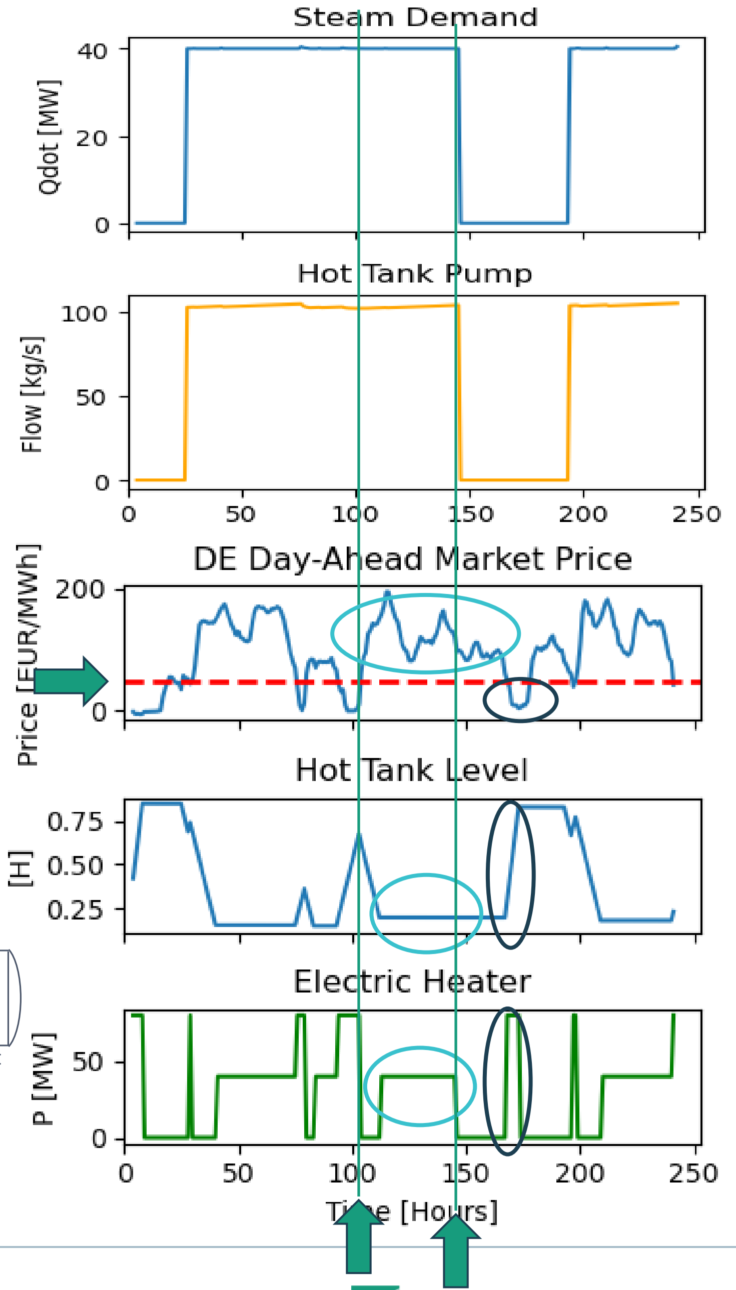
Reference Simulation Case

ColSim

- One of FISE's simulation tool since 1999
- Use efficient calculation engine C++
- Inputs
  - Demand Profile of 40MWth
  - Electricity prices during year 2023 from FISE Energy-Charts at hourly rate
  - Charging price threshold 50EUR/MWh to be comparable to the to gas







ColSim

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Status of Case Studies

System sizing in different electricity market locations. — **Covered in this Presentation**

Sensitivity analysis for external funding.

Different demand profiles.

Integration of a backup auxiliary gas boiler. — **Covered in this Presentation**

Variation of charging price threshold.

Integration of electricity prices forecaster with different horizons. — **Covered in this Presentation**

Effect of the tanks’ upper and lower limits.

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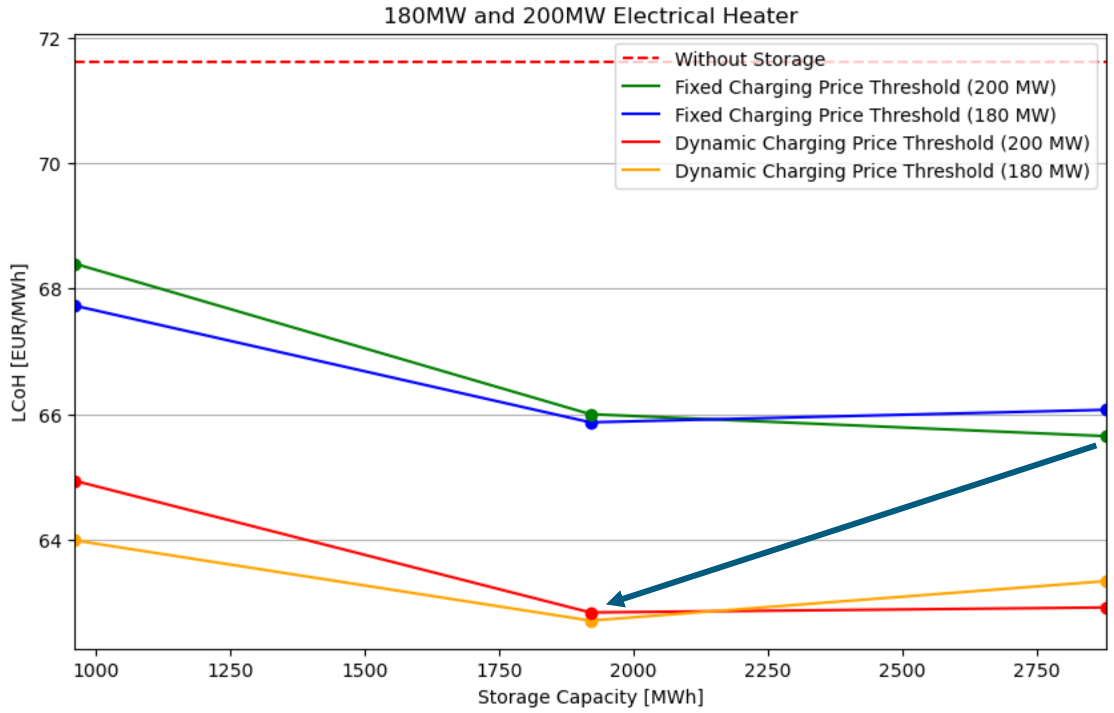
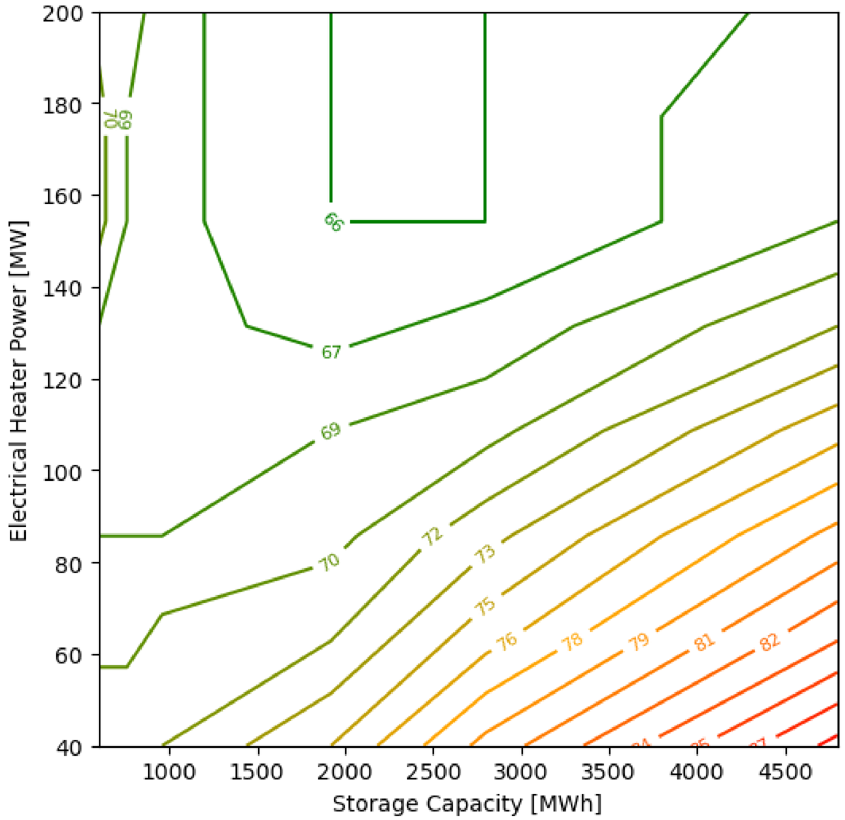
Case Studies

System Sizing Germany

- Different electrical heater sizes from 40 to 210MW
- Different storage tank capacities from 600 to 4800MWh
- Using the German electricity prices during year 2023



71.62EUR/MWhth



With Storage: 65.65EUR/MWhth (200MW – 2880 MWh)
Charging: 14.4h
Discharging: 72h

With Storage & dynamic charging price threshold:
62.71EUR/MWhth (180MW – 1920 MWh)
Charging: 10.6h
Discharging: 48h

Values and detailed calculations are available in the thesis

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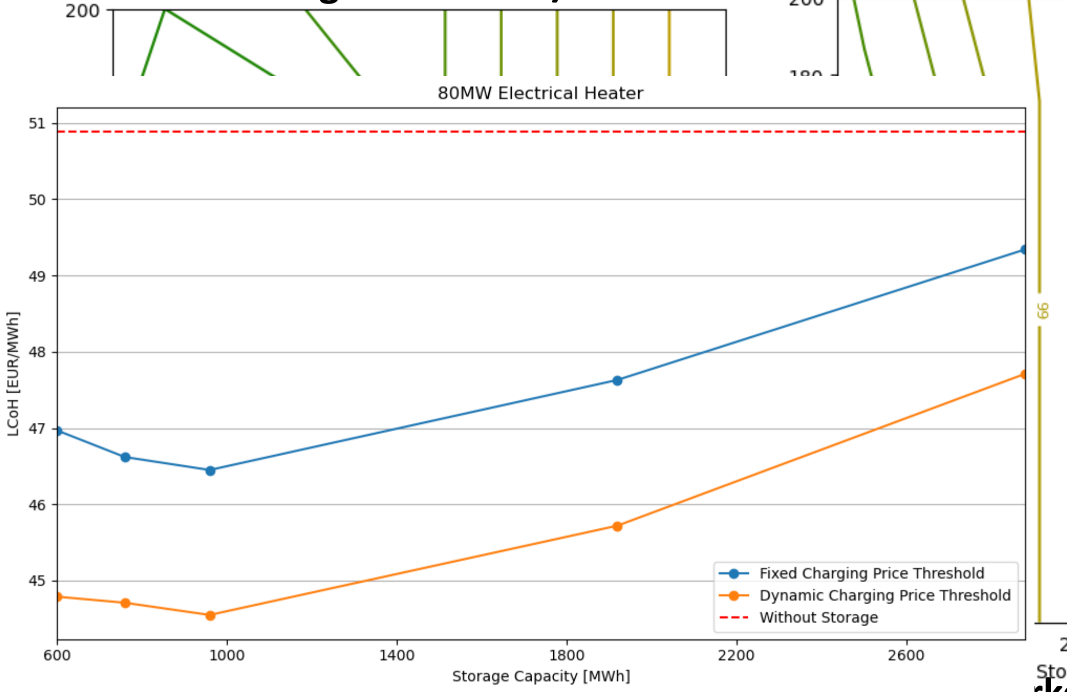
Case Studies

System Sizing Sweden and Italy

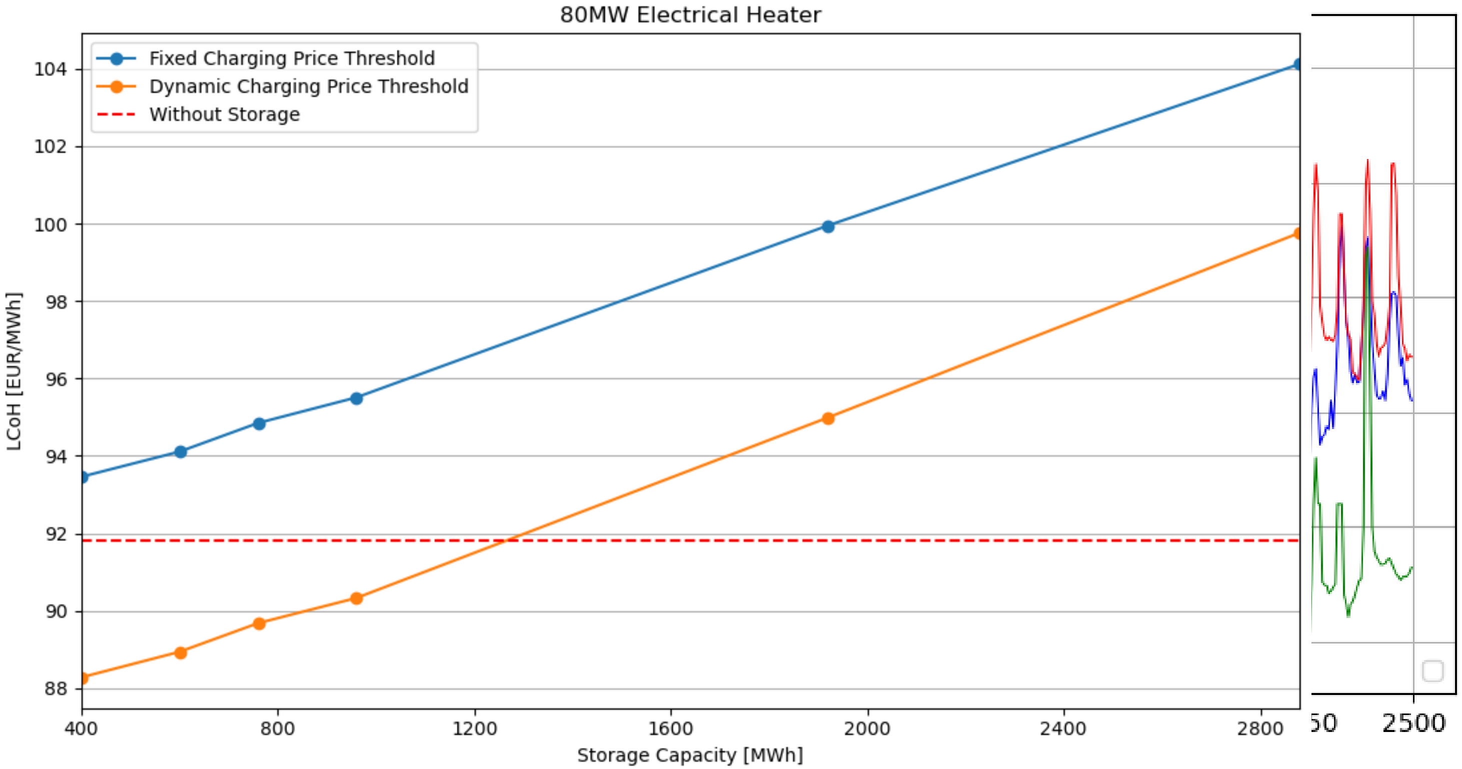
- Swedish market with the highest price fluctuations during 2023 (Green)
- Italian market with the highest mean value in 2023, 128.51EUR/MWh (Red)

Without Storage: 50.88EUR/MWhth



LCoH: 45.46EUR/MWhth

Without Stora



LCoH: 92.28EUR/MWhth

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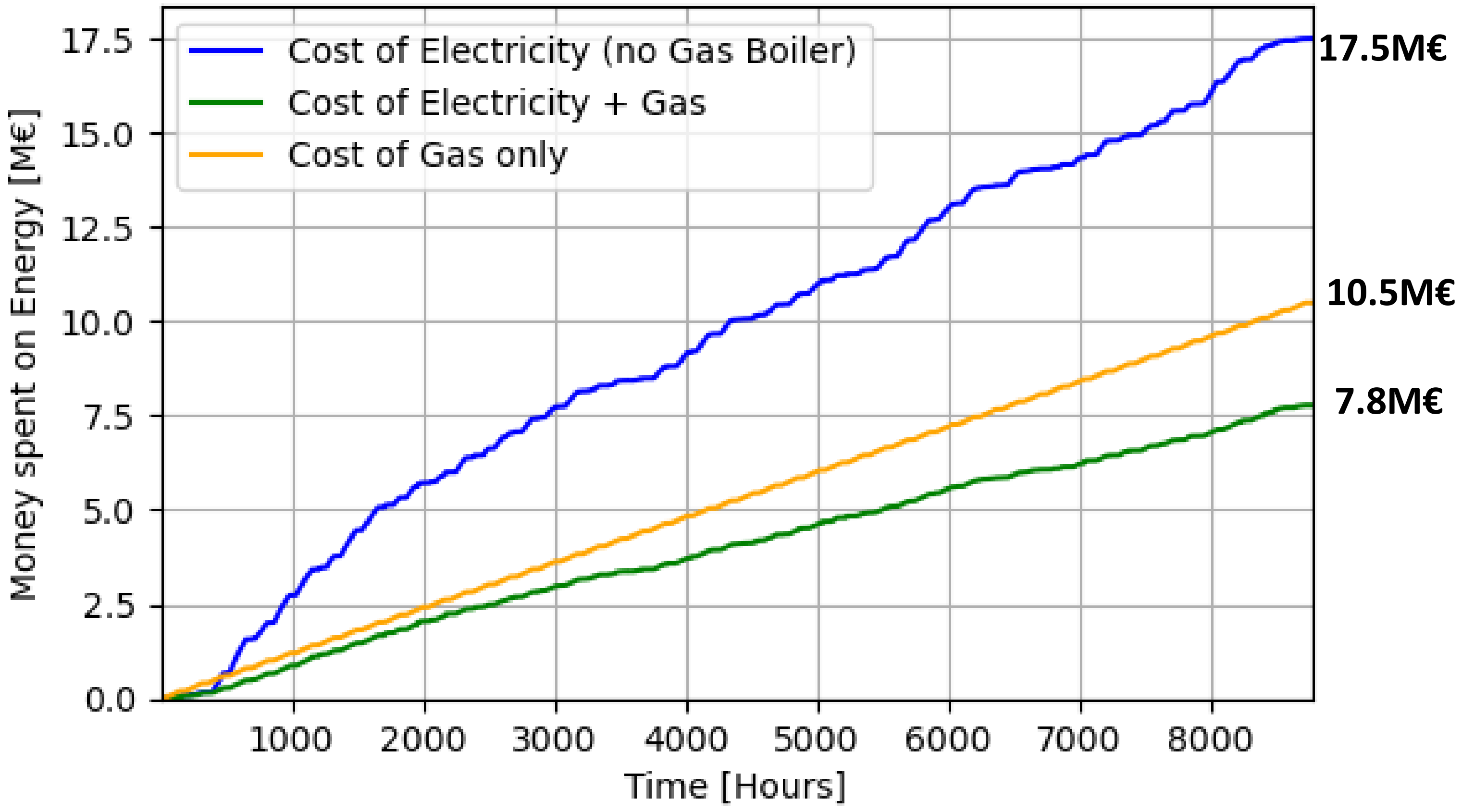
Case Studies

Backup Auxiliary Gas Boiler

- Cost for gas + CO2 42EUR/MWh in 2024

(Germany, 200MW – 2880 MWh, Fixed charging price threshold 50 EUR/MWh)



OPEX reduction by 55%

[Analyse: Heizkosten und Treibhausgasemissionen in Bestandswohngebäuden - Aktualisierung auf Basis der GEG-Novelle 2024 | Ariadne (ariadneprojekt.de)]

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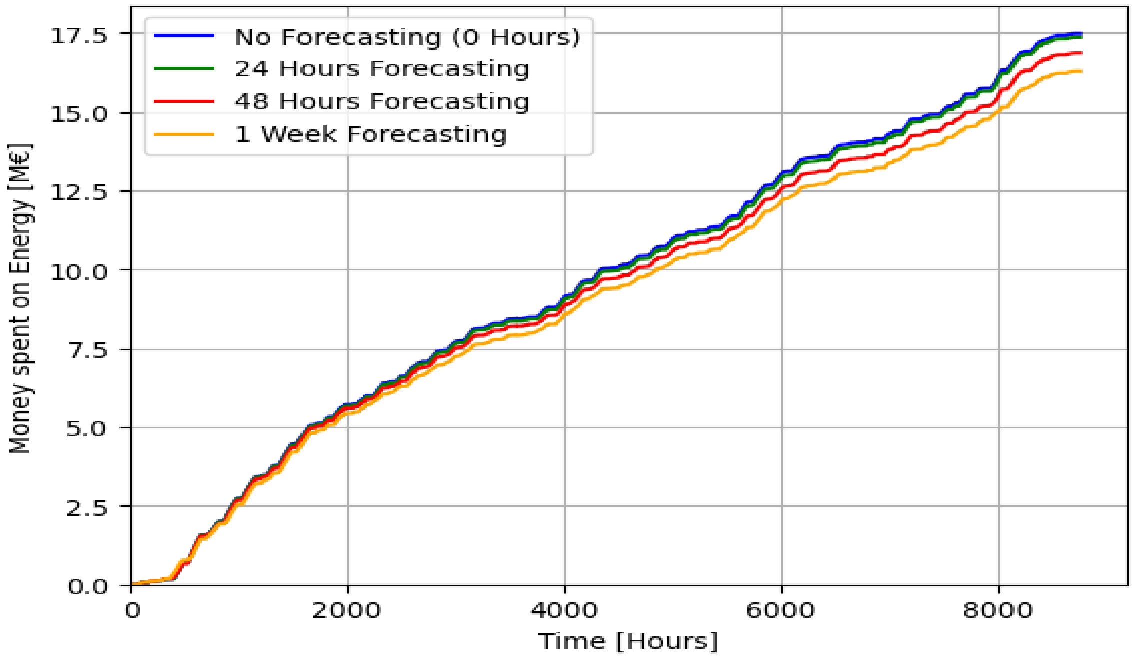
Case Studies

Forecaster

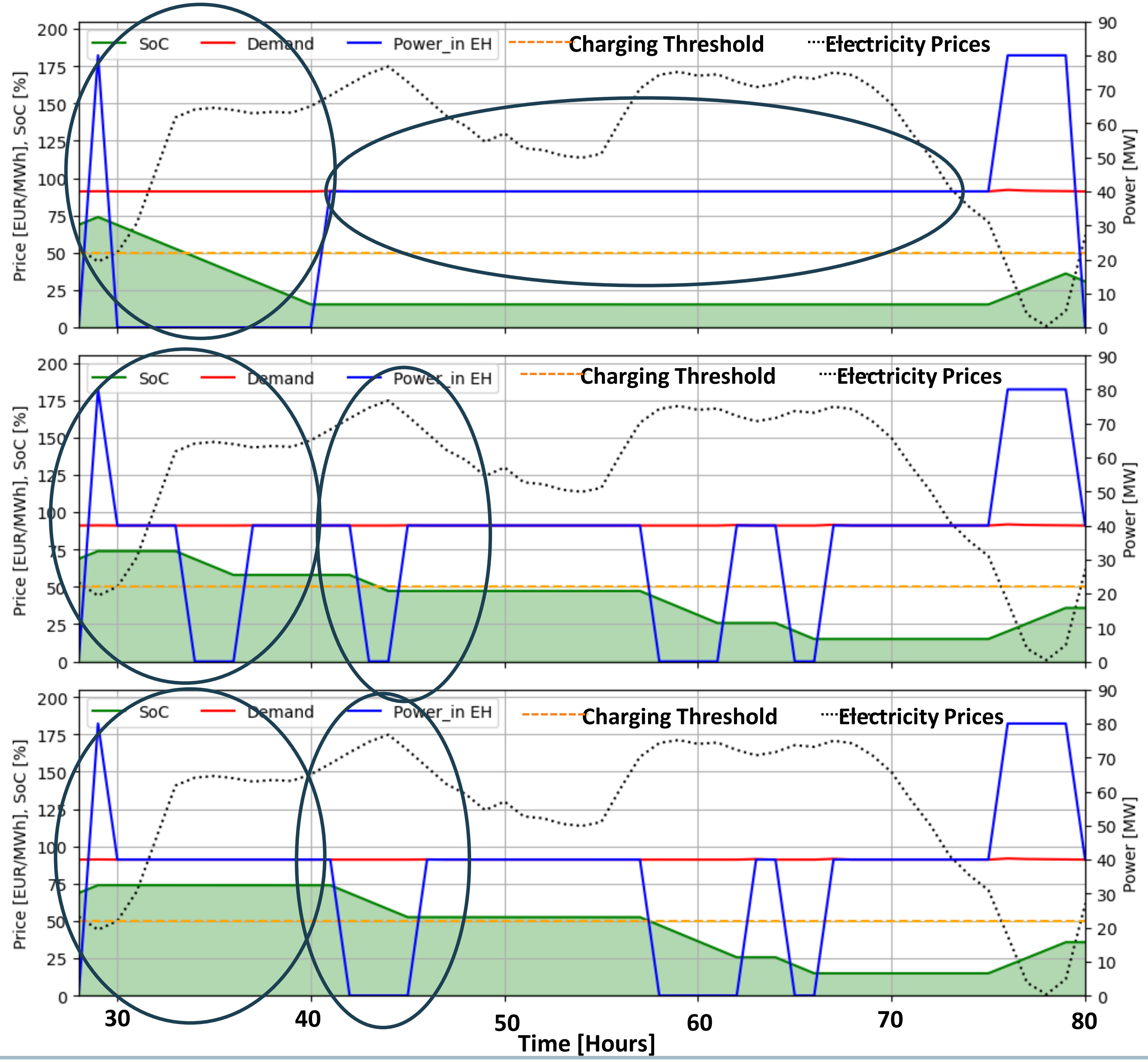
No Forecaster



OPEX reduction by 1.2M€

48h Forecasting

(Germany, 200MW – 2880 MWh, Fixed charging price threshold 50 EUR/MWh)



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Conclusion so far

- What is the influence of the location on the storage system?

  The system size changes based on the location. Smaller system and lower LCoH attainable with high renewable share. A LCoH 45.46EUR/MWhth in Sweden, 65.65EUR/MWhth in Germany.

- What is the difference between fixed charging price threshold and dynamic charging price threshold?

  A dynamic charging price threshold can deal with seasonal electricity price variations, thus reducing the OPEX. A LCoH 88.28EUR/MWhth is attainable in Italy with a dynamic charging price threshold. (62.71EUR/MWhth in GER and 44.55EUR/MWh in SE)

- How can a backup auxiliary gas boiler influence the levelized cost of heat?

  Gas boiler can reduce the OPEX by 55%. Meanwhile, it produced up to 25,000 tons of CO_2 emissions* comparable to a system without a backup auxiliary gas boiler.

- How does an electricity price forecaster influence the levelized cost of heat?

  Forecaster can reduce the OPEX up to 7.5% and LCoH by 4%.

*: 200.8 g CO_2/kWh Specific carbon dioxide emissions of various fuels (volker-quaschning.de)

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Upcoming Future Work

Future work will focus on how to reduce the LCoH further by

- Studying potential OPEX reduction by
  - More advanced predictive controllers.
  - Studying potential future electricity market prices.
  - Optimize tanks’ upper and lower limits.
  - Adjust the charging price threshold for the case with gas boiler to control OPEX and emissions.
- Studying potential CAPEX reduction by
  - New materials and corresponding component sizes.
  - Optimized insulation techniques.
- Consider different scenarios for future grid fees and electricity prices

Thank You
For Your Attention!

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