Energiesimulation mit i7–AnyEnergy am Beispiel einer Carnot-Batterie

Reinhard German, FAU, Monash University,
gemeinsam mit Peter Bazan, Daniel Scharrer, Jonathan Fellerer

Wissenschaftstag Metropolregion Nürnberg, Coburg, 29.7.2022

Lab Overview

Computer Networks and Communication Systems Lab

Reinhard German, 4 Postdocs, ca. 15 PhDs + externals

Quality-of-Service (Dr. Kai-Steffen Hielscher)
- performance/dependability/real-time analysis
- automotive/industrial/satellite/train communications

Connected Mobility (Dr. Anatoli Djanatliev)
- vehicular communications
- distributed simulation, 3D, 5G

Smart Energy (Dr. Peter Bazan)
- power system, multi-energy, electric mobility
- simulation: i7-AnyEnergy
- QoS of ICT for energy

AI in Networking (Dr. Mehdi Harounabadi, IIS)

Adjunct professor
Melbourne, Australia
MONASH University

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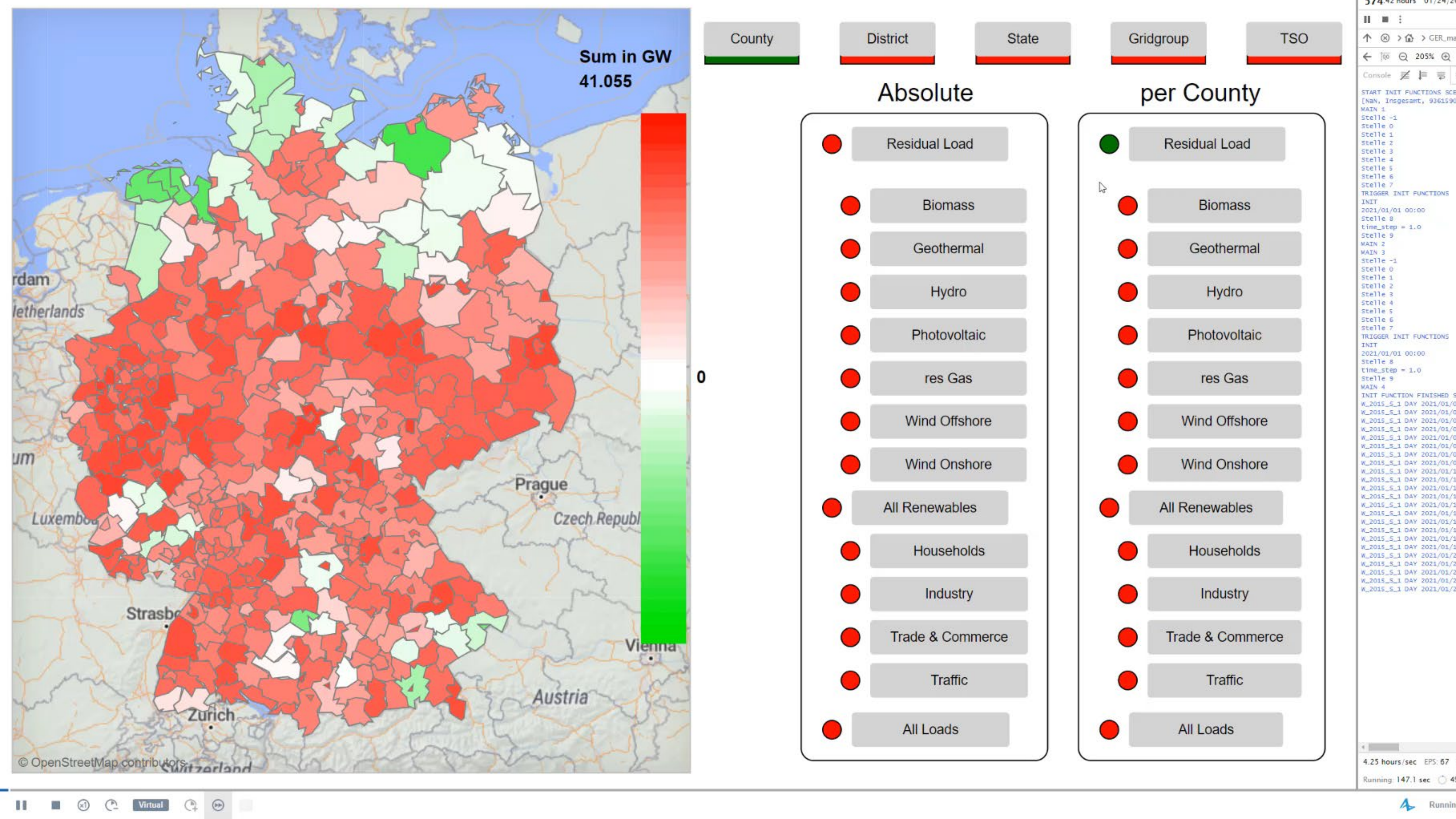
Sum in GW
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Prague
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Switzerland
County
District
State
Gridgroup
TSO
Absolute
per County
Residual Load
Biomass
Geothermal
Hydro
Photovoltaic
res Gas
Wind Offshore
Wind Onshore
All Renewables
Households
Industry
Trade & Commerce
Traffic
All Loads
Virtual
4.25 hours/sec
Running: 147.1 sec

Agenda

Energy Simulation Framework i7-AnyEnergy

Use Case: A Carnot Battery

Conclusions

Energy Simulation Framework i7-AnyEnergy

Energy Simulation Framework i7-AnyEnergy

Motivation

Information and communication technology (ICT) an enabler for the energy transition

– decentralized, bidirectional, fluctuating, controllable loads, storages, new markets and business models

Examples

– households with PV/battery/heating/controller

– neighborhoods, microgrids, communities, virtual power plants

– flexibilities of industrial processes

– cellular approach for national power grid

– ancillary services with electric vehicle fleets

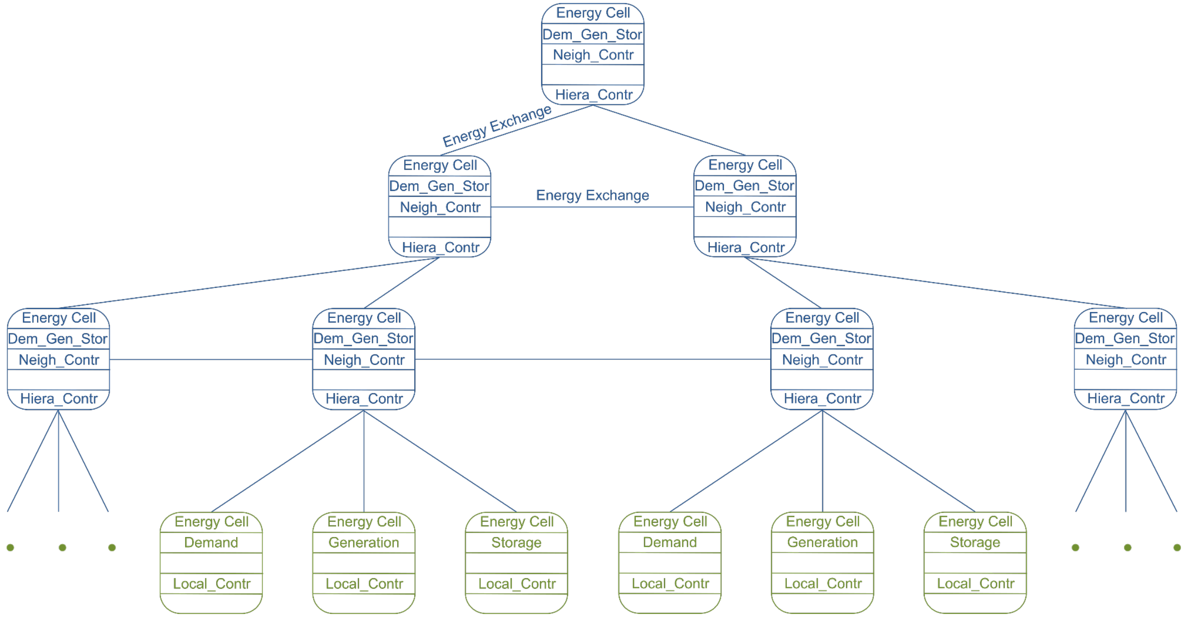
– and, and, and, …

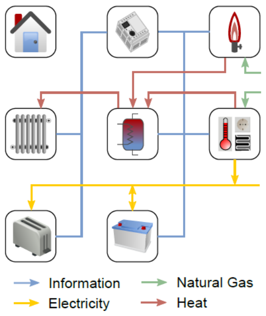
→ Need simulation to understand and design

Energy Simulation Framework i7-AnyEnergy

Unique Features of i7-AnyEnergy

- **building blocks** for reuse and exchange (demand, load, PV, battery, heating, controllers, networks …)
- **multi-energy** (electricity, heat, H2, …)
- based on **cellular approach**
- **hierarchical** structures and **neighborhood** relationships
- **interfaces** for flexible and efficient access throughout complete model
- **control strategies** for decentralized systems
- drag and drop for **rapid visual modeling**
- **configuration of complex models** with text files or database
- **visualization** facilities based on AnyLogic



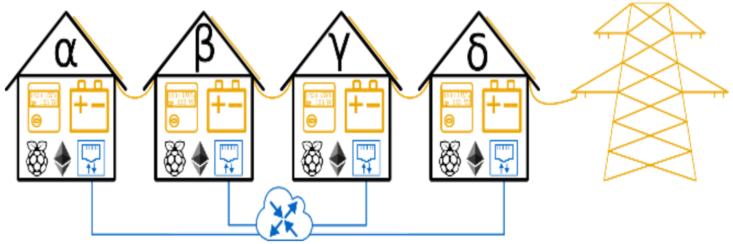


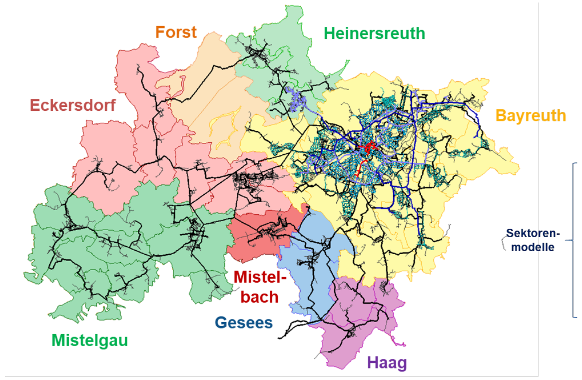
R. German, P. Bazan, “Rapid Prototyping with i7-AnyEnergy and Detailed Co-Simulation with SGsim”, 7th D-A-CH+ Energy Informatics Conference, Oldenburg, 2018.
G. Dengler, P. Bazan, R. German, Simulation of a Cellular Energy System including Hierarchies and Neighborhoods, Energy Informatics.Academy Conference 2022 (EI.A 2022), Veijle, Denmark, August 2022.

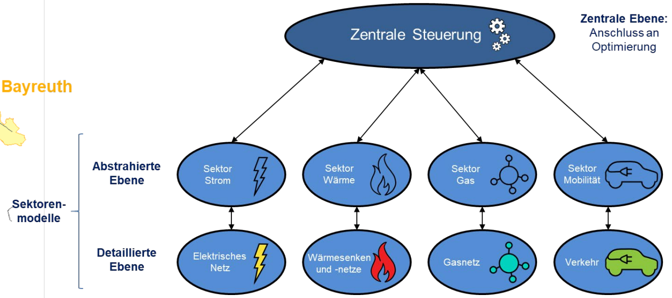
Energy Simulation Framework i7-AnyEnergy

Example use cases with i7-AnyEnergy

- **houses, neighborhoods:** various house configurations with PV, battery, and heating; coordination and flexibility provision with blockchain (ZD.B); virtual battery storage with FCR (SWARM, N-ERGIE, Caterva, Siemens); Carnot battery for renewable energy (EnCN)
- **regional and national level:** electric power system of Germany (KOSiNeK, BMWi); sector coupling of electricity, gas, heat, mobility in Bayreuth (ESM-Regio, BMWK); prizing and cyber attacks in Monash microgrid (Monash Univ.); H2 in sector coupling (City of Nürnberg)
- **mobility related:** flexibility provision of electric vehicle fleets, such as FCR (ZD.B); E-Bus-Port (N-Ergie, VAG); mobility-on-demand with robot taxis (Audi); multi-modal staff mobility at Munich Airport (Munich Airport, Fraunhofer IIS)
- **miscellaneous:** cement plant with renewables (ThyssenKrupp); data center; various battery technologies (Siemens)







Source: VAG - Claus Felix

Use Case: A Carnot Battery

Use Case: A Carnot Battery

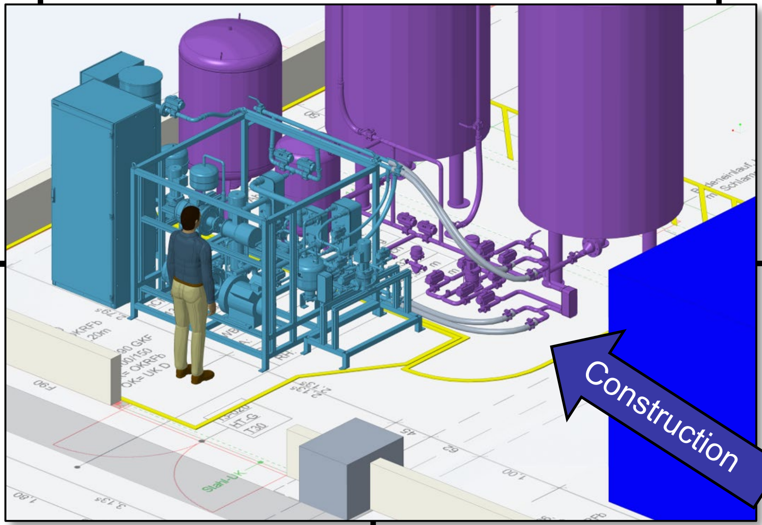
Context

S. Staub et. al, “Reversible Heat pump-Organic Rankine Cycle Systems for the Storage of Renewable Electricity”, Energies 2018

Chair of Energy Process Engineering

- HP-ORC
  - Organization
  - Feasibility studies
  - System dimensioning

ENERGIE CAMPUS NÜRNBERG



Computer Science 7

Lab for Computer Networks and Communication Systems

- Simulation
  - Energy flows
  - Integration in energy systems
  - Economics

Data

LTT ERLANGEN

Institute of Engineering Thermodynamics

- Simulation
  - Working Fluid
  - System
  - Operation modes

Data

Construction

iPAT

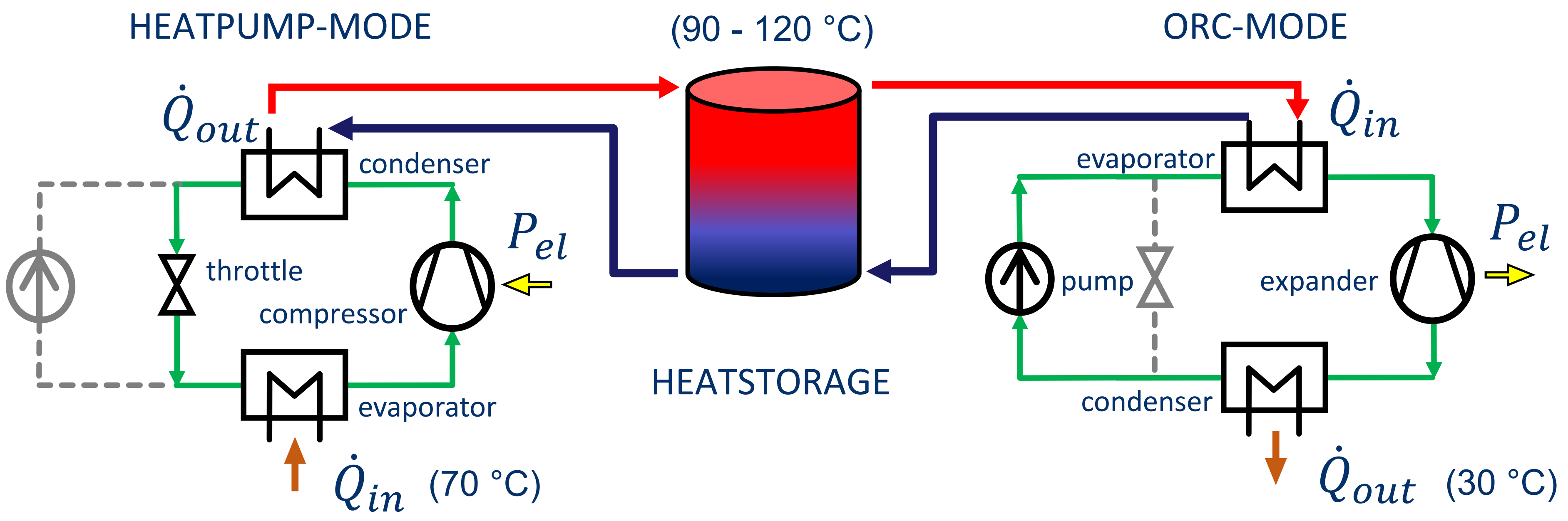
Institute of Process Machinery and Systems Engineering

- Laboratory scale
  - Planning
  - Construction
  - 200h stress test

Main idea and project coordination: Prof. Dr.-Ing. Jürgen Karl

Use Case: A Carnot Battery

Technical Concept



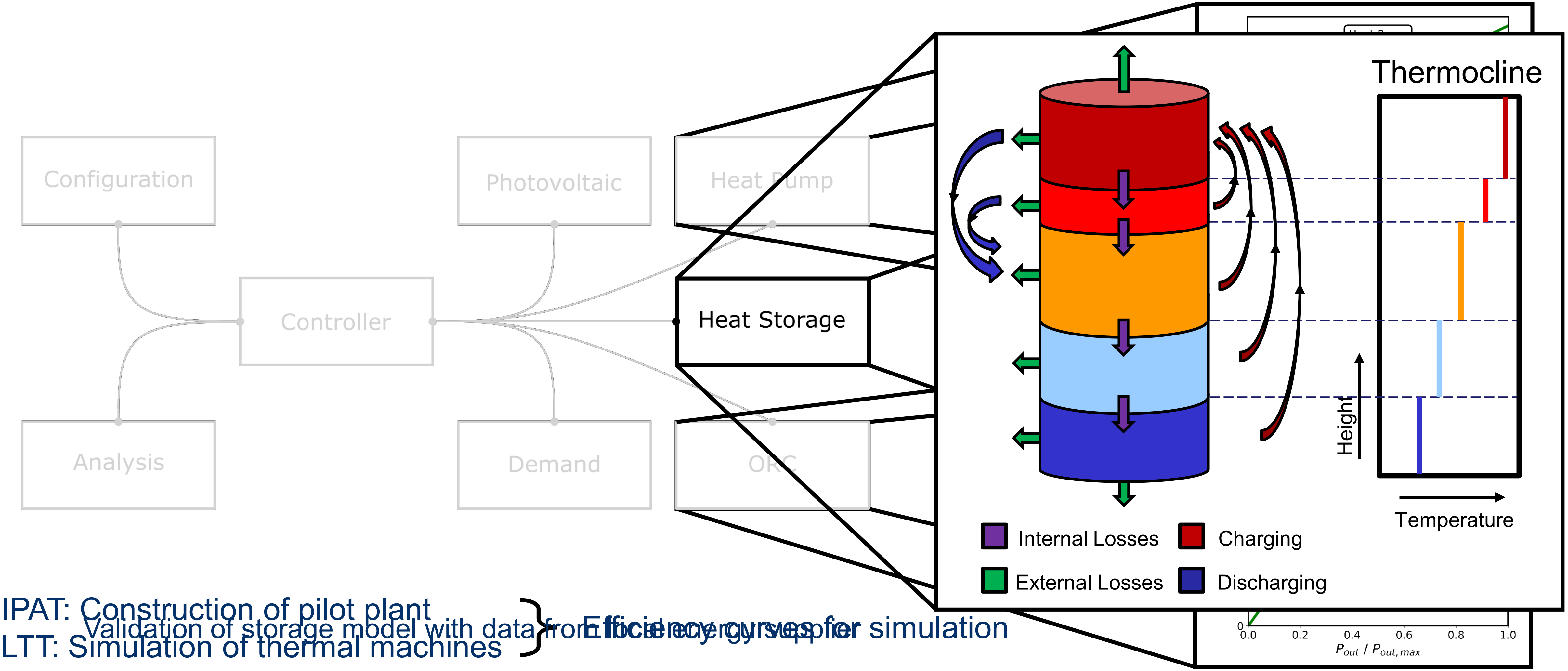
Ongoing PhD-thesis of Daniel Scharrer:

Simulation and application analysis of a Carnot Battery System at house and grid level including life cycle assessment

Use Case: A Carnot Battery

Simulation of a Carnot Battery

D. Scharrer, M. Pruckner, P. Bazan and R.German, "Dynamic Modeling and Sensitivity Analysis of a Stratified Heat Storage Coupled with a Heat Pump and an Organic Rankine Cycle" Winter Simulation Conference, Phoenix, AZ / Virtual, 2021



IPAT: Construction of pilot plant

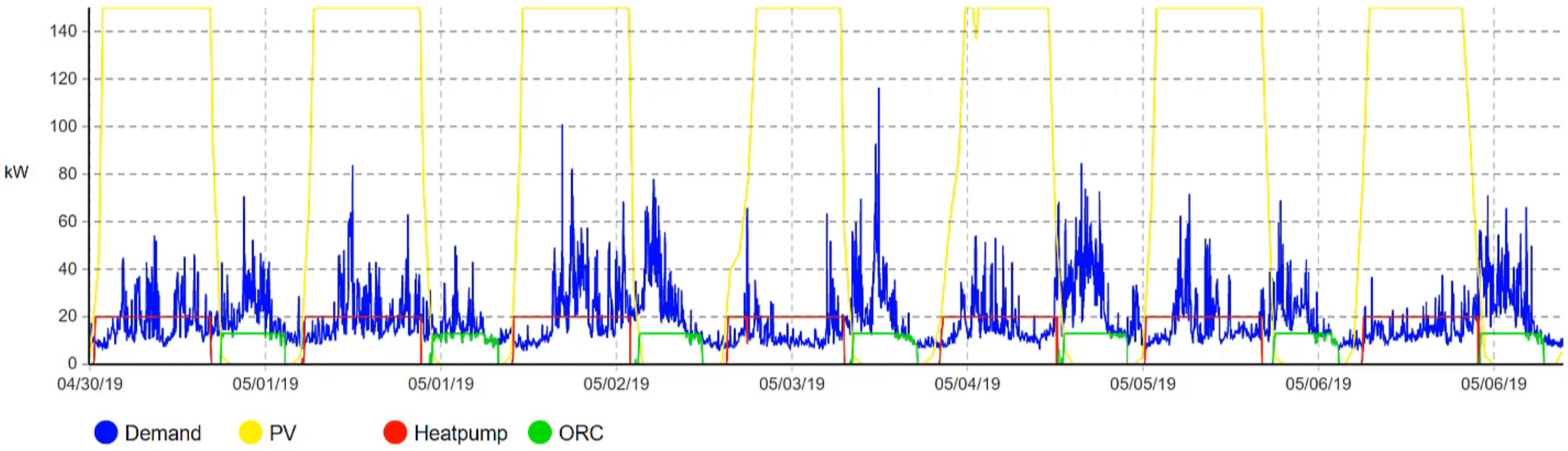
LTT: Simulation of thermal machines } Efficiency curves for simulation

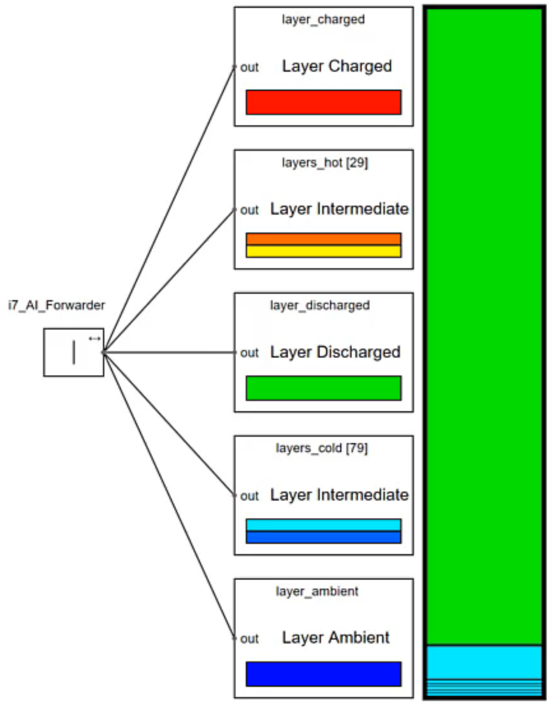
Validation of storage model with data from local energy supplier

Use Case: A Carnot Battery

Simulation of a Carnot Battery

Heat Storage with 111 layers, which represent a 1 °C step size for the evaluated temperature range 10 – 120 °C.





Not all 111 layers are always represented. Based on thermodynamic calculations, the simulation creates and removes layers as necessary

Use Case: A Carnot Battery

Community Application

D. Scharrer, P. Bazan and R.German, “Dynamic simulation of an HP-ORC-Heat Storage pilot plant for an economic evaluation and necessary cost reduction”
International Conference on Applied Energy, Bangkok / Virtual, 2020

Rule-based behaviour:

1. Satisfy demand
2. Charge storage with excess

→ $Cost_{(waste)heat}, Loss_{feedin}$

1. Discharge storage
2. Buy from grid

→ $Savings_{grid}$

$$Savings_{total} = Savings_{grid} - Loss_{feedin} - Cost_{(waste)Heat} - Invest_{year}$$

Setup Parameter	
PV Efficiency	15 %
HP $P_{in,max}$	20 kW
HP Efficiency	5.31
ORC $P_{out,max}$	7 – 13 kW
ORC Efficiency	10.06 %

Use Case: A Carnot Battery

Simulation Results for Carnot Battery - Pilot Plant

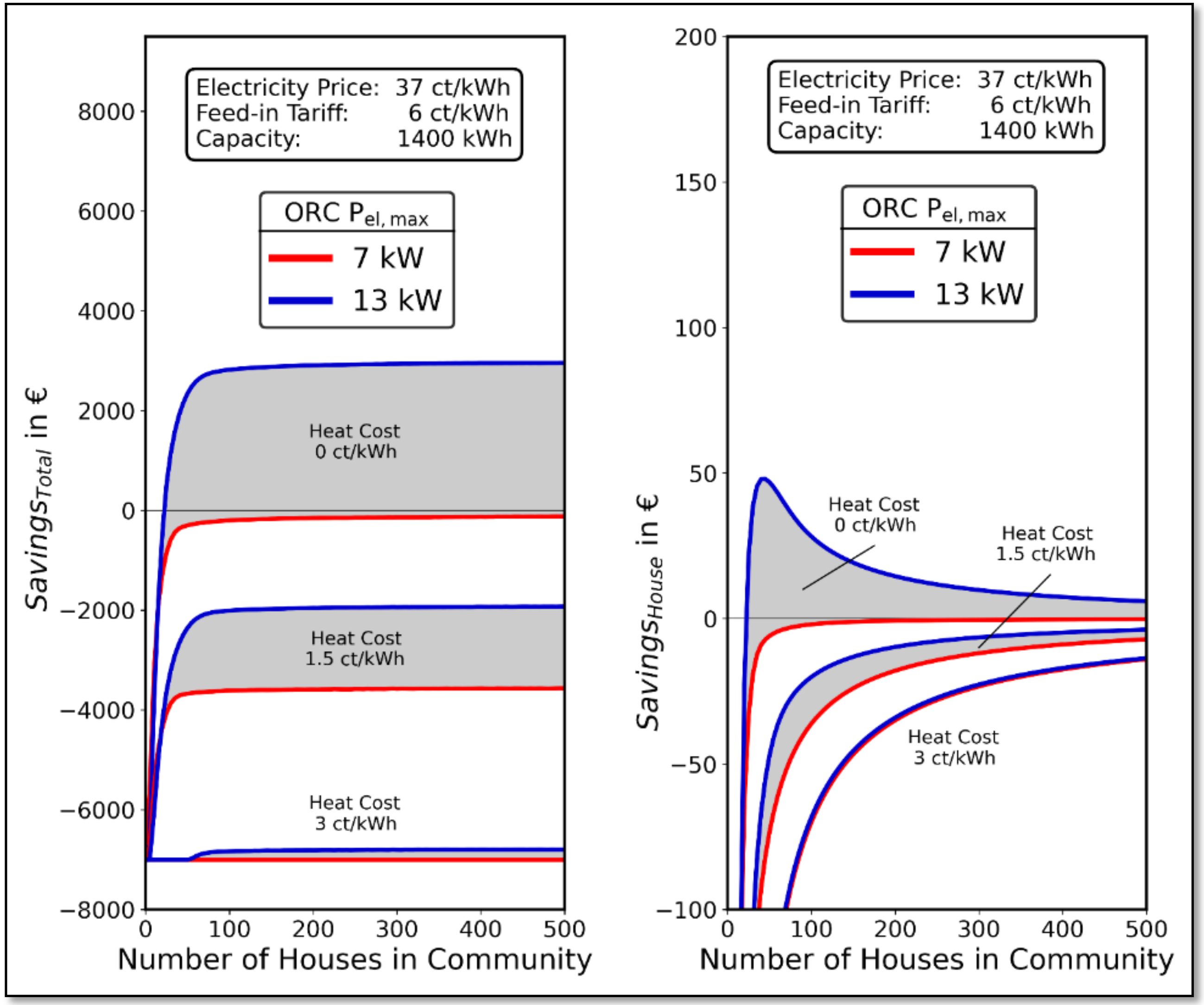
Application of pilot plant:

- $P_{in,max}$ of HP is 20 kW
- $P_{out,max}$ of ORC between 7 - 13 kW
- Storage capacity variable

Investment Costs	
HP-ORC	120.000 €
Maintenance	6.000 €
Storage	10 €/kWh

Operational Costs	
Electricity Price	37 ct/kWh
Feed-in Tariff	6 ct/kWh
Heat Source	? ct/kWh

→ Pilot plant under current German market conditions only profitable if (waste) heat is available for free!



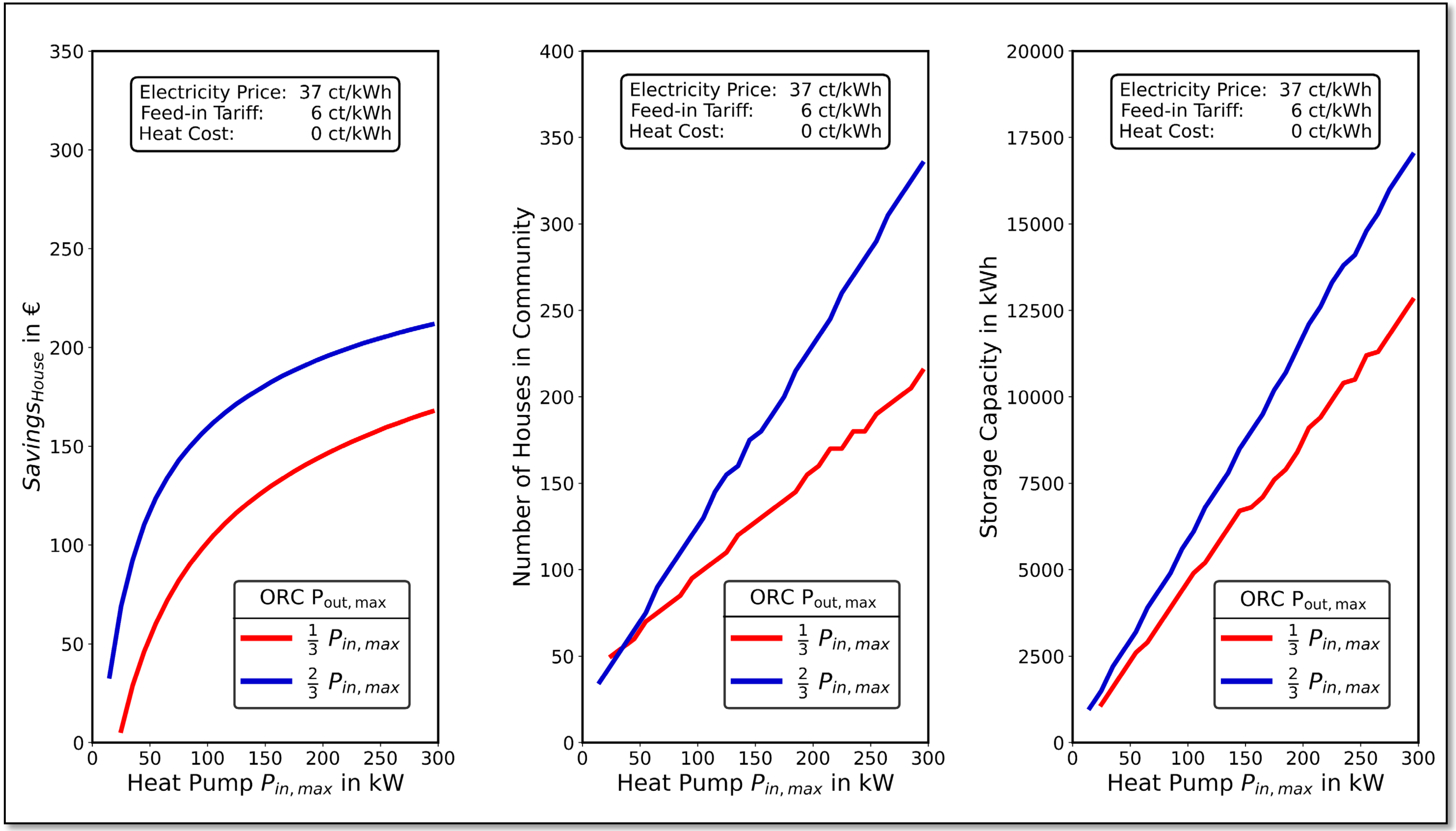
Use Case: A Carnot Battery

Simulation Results for Carnot Battery – Power Scaling

Assumptions:

- (Waste) Heat is free, to analyze the potential of the Carnot battery
- Investment costs are scaled according to the „0.6 rule“

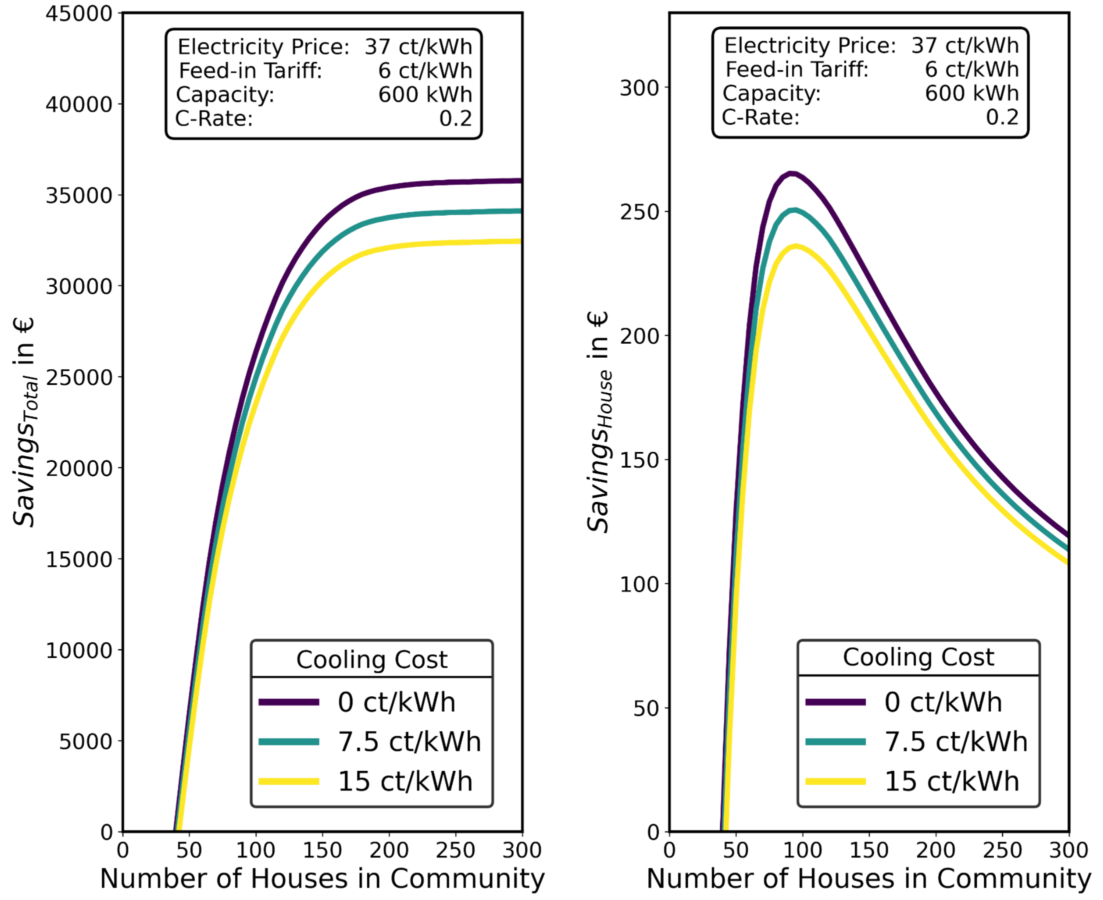
Increasing the input power of the Carnot battery enables an application under current German market conditions!



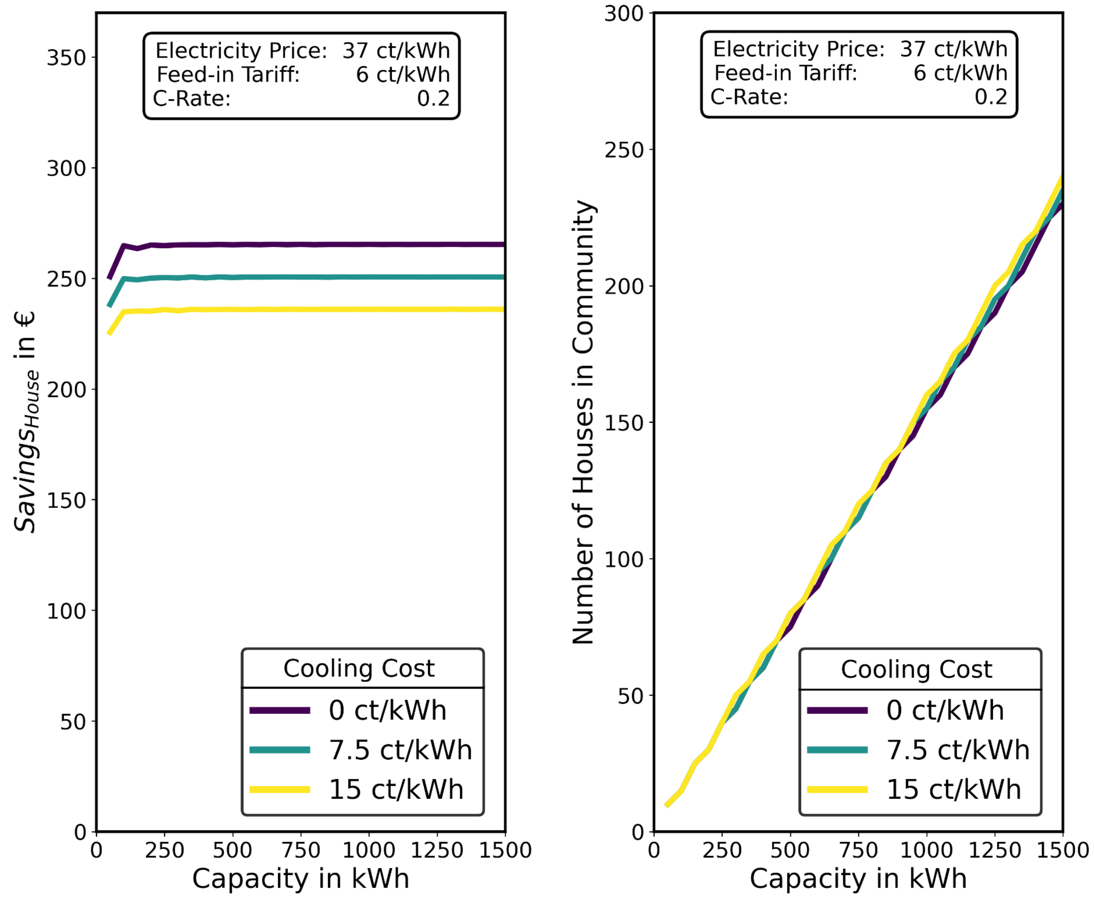
Use Case: A Carnot Battery

Comparison with an Electrochemical Battery

Community Scaling



Power Scaling

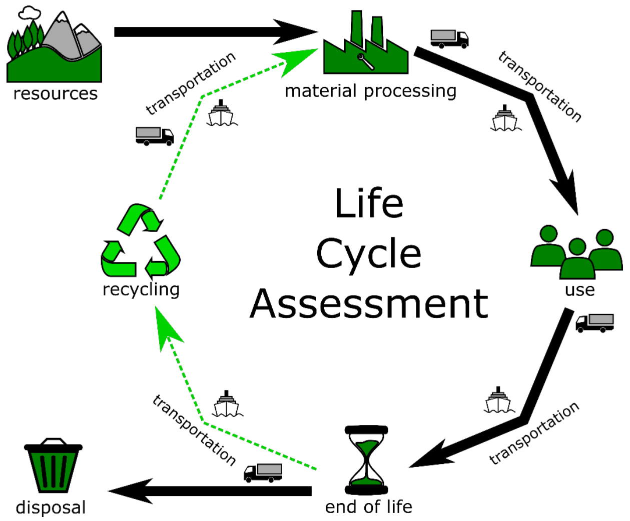


Use Case: A Carnot Battery

Life Cycle Analysis for a 1000 kWh storage capacity

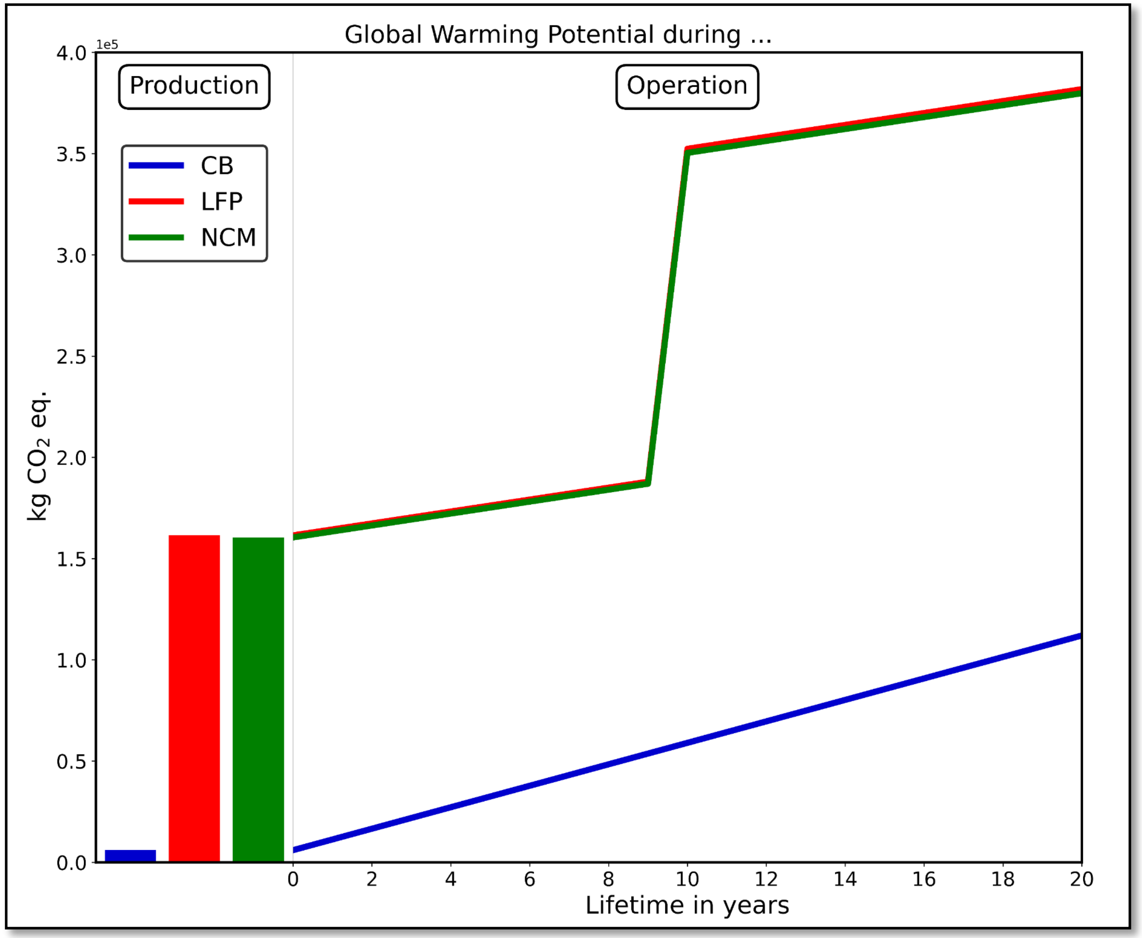
D. Scharrer et. al, “Life Cycle Assessment of a Reversible Heat Pump-Organic Rankine Cycle-Heat Storage System with Geothermal Heat Supply”
Energies, 2020

A life cycle analysis (LCA) evaluates the environmental impact during production and operation (until end of life) of the assessed item.



LCA results of the Carnot battery (CB) are compared to literature values for lithium ion batteries:

- lithium iron phosphate (LFP)
- nickel cobalt manganese oxide (NCM)



Carnot battery has a smaller environmental impact than lithium-ion batteries!

Use Case: A Carnot Battery

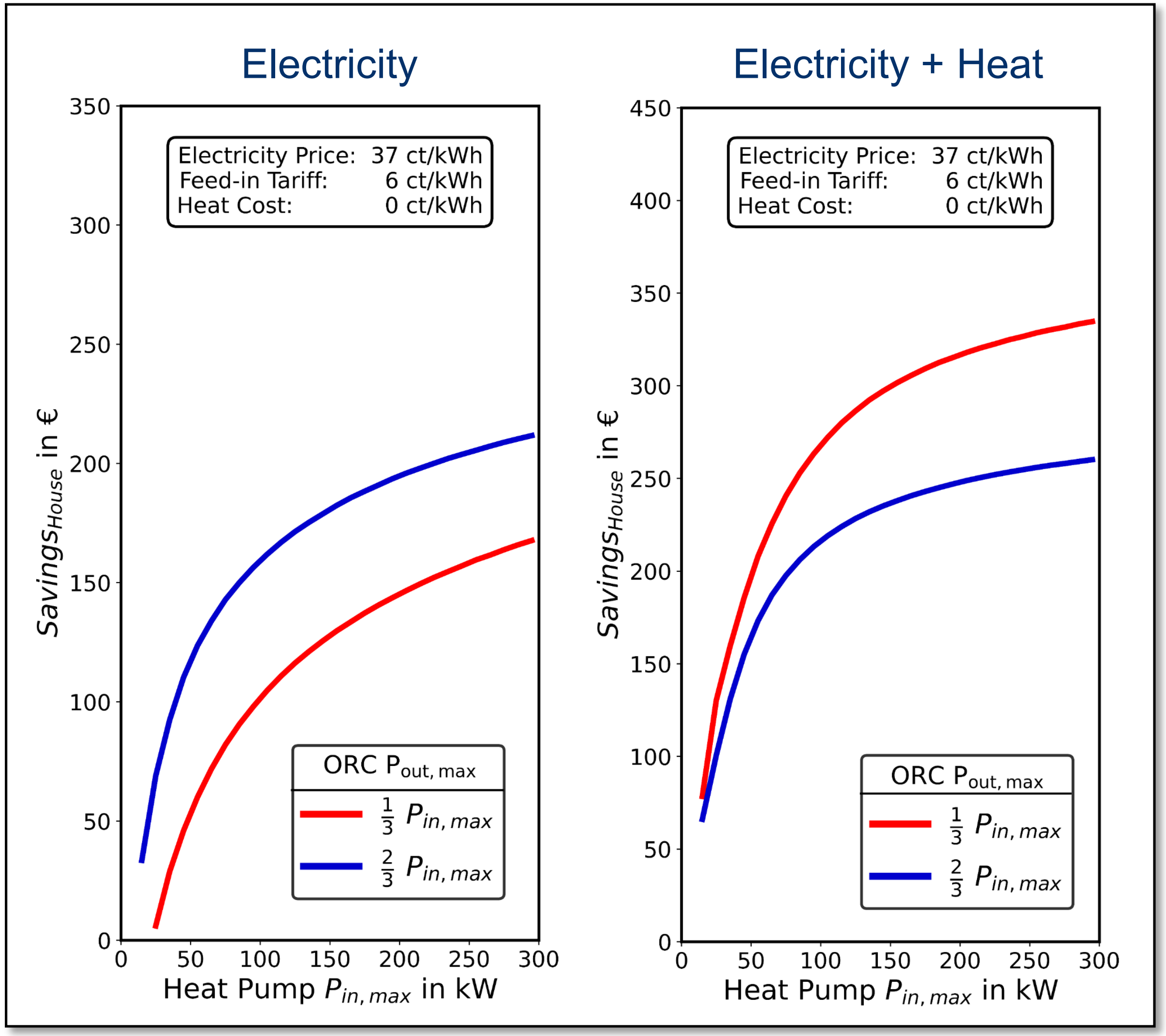
Additional Usage of Heat

Increasing the condensation temperature of the ORC to 50°C:

- enables the Carnot battery to satisfy parts of the communities low temperature heat demand
- reduces its overall efficiency

$$\text{Savings}_{total} = \text{Savings}_{grid} - \text{Loss}_{feedin} - \text{Cost}_{(waste)Heat} - \text{Invest}_{year} + \text{Savings}_{Heat}$$

➡ Carnot battery becomes profitable under current German market conditions



Conclusions

Conclusions

i7-AnyEnergy

- multi-energy cellular approach with hierarchy and neighborhood
- interface and filter framework, centralized and decentralized control strategies
- rapid, scalable, visual, textual

Carnot battery

- profitability under current German market conditions depends critically on heat costs
- environmental impact better than with lithium ion batteries

Further work

- Quality-of-Service and resilience of energy ICT (DFG project with Univ. Oldenburg)
- Simulation-as-a-Service (DFG project NFDI4energy)
- e-trucks (PhD Jonathan Fellerer)

→ **designing your smart energy system?**