Lehrstuhl für Energiesysteme
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Geothermal combined heat and power (chp) concepts

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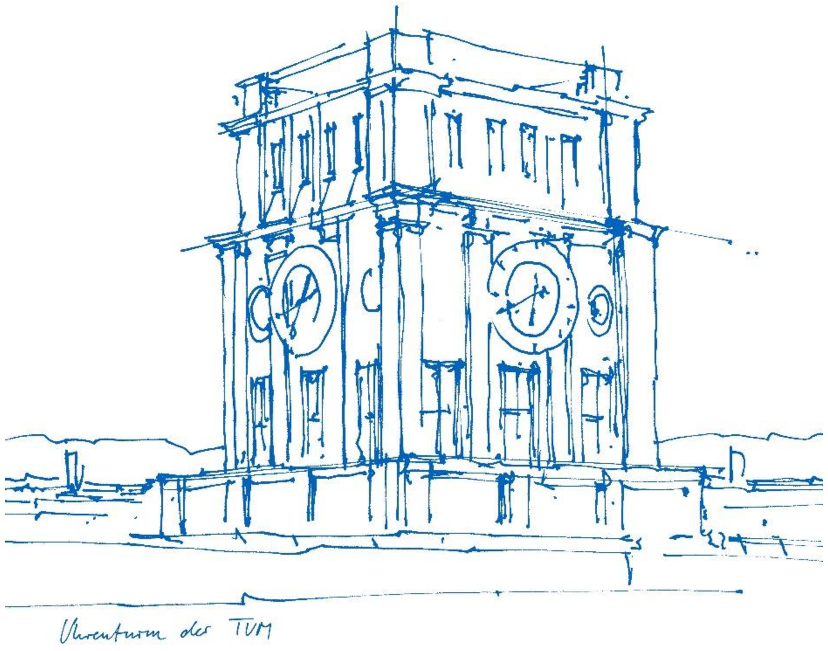


Outline

1. Deep Geothermal Energy in Germany and the Geothermal Alliance Bavaria
2. Motivation for power generation from geothermal energy
3. CHP plant modeling
4. TUM-ORC and comparison with the state of the art parallel chp concept

Deep Geothermal Energy in Germany

District heating [2]:

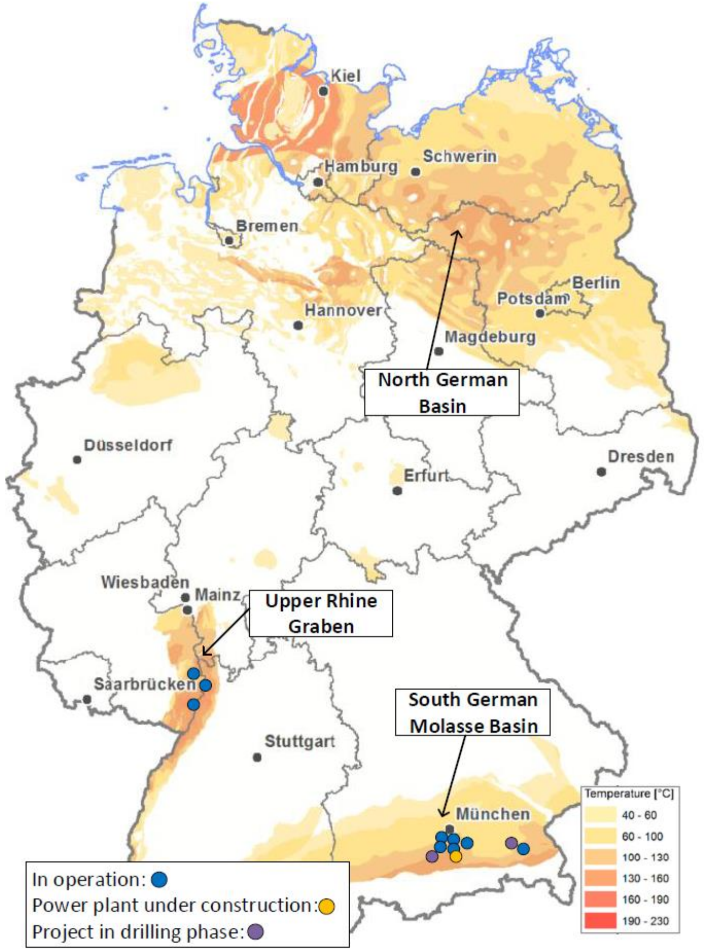
- Installed capacity: ~ 313,5 MW (2017)
- Production: 893,3 GWh (2017)

Power Generation [2]:

- Installed capacity : ~ 36 MW (2017)
- Production: 160 GWh (2017)

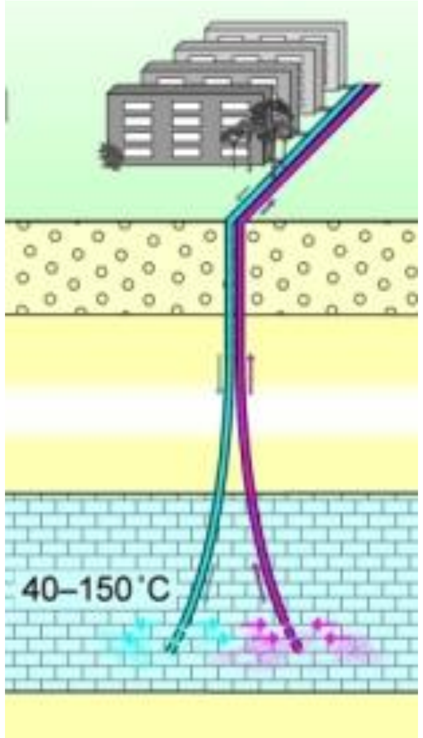
Facilities in Bavaria:

- 800 – 5000 m vertical depth
- 60 – 150°C thermal water temperature



[3], [4]

Hydrothermal doublet



[1]

The Geothermal-Alliance Bavaria

Technical University of Munich

Friedrich-Alexander University Erlangen-Nuremberg

University of Bayreuth

+ Several local operators of geothermal facilities (district heating and power generation)

➡ Strengthen and promote geothermal energy research and applications

Bavarian State Ministry of Education, Science and the Arts

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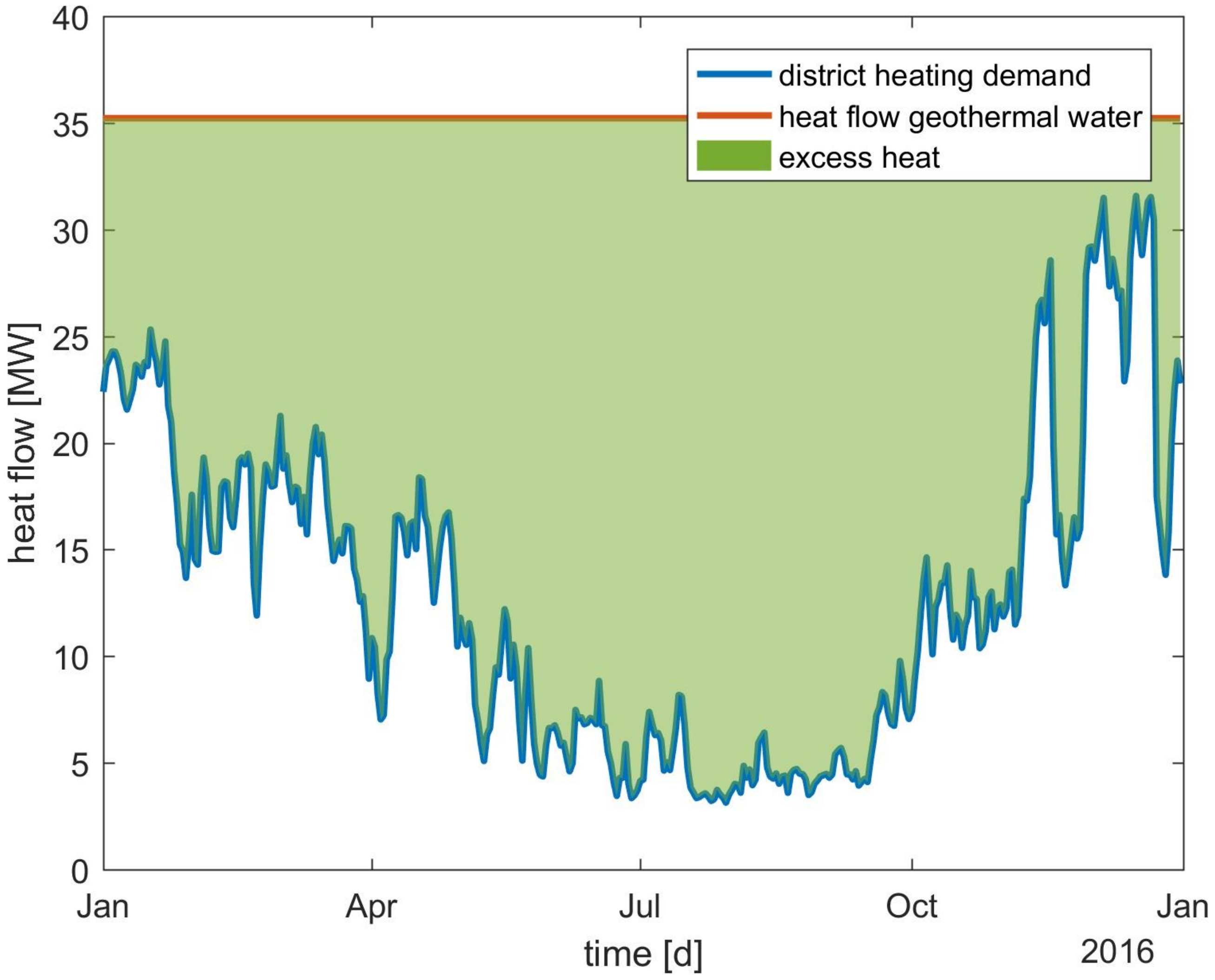
Motivation: Why electricity from geothermal energy?



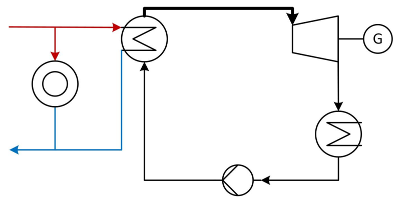
Theoretical heat stored in the geothermal water: 308 GWh

Heat demand: 113 GWh

➡ ≈ 63% excess heat

Key influencing factors for combined heat and power (chp) production from geothermal energy

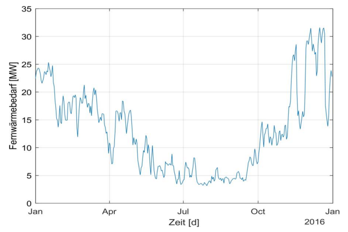
cycle architecture



thermal water

- temperature
- massflow
- pressure

heat demand



What is the optimum design size for the power block in heat driven geothermal chp plants?

Thermodynamic and economic CHP model

- Design specifications for power block
- Optimized operating strategy

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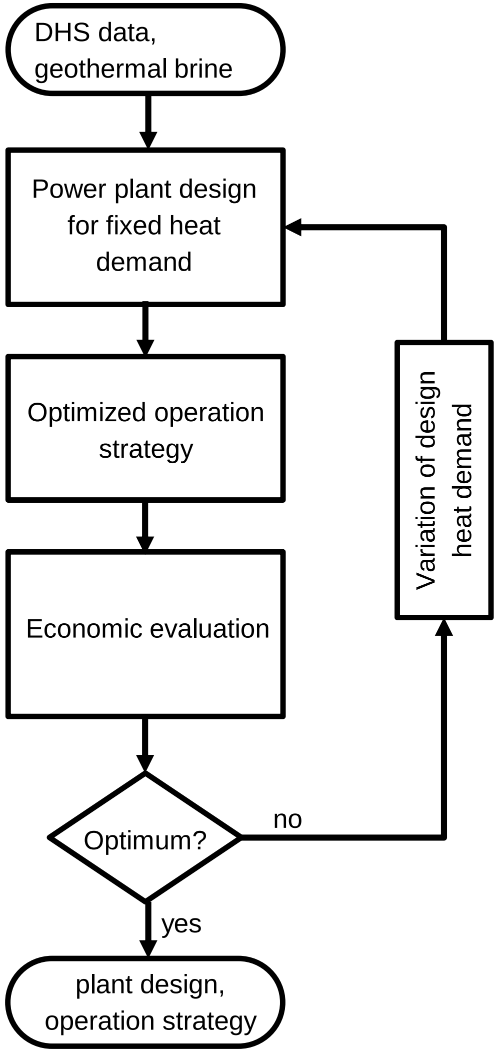
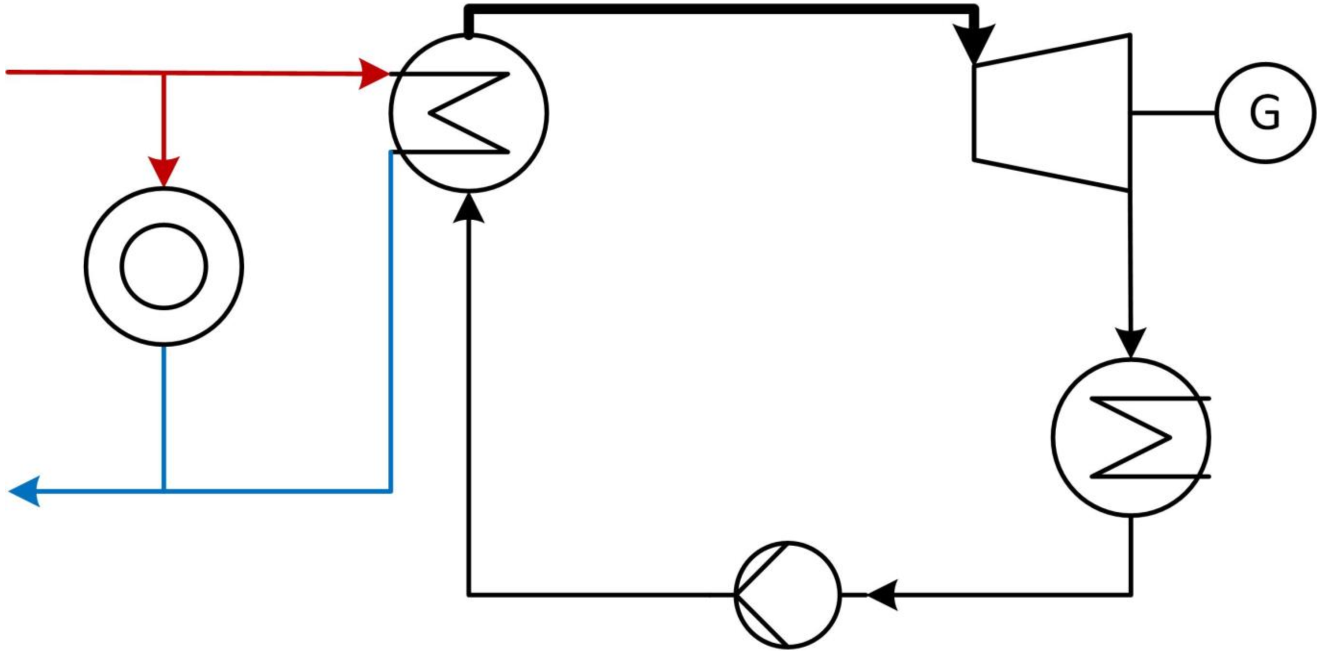
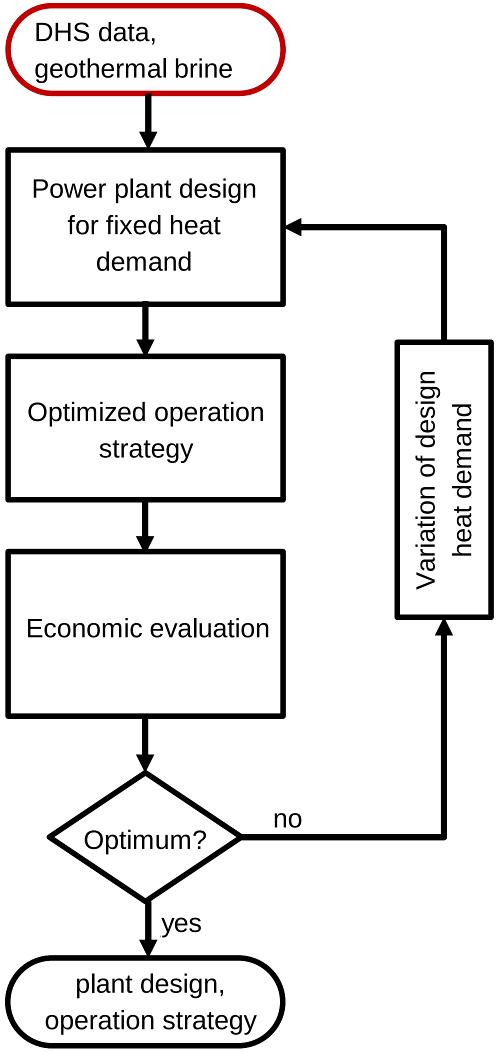
Example: Parallel CHP

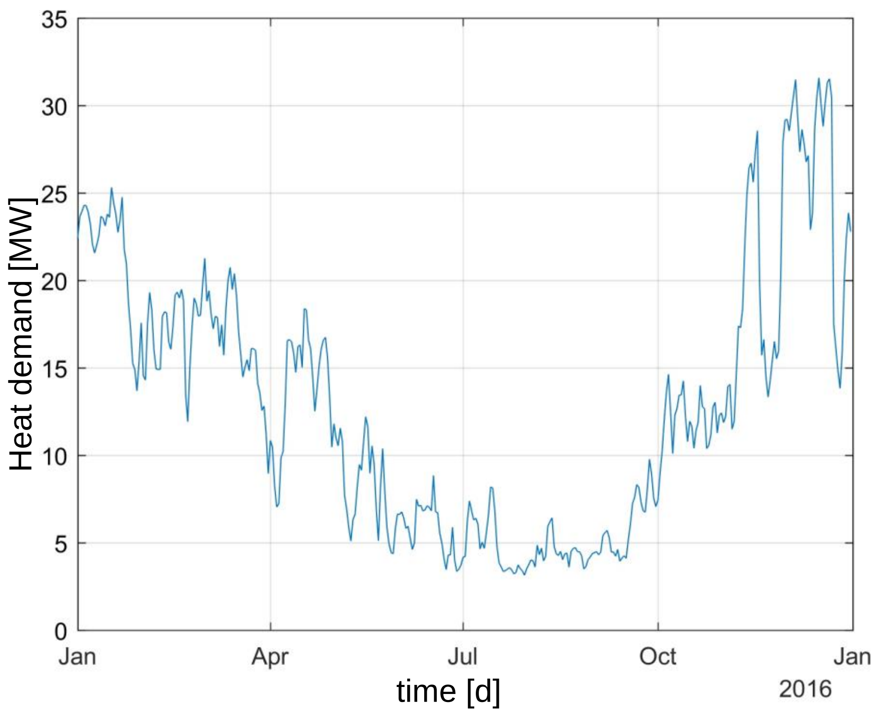


MATLAB + EBSILON *Professional* + REFPROP



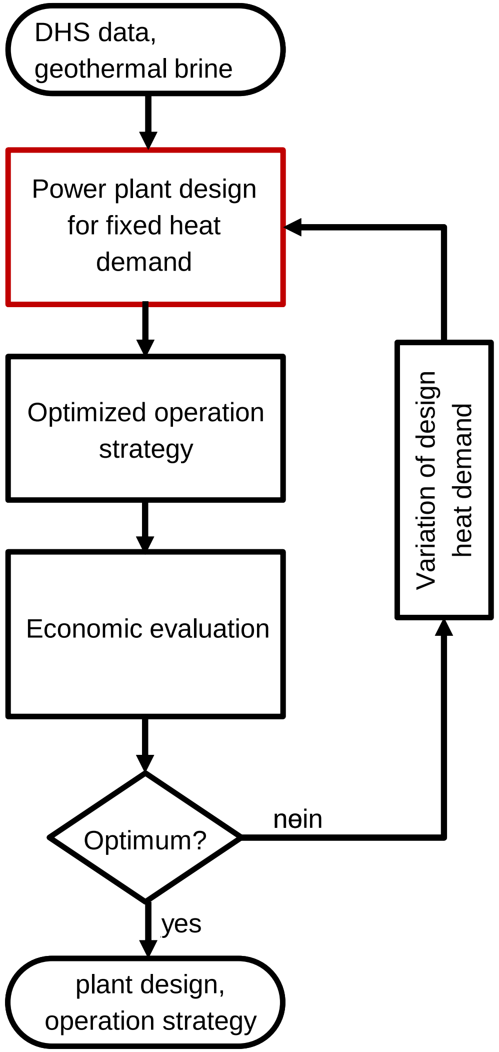
Input: District Heating System data, geothermal brine

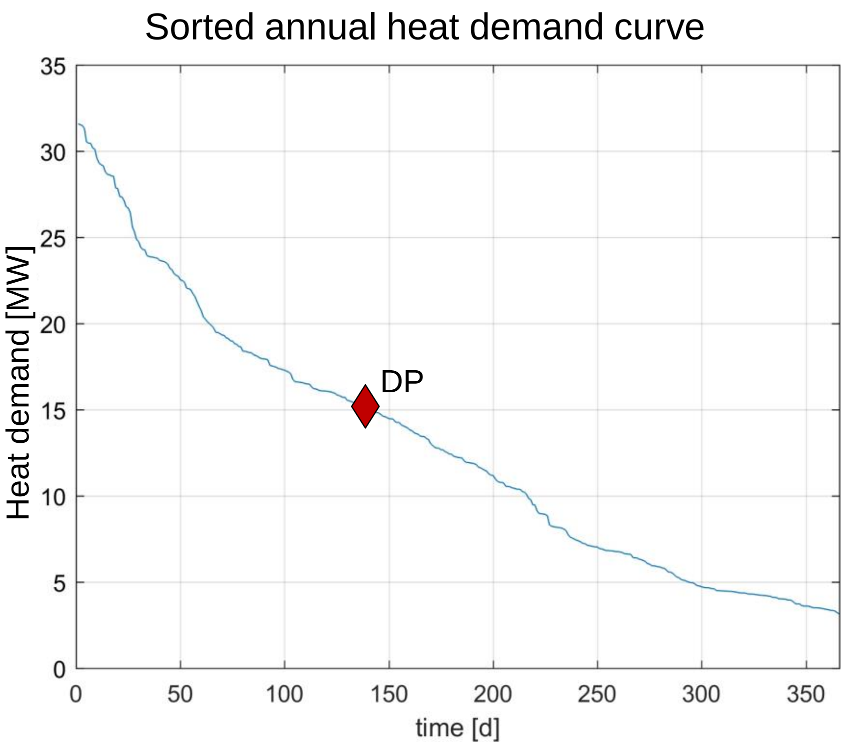




District Heating System data	
Return temperature	50°C
Supply temperature	75°C
Geothermal brine	
Temperature	122°C
Mass flow	125 kg/s
pressure	9 bar

Design: Design point and assumptions





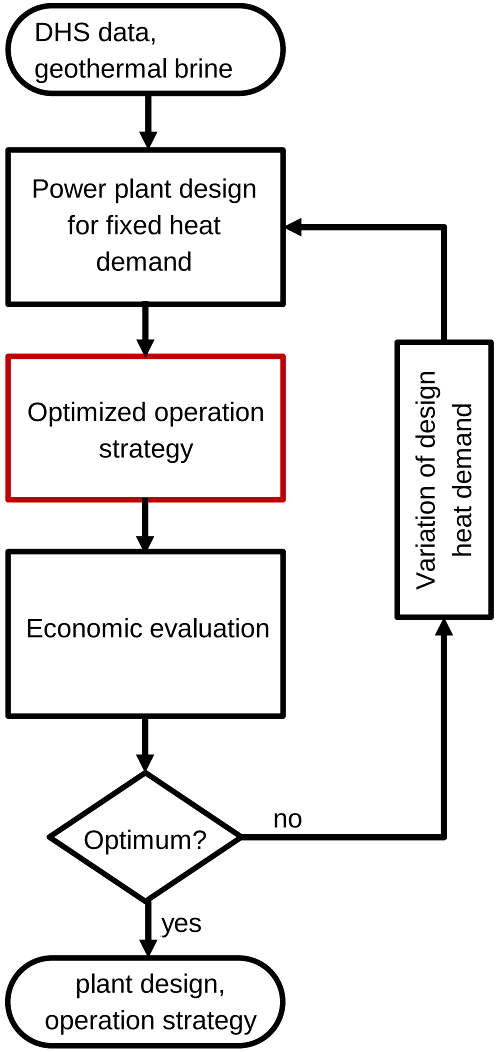
Assumptions and boundary conditions:

Pressure losses	neglected
Heat losses	neglected
Heat exchanger efficiency	0.9
Pump efficiency	0.8
Turbine efficiency	0.8
Live vapor superheating	3 K
Condensation temperature	40 °C
Ambient temperature	15 °C
Working fluid	R245fa

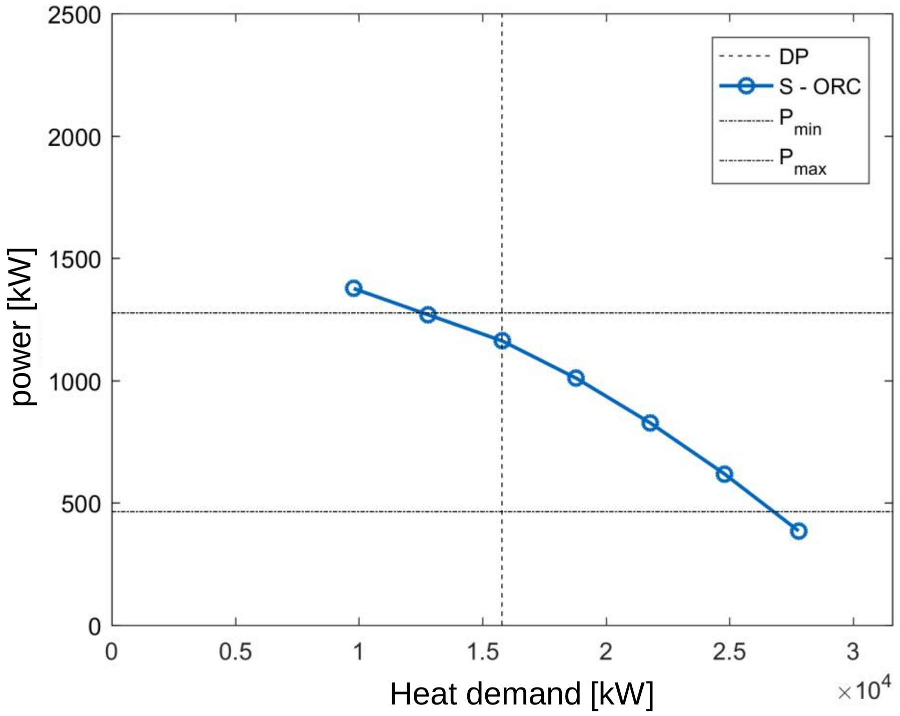
➡ Thermodynamic optimization of the net power output

➡ Component sizes for economic evaluation

Optimized operation strategy

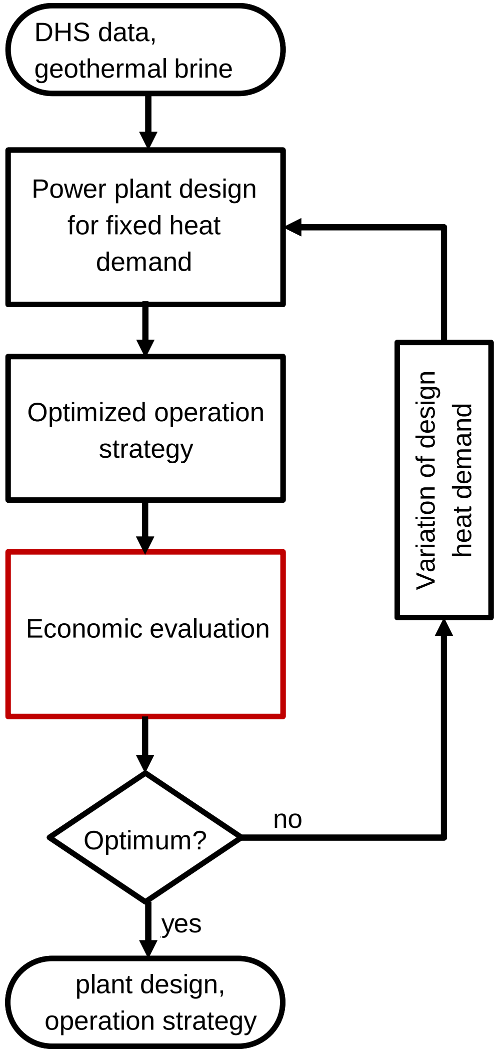


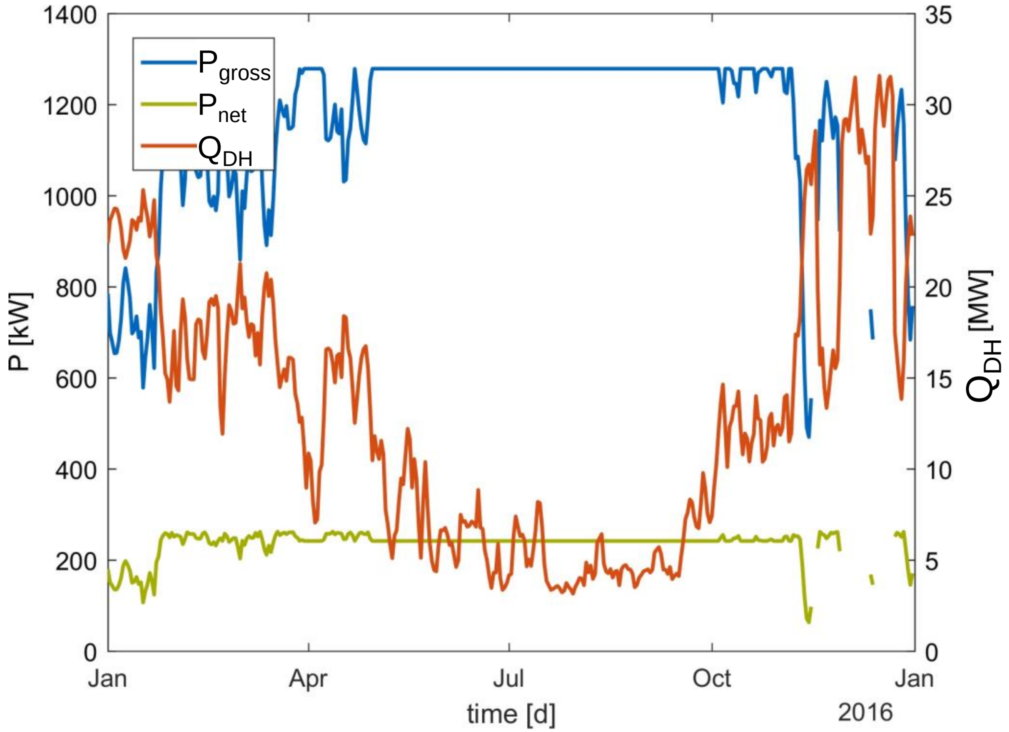
- Calculation of optimum power output for varying district heating demands
- Varying district heating demands result in varying brine mass flows for the power block and varying optimum working fluid mass flows
- The off-design behavior of the components has to be considered

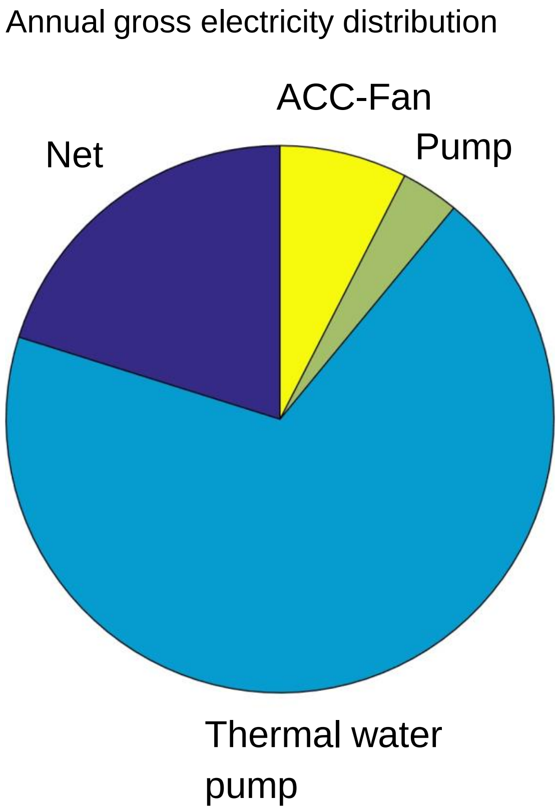


➡ Optimum power output for varying district heating demands

Economic Evaluation

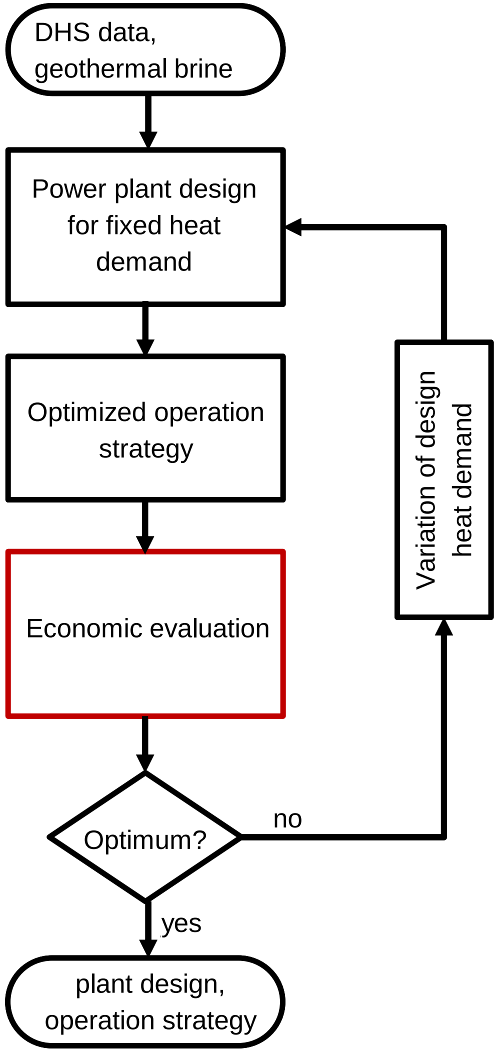






	ORC
E_{net}	1931 MWh
E_{gross}	9587 MWh

Economic Evaluation



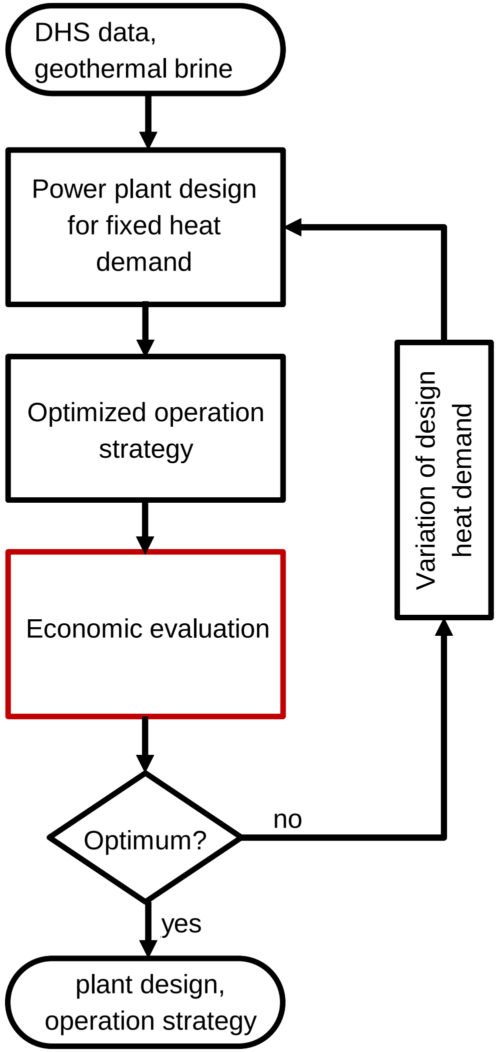
Two cases:

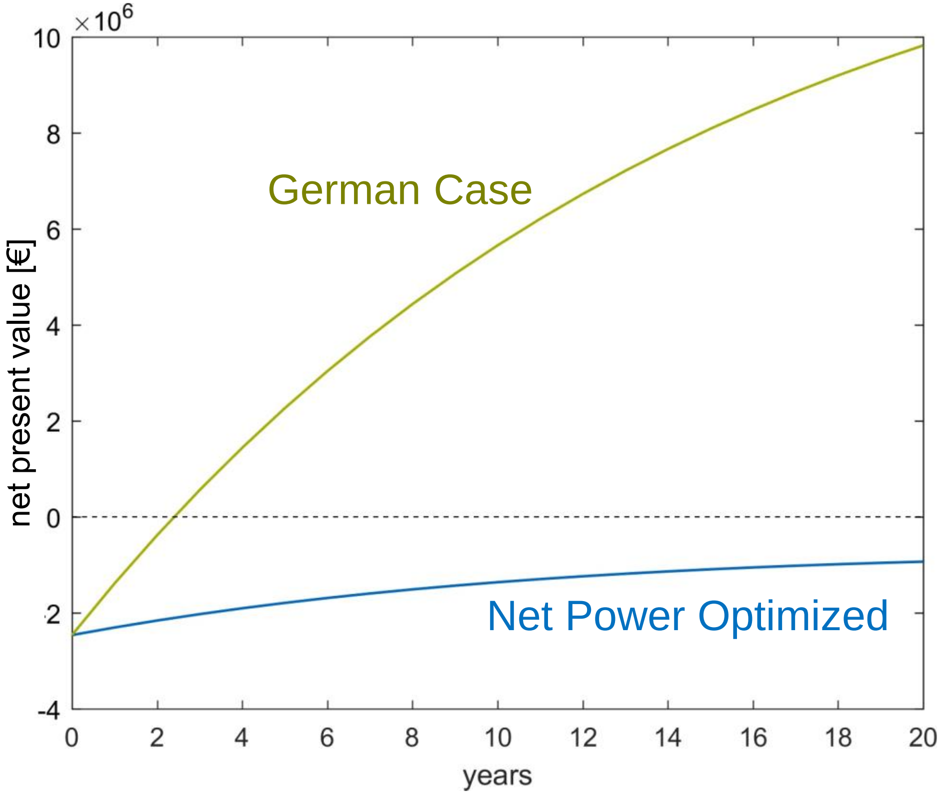
- Optimized for net power output
- German Case: The gross produced electricity is sold and the power demand for pumps and ACC-fans is bought from the grid.

Assumptions and boundary conditions:

running time	20a
availability	85%
electricity sale price (EEG feed-in tariff)	25.2 ct/kWh
electricity purchase price	10 ct/kWh
personnel costs	function of transferred heat
other operating equipment	1% Invest
maintenance	3% Invest
insurance	0.6% Invest
inflation	1.5%
calculatory interest rate	6.5%

Economic Evaluation





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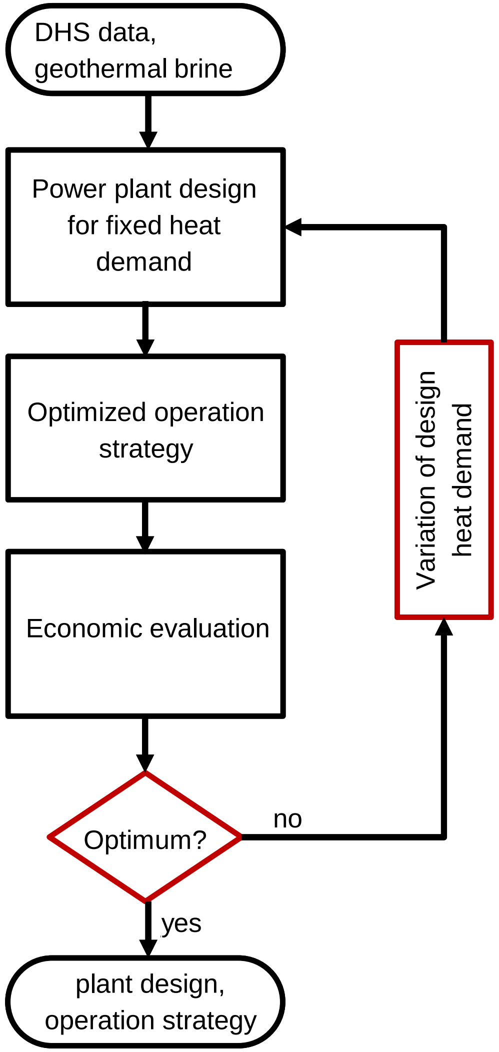
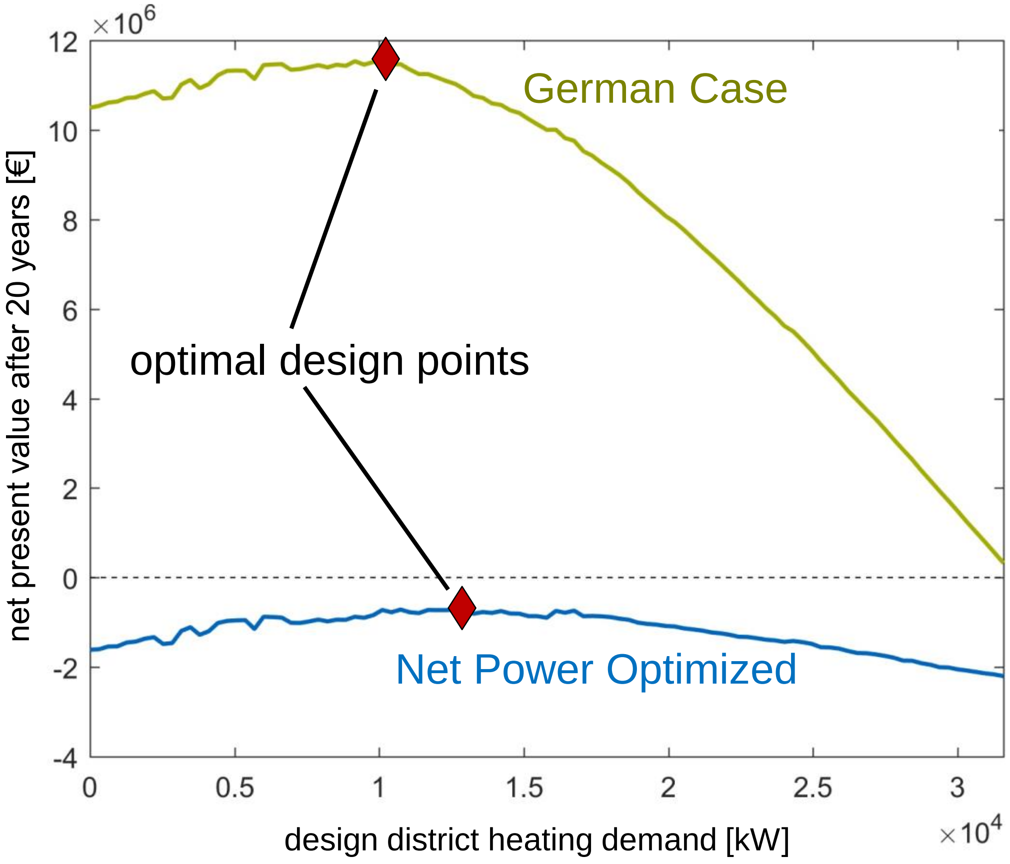
➡ Net Power Optimized: negative NPV for this specific design point
German Case: positive NPV for this specific design point

Variation of the design point: economic evaluation





➡ No design point with positive NPV for Net Power Optimized Case.

➡ German Case is highly profitable with an optimal design point at about 1/3 of the maximum heat demand.

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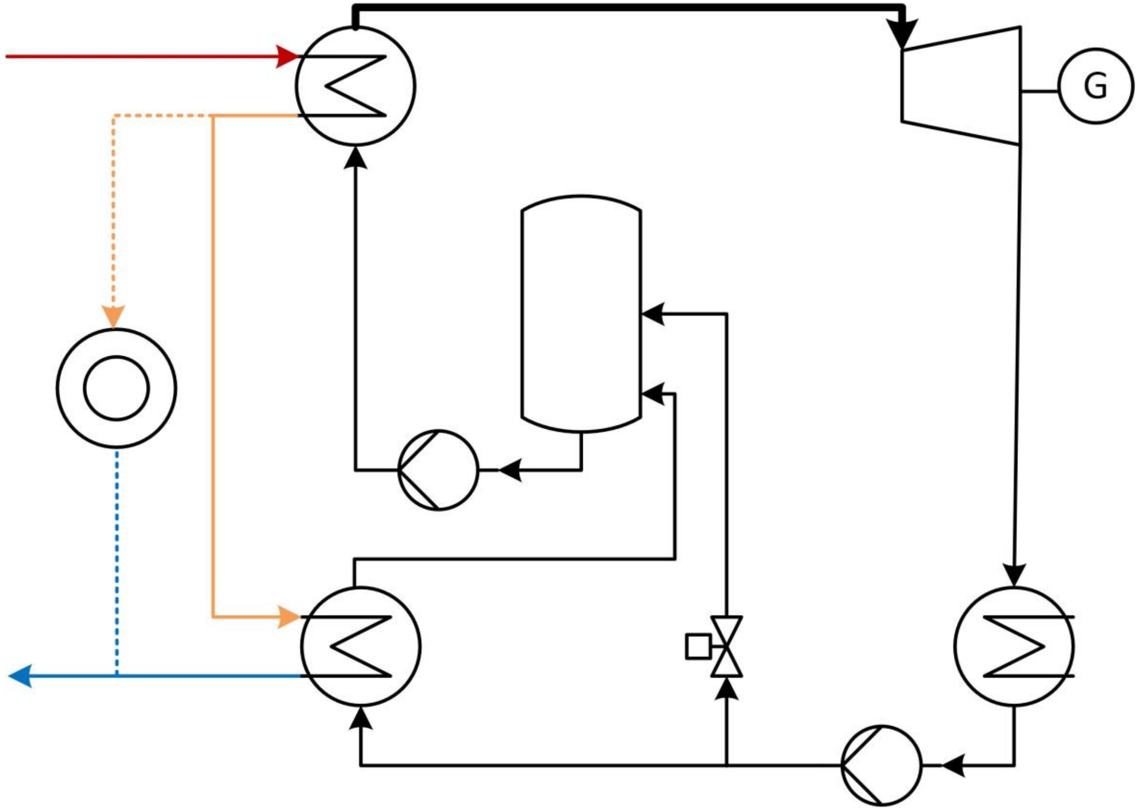
TUM-ORC

Operating mode:

1. Low district heating demand

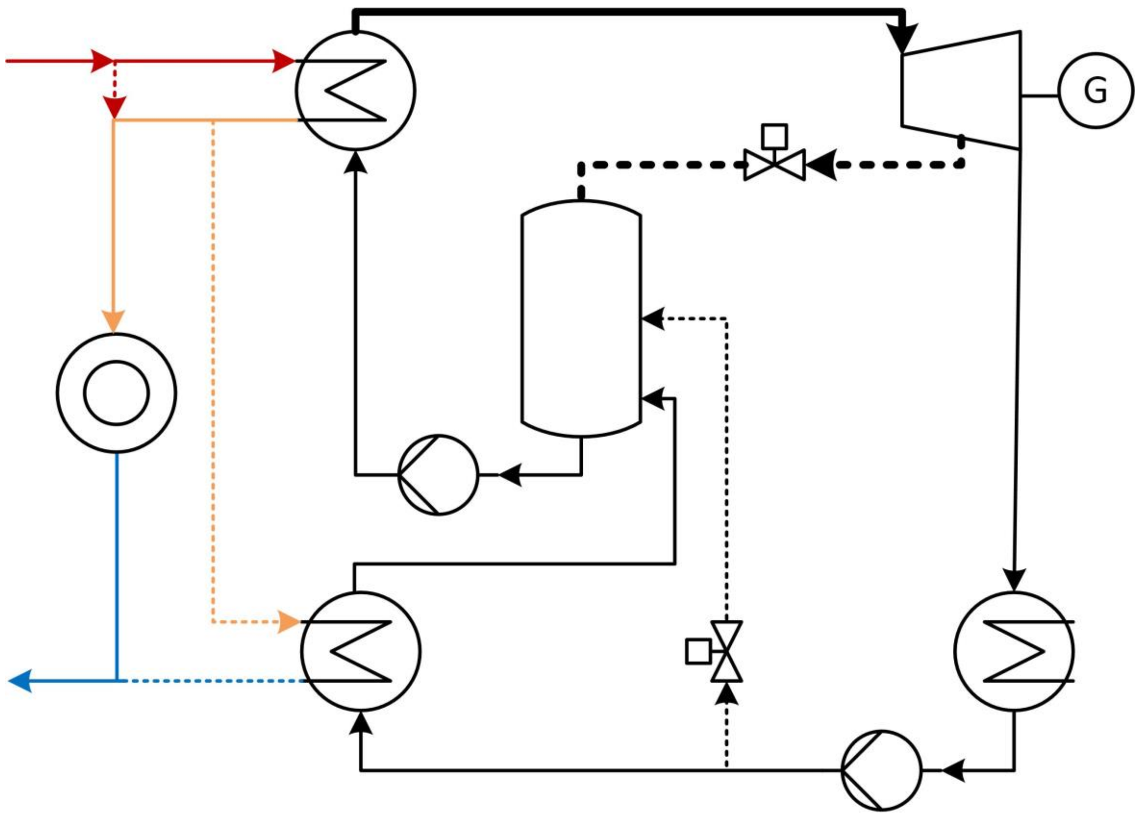


TUM-ORC

Operating mode:

1. Low district heating demand

2. Medium district heating demand



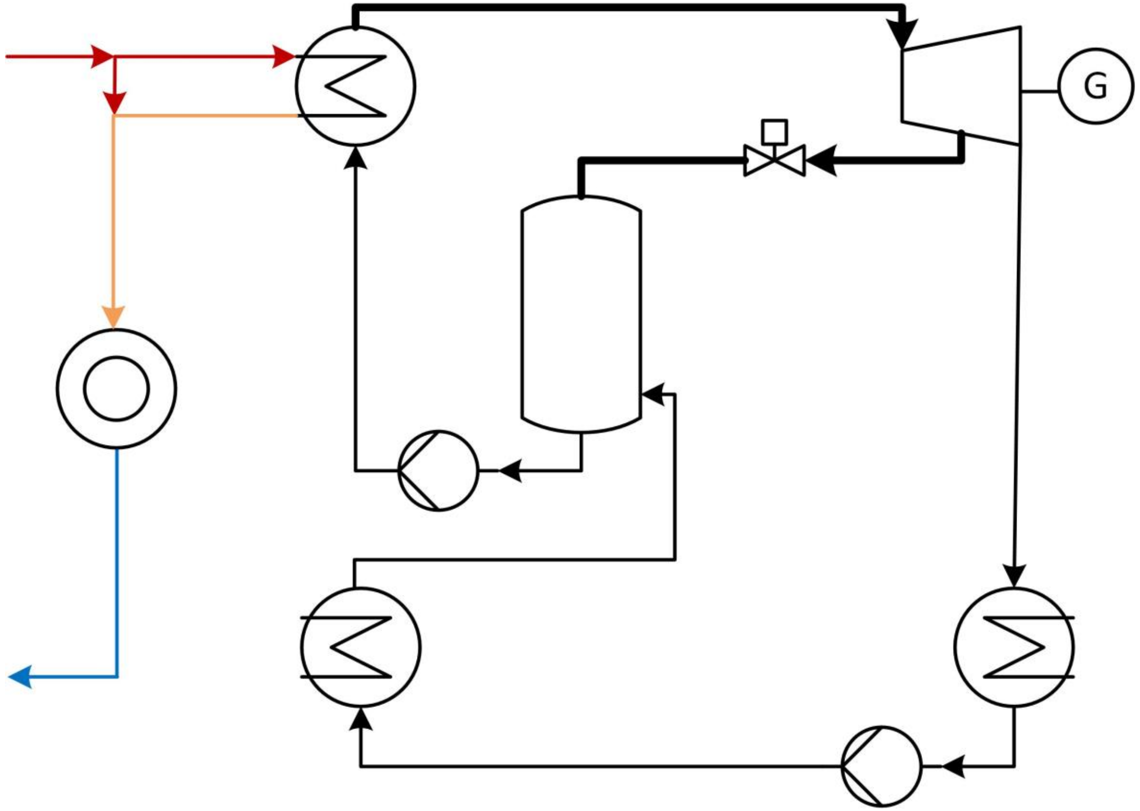
TUM-ORC

Operating mode:

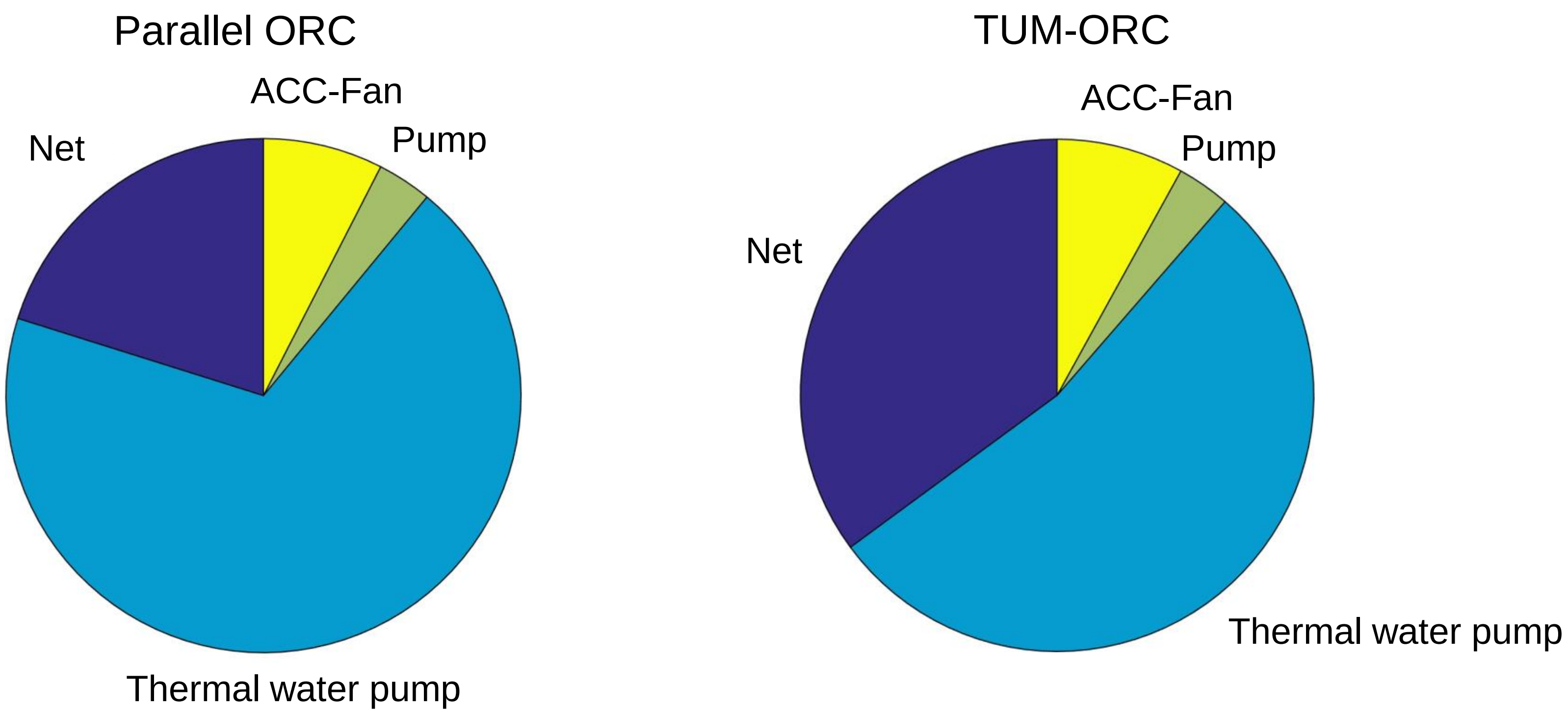
1. Low district heating demand

2. Medium district heating demand

3. High district heating demand



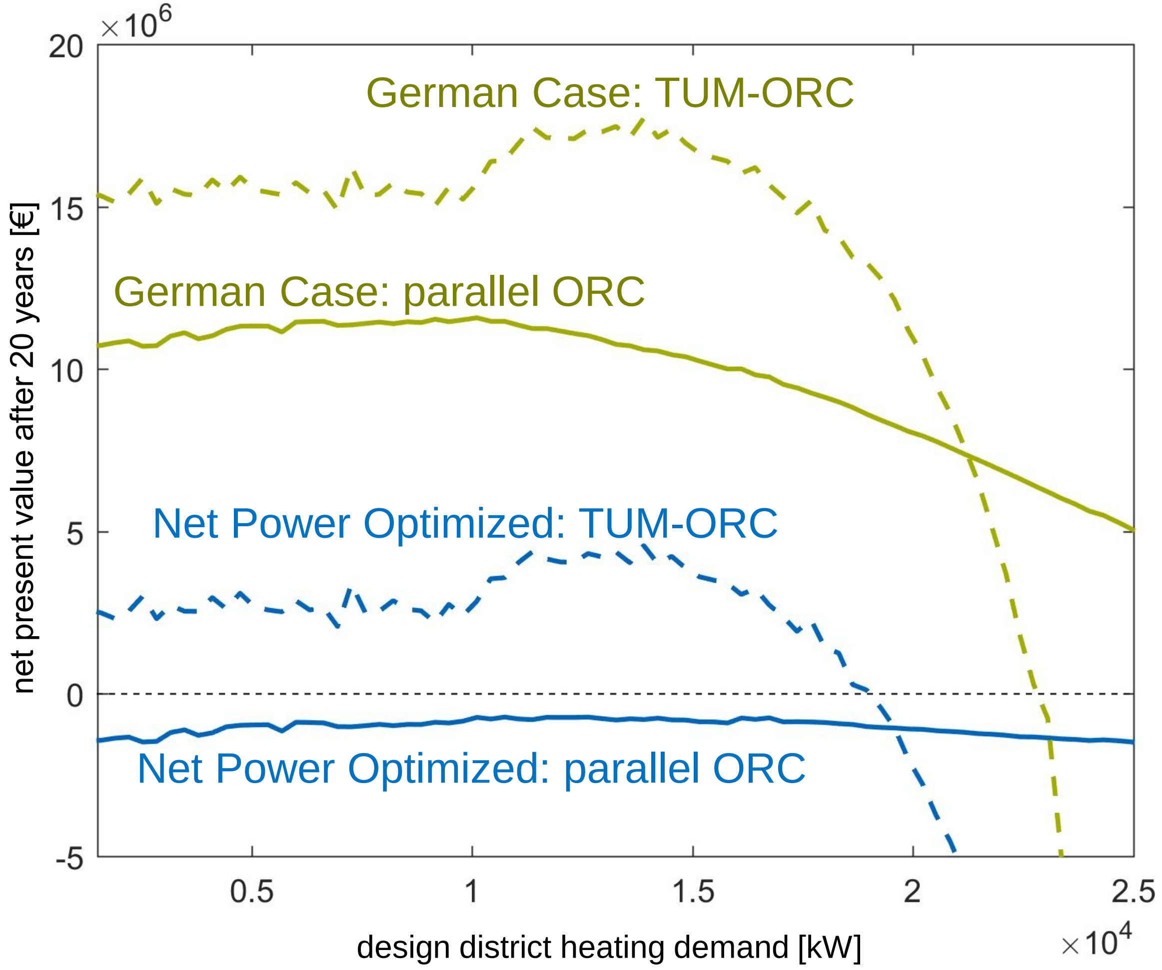
Comparison: Annual gross electricity distribution



Annual produced electricity:

	Parallel-ORC	TUM-ORC
E_{net} [MWh]	1947	5626
E_{gross} [MWh]	9319	14880

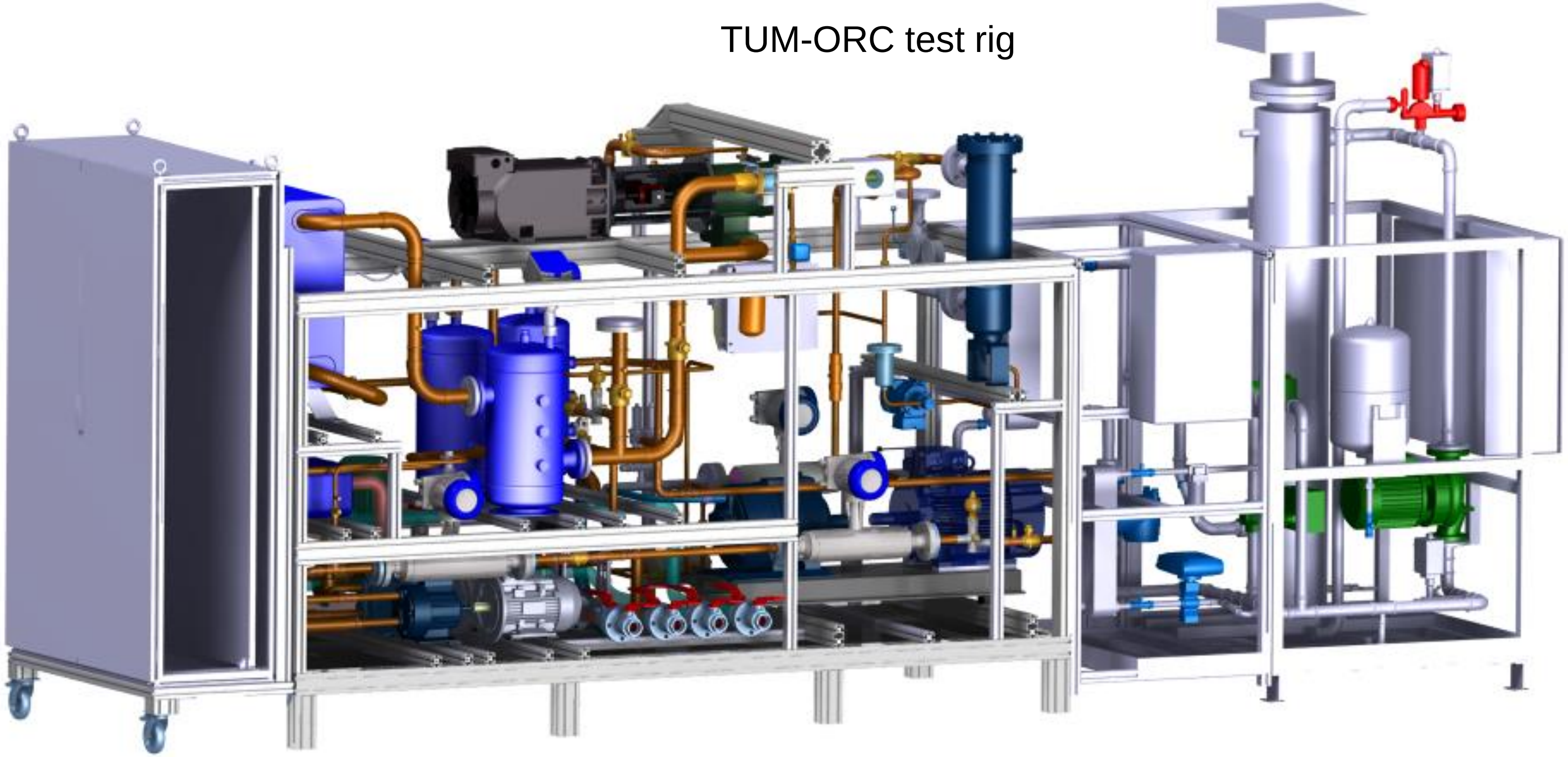
Comparison: NPV after 20 years for varied design points



➡ NPV is higher for TUM-ORC and also the net power optimized case is economically viable with the TUM-ORC concept.

Thank you for your attention.

TUM-ORC test rig



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Bibliography:
[1] Bayrisches Landesamt für Umwelt, www.lfu.bayern.de
[2] GeotIS: Geothermische Standorte, www.geotis.de
[3] Thorsten Agemar, Josef Weber, and Rüdiger Schulz. Deep geothermal energy production in Germany. Energies, 7(7):4397–4416, 2014.
[4] Schifflechner C. Assessment of Hydrothermal Deep Geothermal Plants for combined Heat and Power Production with Respect to a Novel Monitoring Software. Master‘s thesis, 2019