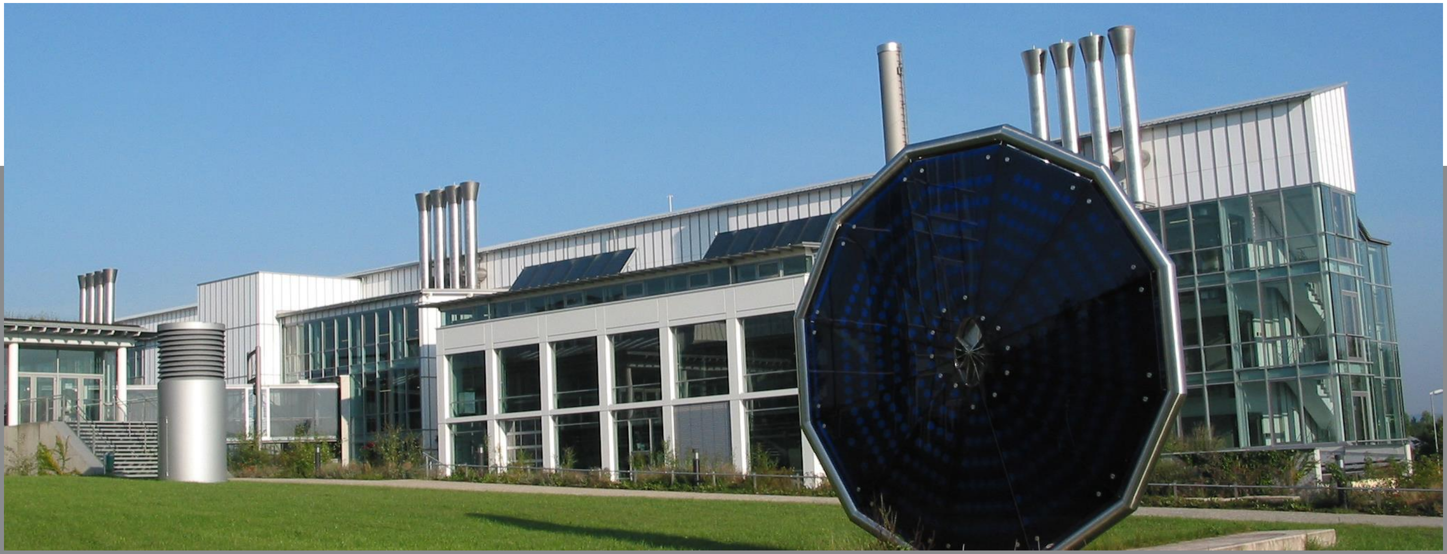

A Retrofit for Geothermal ORC based on Concentrated Solar Thermal Systems

4th International Seminar on ORC Power Systems 2017, 13-15 Sept., Milano

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LEHRSTUHL FÜR TECHNISCHE THERMODYNAMIK UND TRANSPORTPROZESSE
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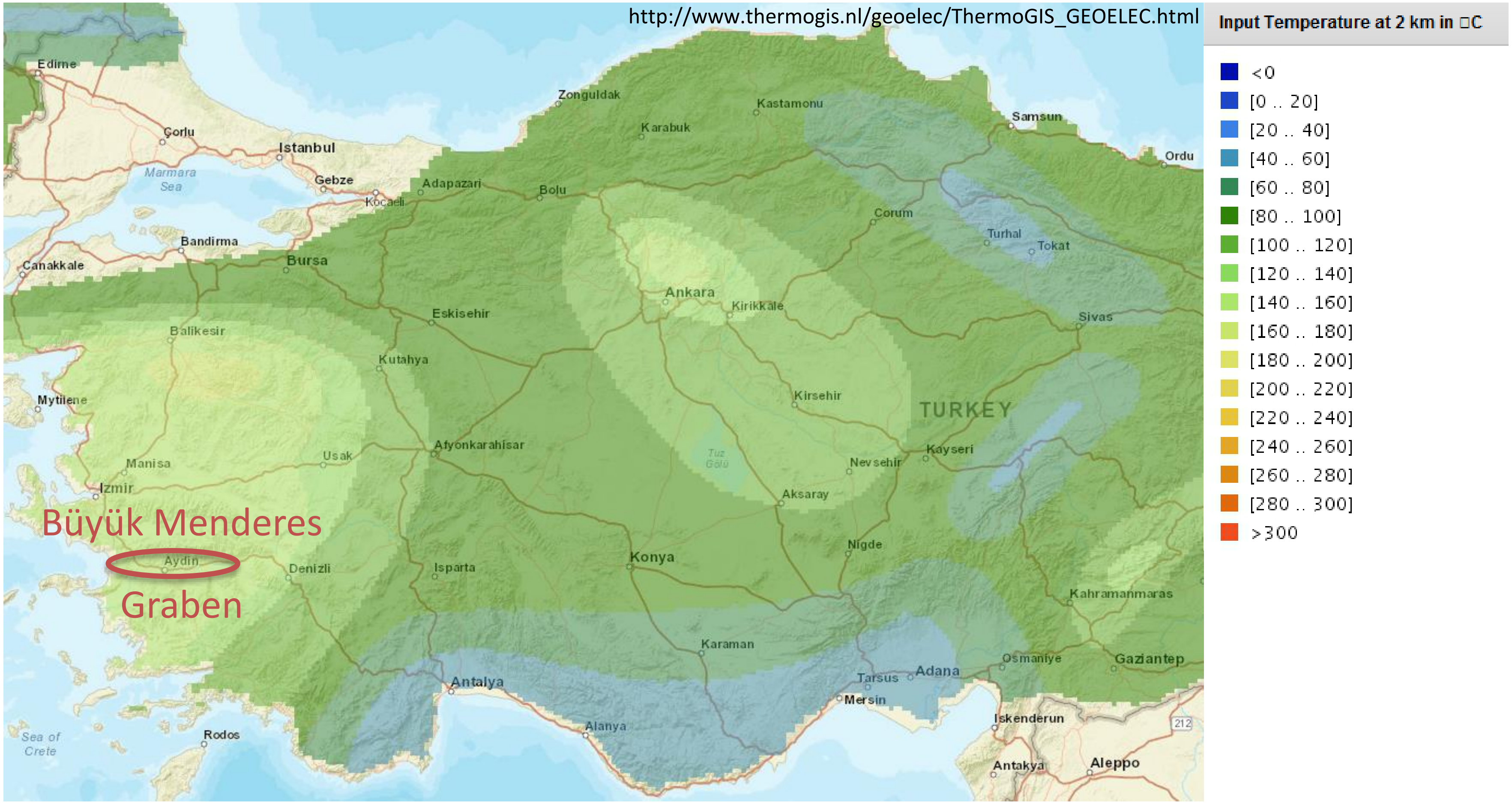
Motivation

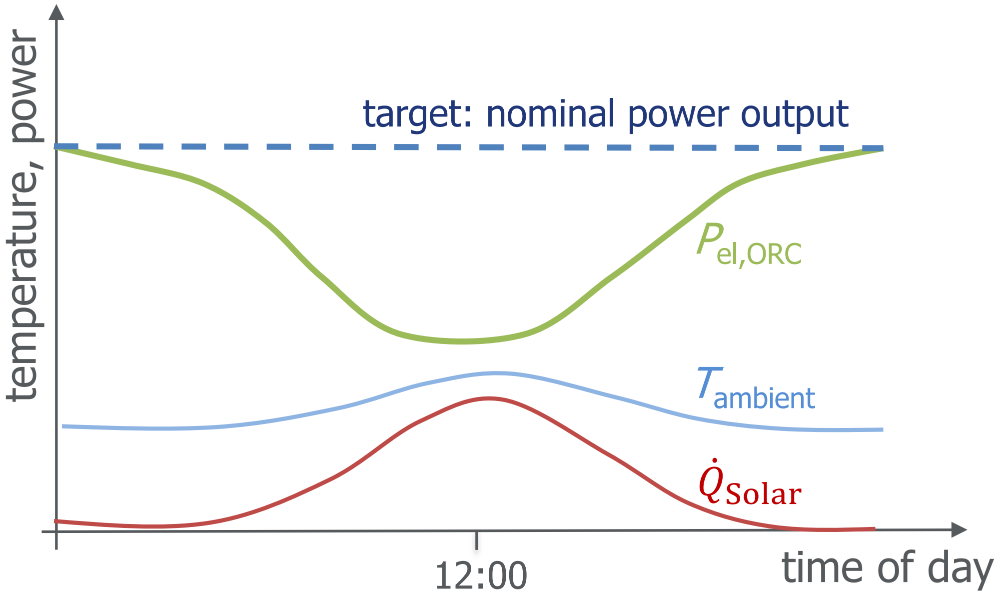
Geothermal power generation in Turkey



Motivation

Geothermal power generation in Turkey – General aspects

- Installed capacity*: 650 MW_{el} in 2015; 1284 MW_{el} expected in 2020
- Increasing part of binary power plants (ORC) → about 320 MW_{el} in 2016
- Air-cooled units retrofitted by (solar-thermal) parabolic trough collectors



*M. Antics, R. Bertani, B. Sanner; *Summary of EGC 2016 Country Update Reports on Geothermal Energy in Europe*, Proceedings of the European Geothermal Congress 2016, Strassbourg (France), 2016

Motivation

Geothermal power generation in Turkey – General aspects

Literature/ state of the art

Astolfi et al. (2011):
- Solar-geo hybrid
- Annual simulation
- Supercritical ORC

Ghasemi et al. (2014):
- Solar retrofit
- Case study (Turkey)
- Selected days

DiMarzio et al. (2015):
- Stillwater, USA
- Existing hybrid plant
- Preheating brine

enpros

Geological background / project experience in Turkey

Solar retrofit
(case study; Büyük Menderes Graben)

Specifications of the parabolic trough collector (CF 100)

protarget
SOLAR POWER SYSTEMS

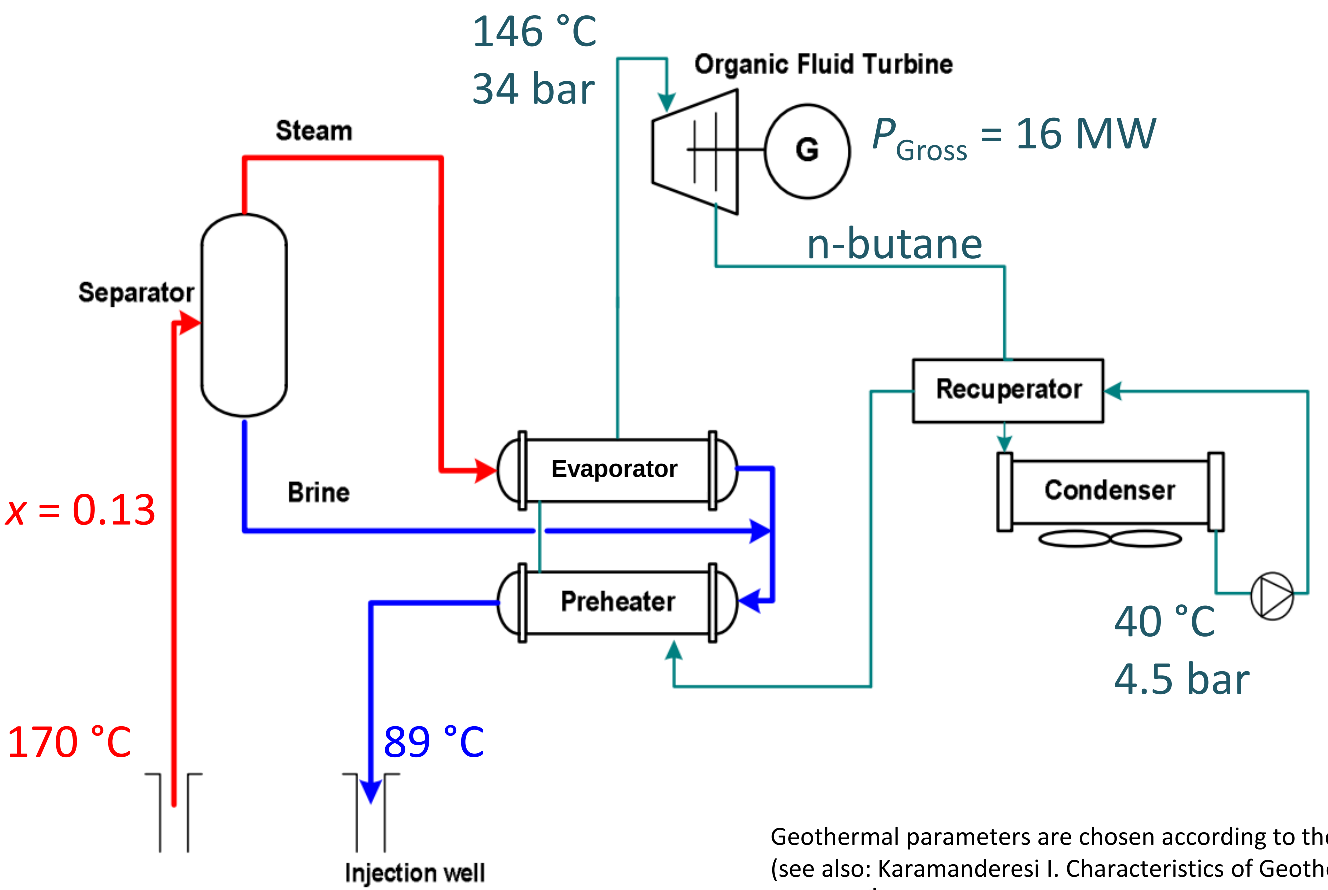
Objectives

Concepts
- Integration of solar heat input
- Simulation over the period of one year
- Efficiency

Limitations
- Capacity of existing components
- Thermal stability

(Economics)

Methods
Geothermal binary power plants in Turkey – standard scheme



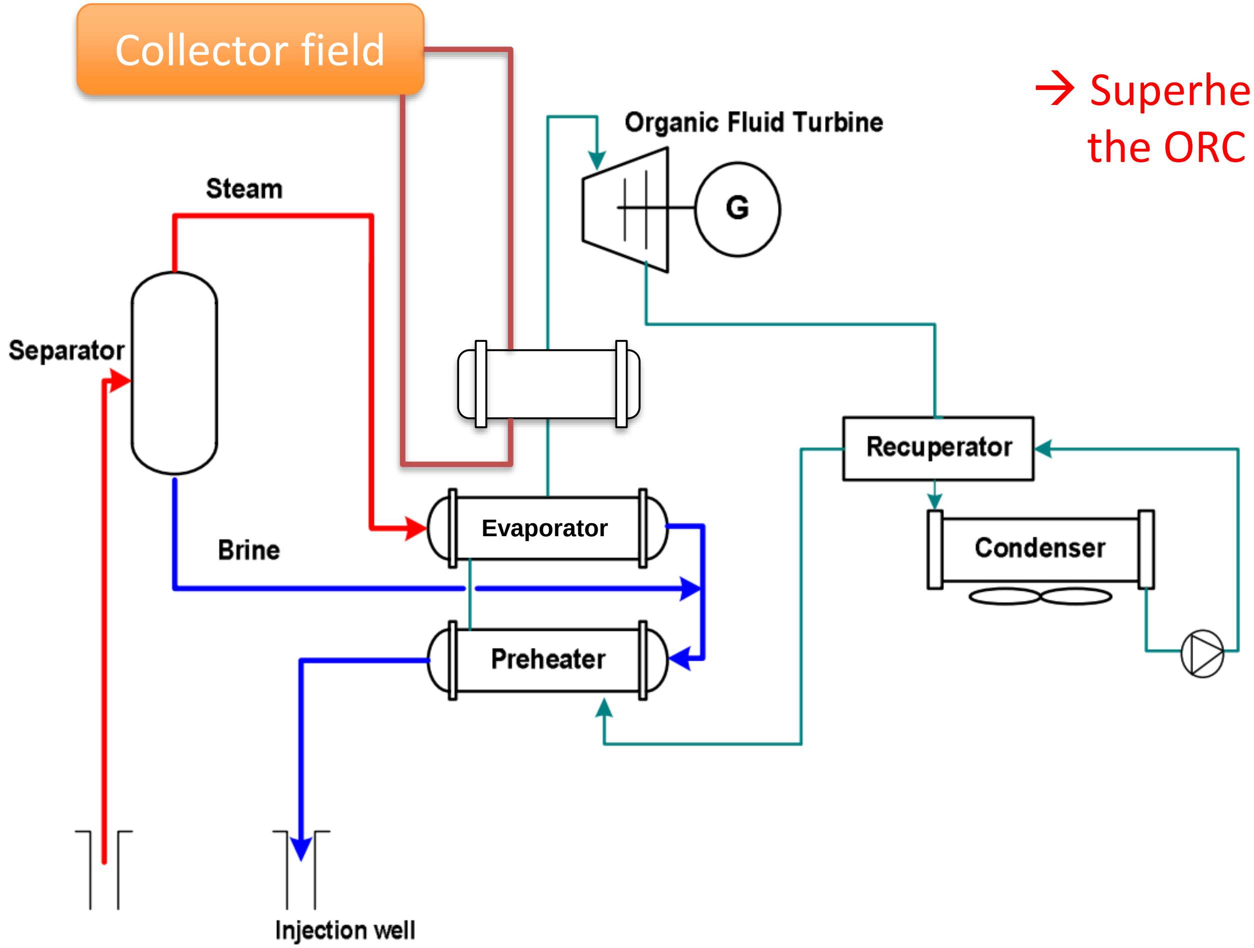
Design case

ϑ_a = 18 °C

Geothermal parameters are chosen according to the Aydin-Salavati field (see also: Karamanderesi I. Characteristics of Geothermal Reservoirs in Turkey. Bornova/İzmir (Turkey): 2013.)

Methods

Promising concept for the solar retrofit - superheater



→ Superheating of the ORC working fluid

Methods

Off-design calculation of the ORC unit

Turbine*: $$\eta_{\mathrm{is}} = r_{\mathrm{h}} r_{\mathrm{v}} \eta_{\mathrm{is,Design}} = \mathrm{f}\left(\Delta\mathrm{h}, \dot{V}_{\mathrm{outlet}}\right)$$

Preheater, condenser, recuperator**: $$kA_{\mathrm{off}} = kA_{\mathrm{des}} \left(\frac{\dot{m}_{\mathrm{off}}}{\dot{m}_{\mathrm{Design}}}\right)^{n}$$

Evaporator: $$\Delta T_{\mathrm{pp}} = \mathrm{constant}$$

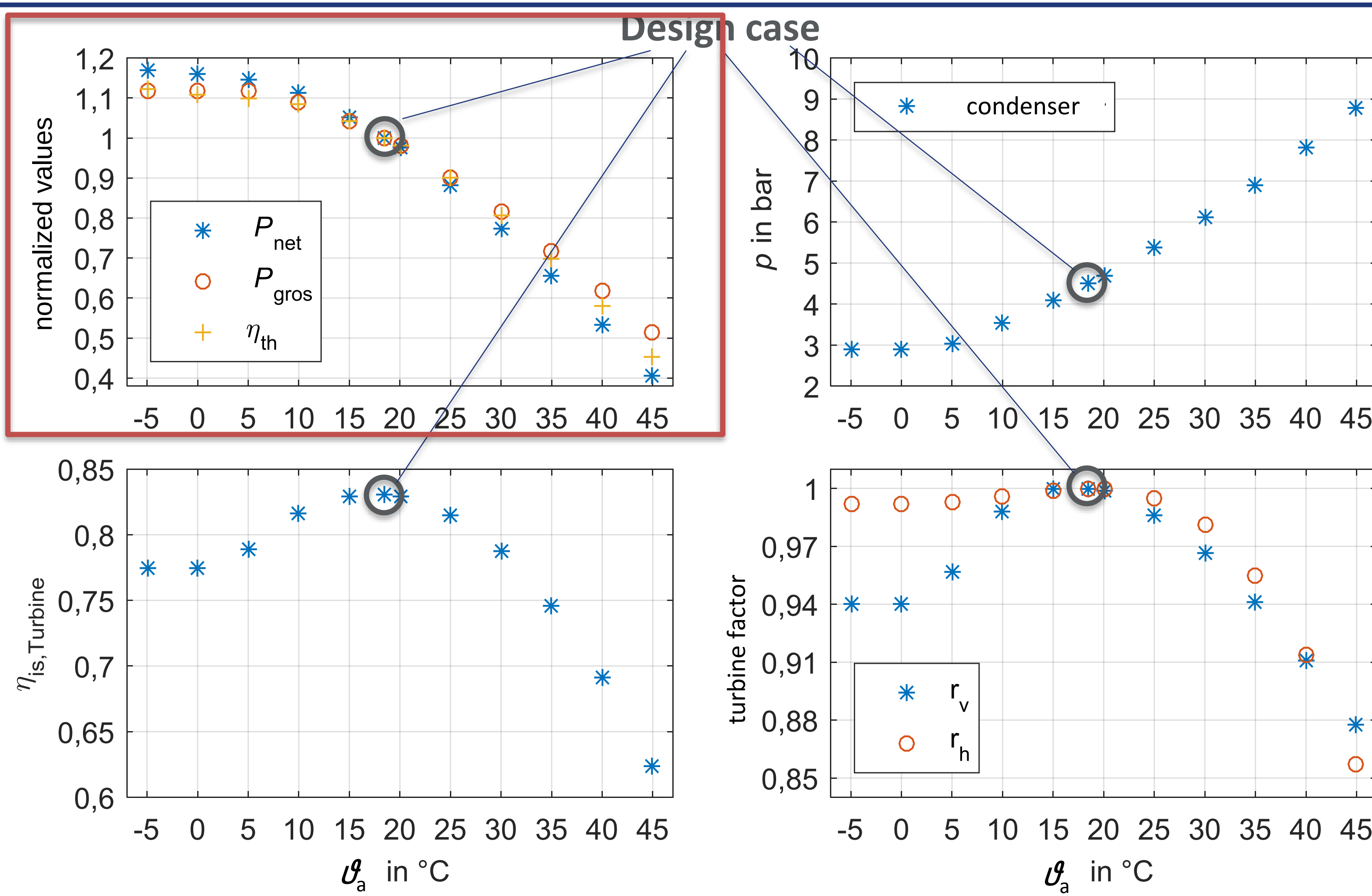
$$p_{\mathrm{evp}} = \mathrm{constant};\ p_{\mathrm{cond}} = f(\vartheta_{a}, \dot{V}_{air})$$

*Ghasemi H, Sheu E, Tizzanini A, Paci M, Mitsos A. *Hybrid solar–geothermal power generation: Optimal retrofitting*. Appl Energy 2014;131:158–70. doi:10.1016/j.apenergy.2014.06.010.

** Manente G, Toffolo A, Lazzaretto A, Paci M. *An Organic Rankine Cycle off-design model for the search of the optimal control strategy*. Energy 2013;58:97–106.

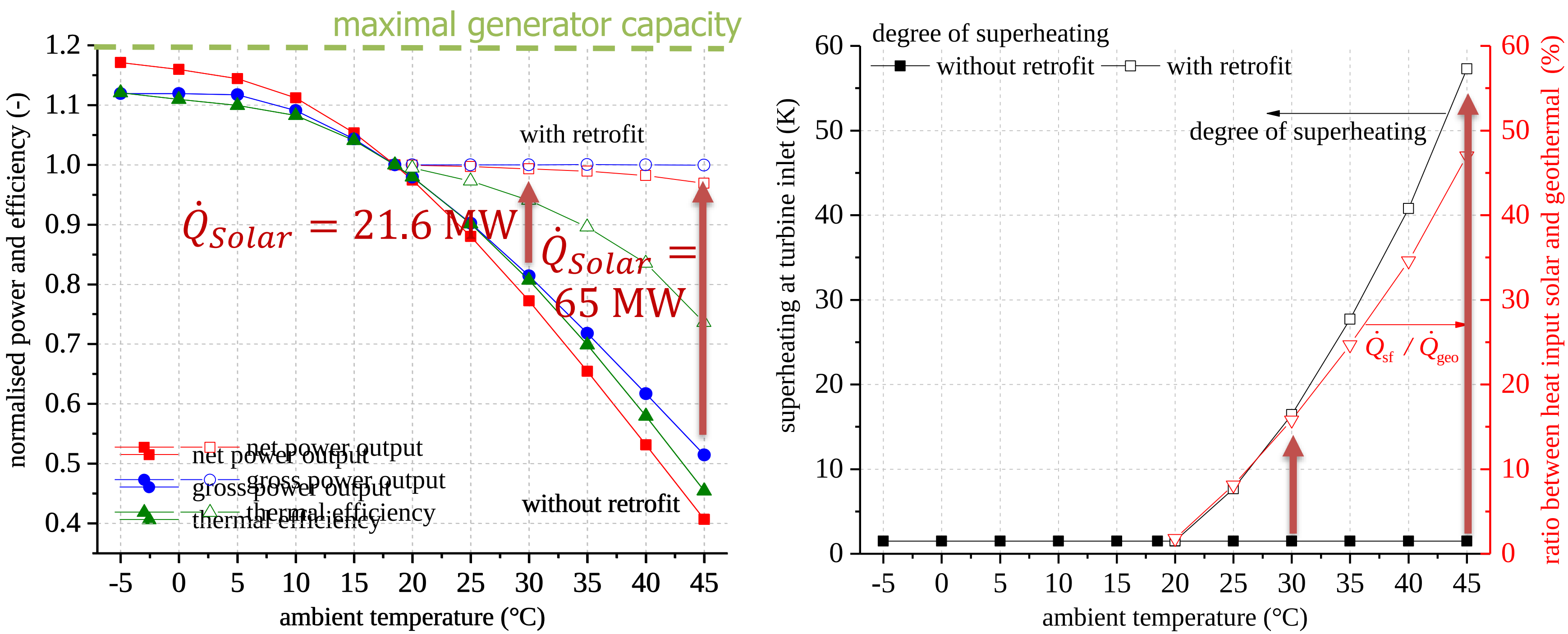
Results

Off-design calculation of the ORC unit



Results

Solar superheating – Design identifcation for the retrofit



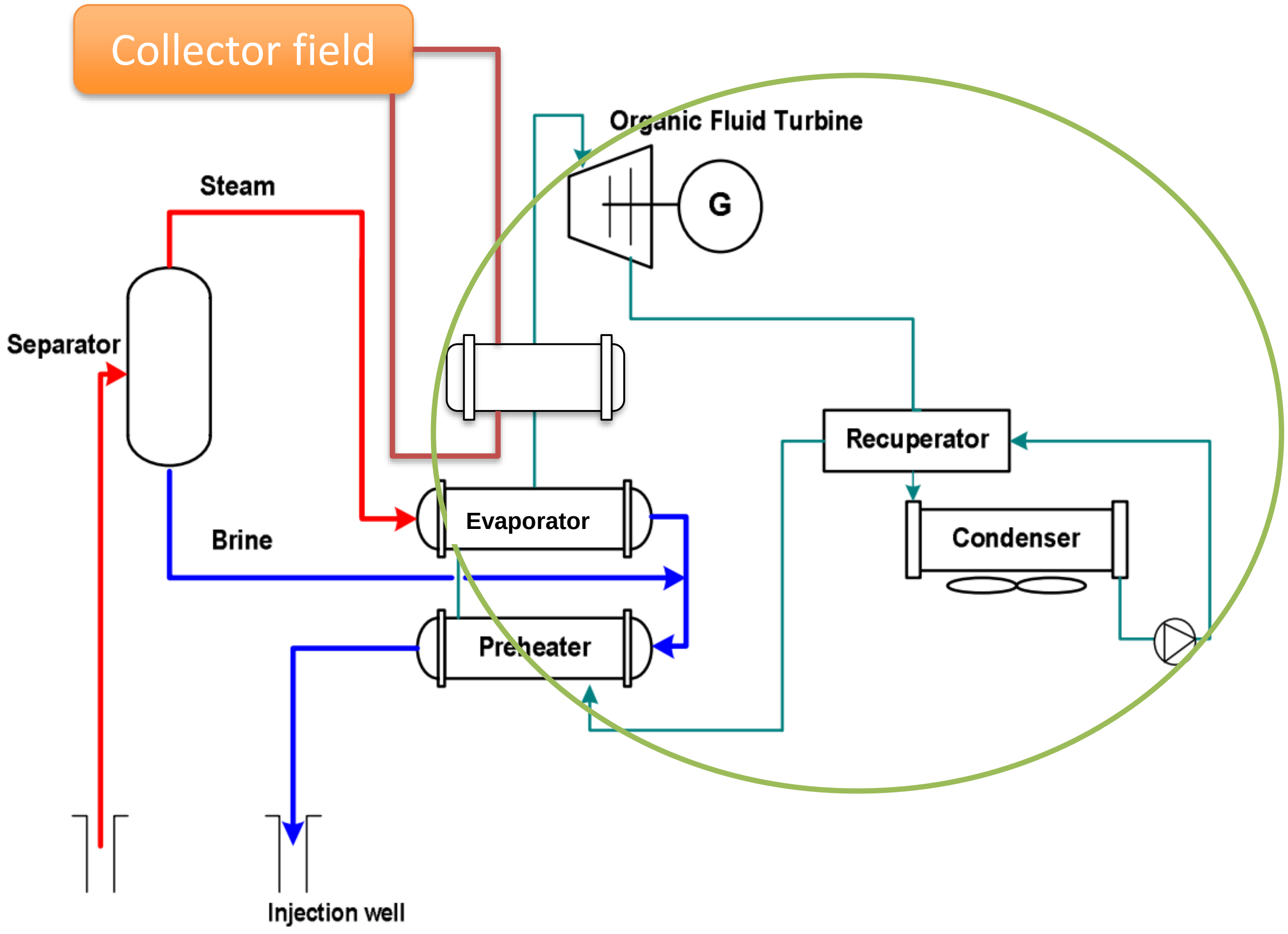
→ No problems rearding thermal stability ($\vartheta_{max,ORC}$ = 200 °C)*

→ Solar heat input is limited by pump and generator capacity

*Pasetti M, Invernizzi CM, Iora P. *Thermal stability of working fluids for organic Rankine cycles: An improved survey method and experimental results for cyclopentane, isopentane and n-butane*. Appl Therm Eng 2014;73:764–74.

Methods II

Solar superheating – detailed simulation over the period of one year

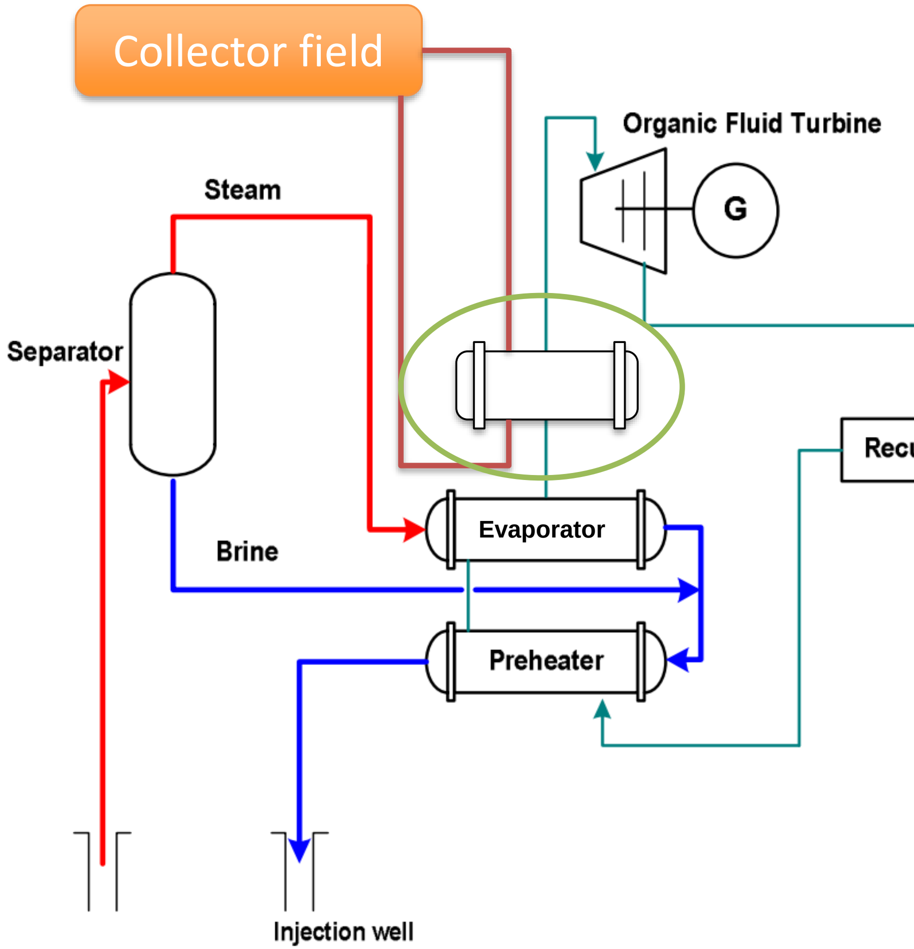


1. Operational parameter of the ORC module in Cycle-Tempo ($\vartheta_a = -5 \ldots 45\ °C$; $\Delta T_{SH} = 0 \ldots 30\ K$)

→ $P_{\mathrm{ORC}} = f(\vartheta_{\mathrm{a}}, \Delta T_{\mathrm{SH}})$

Methods II

Solar superheating – detailed simulation over the period of one year



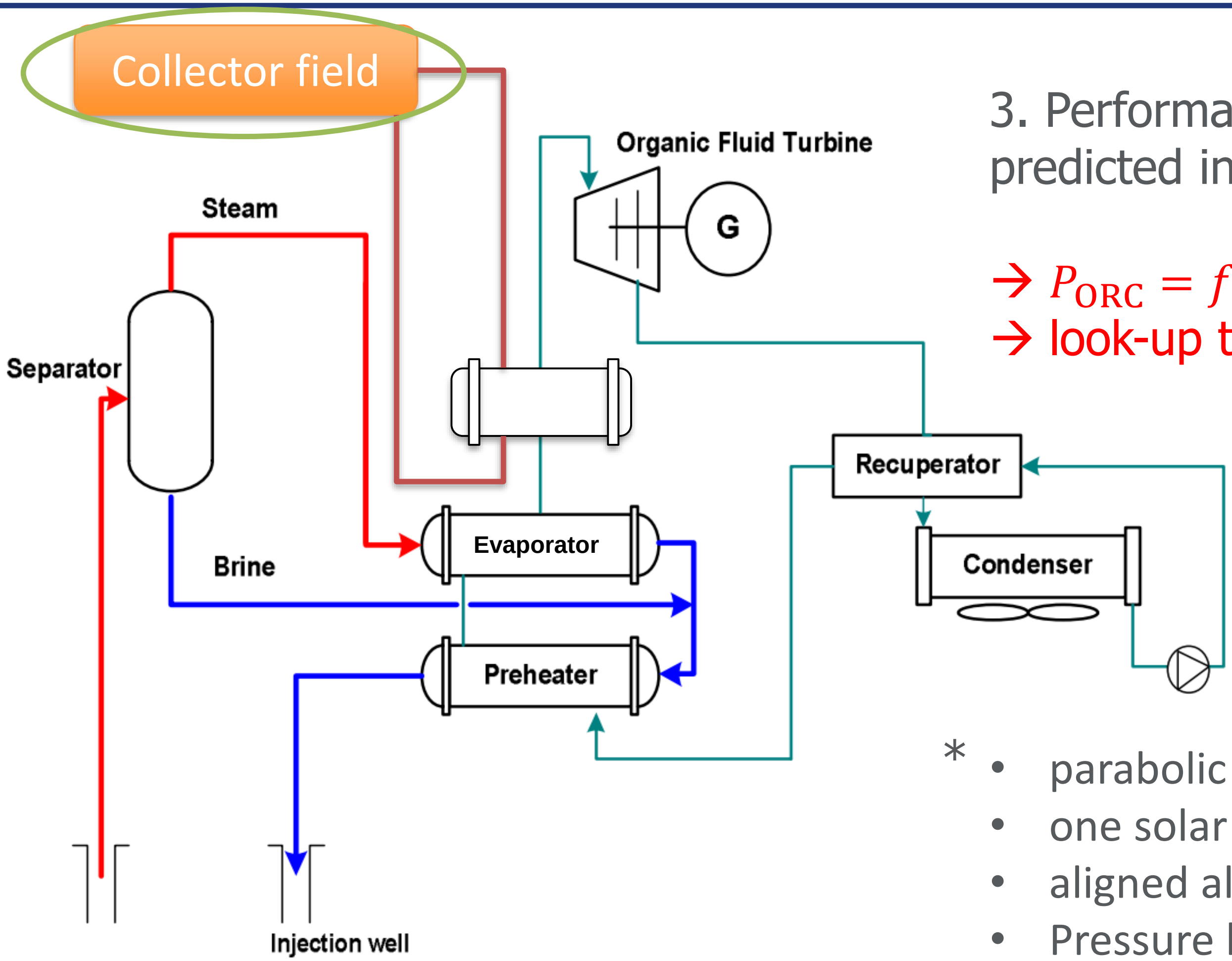
2. Design and operational parameter of the solar superheater* in Matlab

→ $P_{\mathrm{ORC}} = f\,(\vartheta_{\mathrm{a}}, \vartheta_{\mathrm{sf}}, \dot{m}_{\mathrm{sf}})$

* A tube-and-shell HEX is designed according to the method proposed by Kern. Common diameters are obtained from Kakac and Liu

Methods II

Solar superheating – detailed simulation over the period of one year



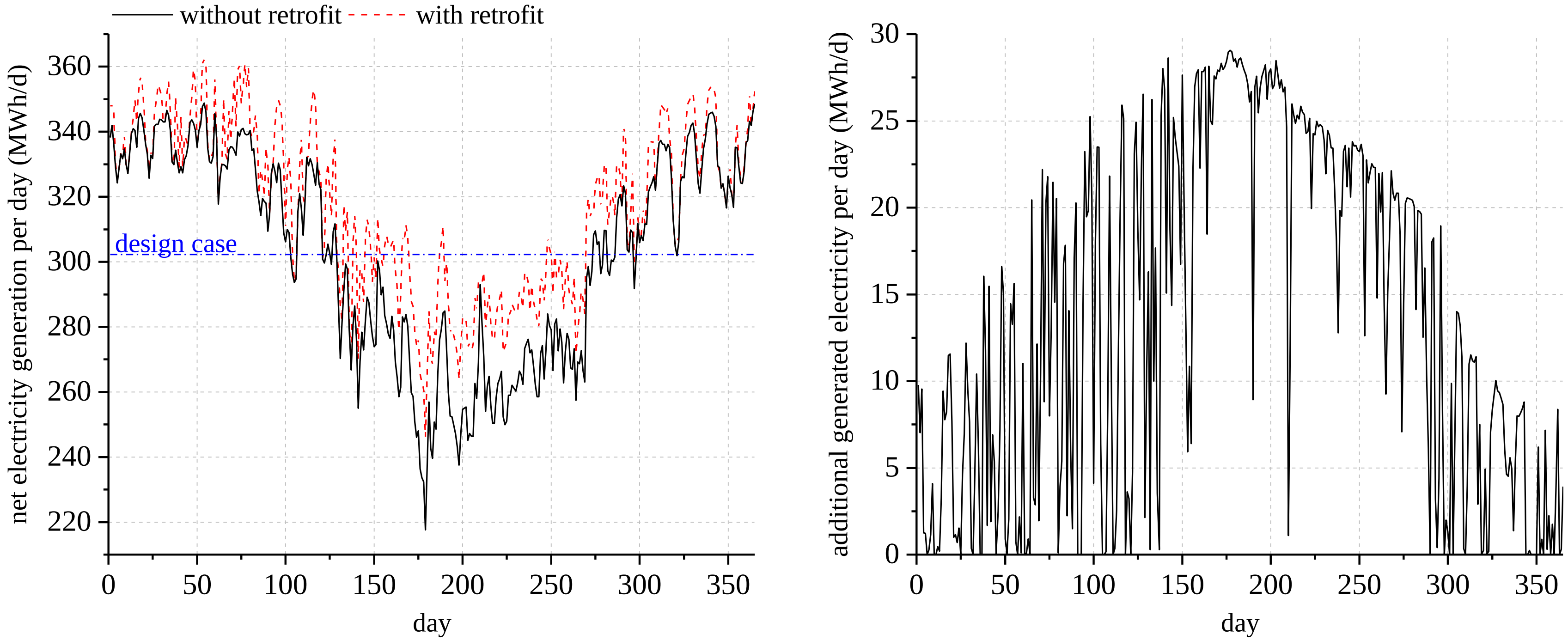
3. Performance of the solar field* is predicted in hourly steps in Matlab

→ $P_{\mathrm{ORC}} = f(\vartheta_{\mathrm{a}}, DNI, \mathrm{date, time})$
→ look-up tables

*
- parabolic trough collectors CF-100
- one solar collector assembly (SCA)
- aligned along the north-south axis
- Pressure losses neglected
- $\dot{Q} = \eta_{\mathrm{opt}} \cdot \eta_{\mathrm{ilo}} \cdot \eta_{\mathrm{slo}} \cdot \eta_{\mathrm{elo}} \cdot \eta_{\mathrm{th,sf}} \cdot A_{\mathrm{eff}} \cdot DNI$

Results II

Simulation over period of one year – (Case 1: 21.6 MW_{th})



→ In the summer, the retrofit provides up to 30 MWh/d additional power

→ During the winter and early spring, the amount of DNI is relatively low

Results II

Simulation over period of one year – Variation of solar field size

Design/performance parameter	**unit**	**value**
Solar thermal power	MW	21.6
Effective area of the collectors	m^2	32340
Inlet temperature of the heat transfer fluid	°C	172.3
Outlet temperature of the heat transfer fluid	°C	200
Mass flow rate of the heat transfer fluid	kg/s	178.4
ORC turbine inlet temperature	°C	163.1
Degree of superheating (ORC)	K	20
Heat transfer area of the solar superheater	m^2	259.5
Additionally generated electricity per year	GWh/a	5.2
Relative increase of the generated electricity	%	4.5
Annual solar insolation to electric efficiency	%	10.5

→ Under technical and thermodynamic cirteria the retrofit is reasonable

Conclusions

Present study

- Superheating is not limited by thermal stability of the ORC working fluid.
- Generator and pump capacity is a constraint for the solar heat input.
- An increase of the annual generated electricity by 5 % is feasible.

Economic aspects

- Economic feasibility is guaranteed with a yearly DIN sum of 2086 kWh/m².
  → 10 % increase compared to the yearly DIN average close to Sulatnhisar
  → For comparison Stillwater, Nevada (USA) yearly ID sum is 2160 kWh/m²
- For details, please see:

  F. Heberle, M. Hofer, N. Ürlings, H. Schröder, T. Anderlohr, D. Brüggemann: *Techno-economic analysis of a solar thermal retrofit for an air-cooled geothermal Organic Rankine Cycle power plant.* Renewable Energy, vol. 113, pp. 494-502, doi:10.1016/j.renene.2017.06.031, June 2017

Outlook

- Improving the model of the solar field

→ Auxiliary power requirements of the solar thermal unit and pressure losses

- Decreasing the uncertainties of the entire model

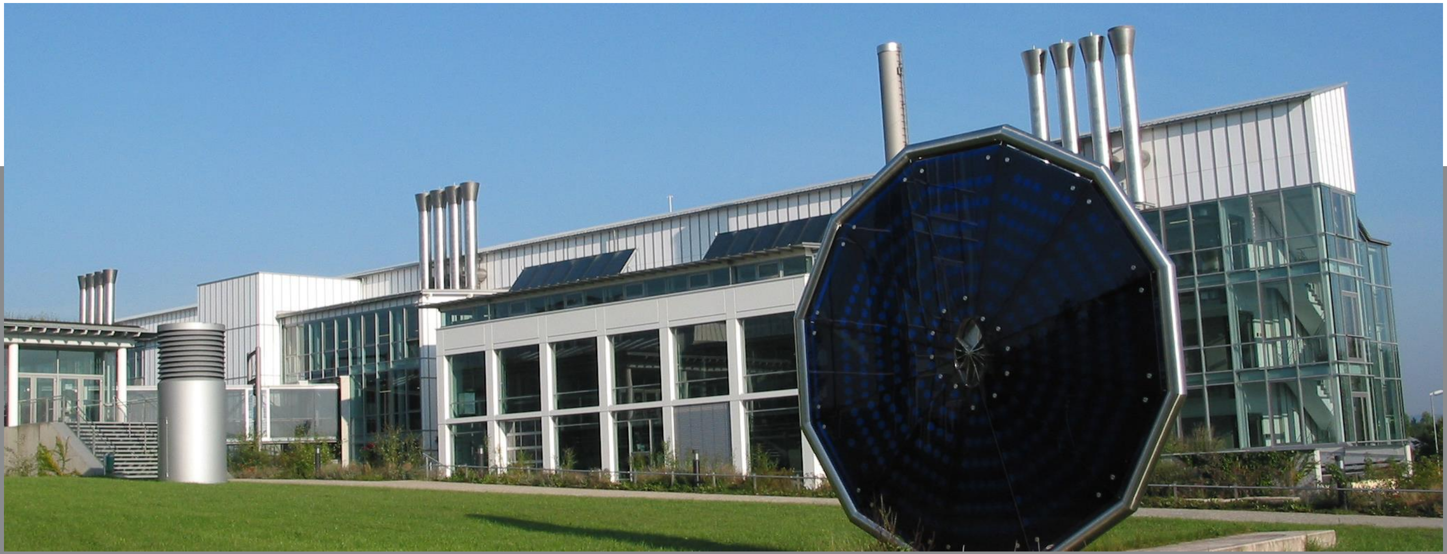
→ Reduction of the simulation step size or even a dynamic simulation

→ Available climate data

- Legal restrictions

→ Feed-in tariffs for hybrid power plants are not clearly defined

→ Land use might be regulated due to extensive agriculture



Thank you

www.zet.uni-bayreuth.de

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