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Enhanced Biomass CHP plants for district heating systems

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Outline

- Background
- Thermodynamic analysis
- Case study
- Comparison of various simulations
- Conclusion

Background

Harbin, China:
Six large AHP with
a total capacity of 225 MW

Datong, China:

Two AHPs were installed for two turbines

One AHP in a central substation

The benefit of the entire installation was

- increased heat recycling of low-grade heat by 1.9 PJ (0.53 TWh) each year
- lower emissions of dust, SO_2, NO_x and CO_2 since coal was used as fuel

Characteristics concerning heat deliveries and net temperature

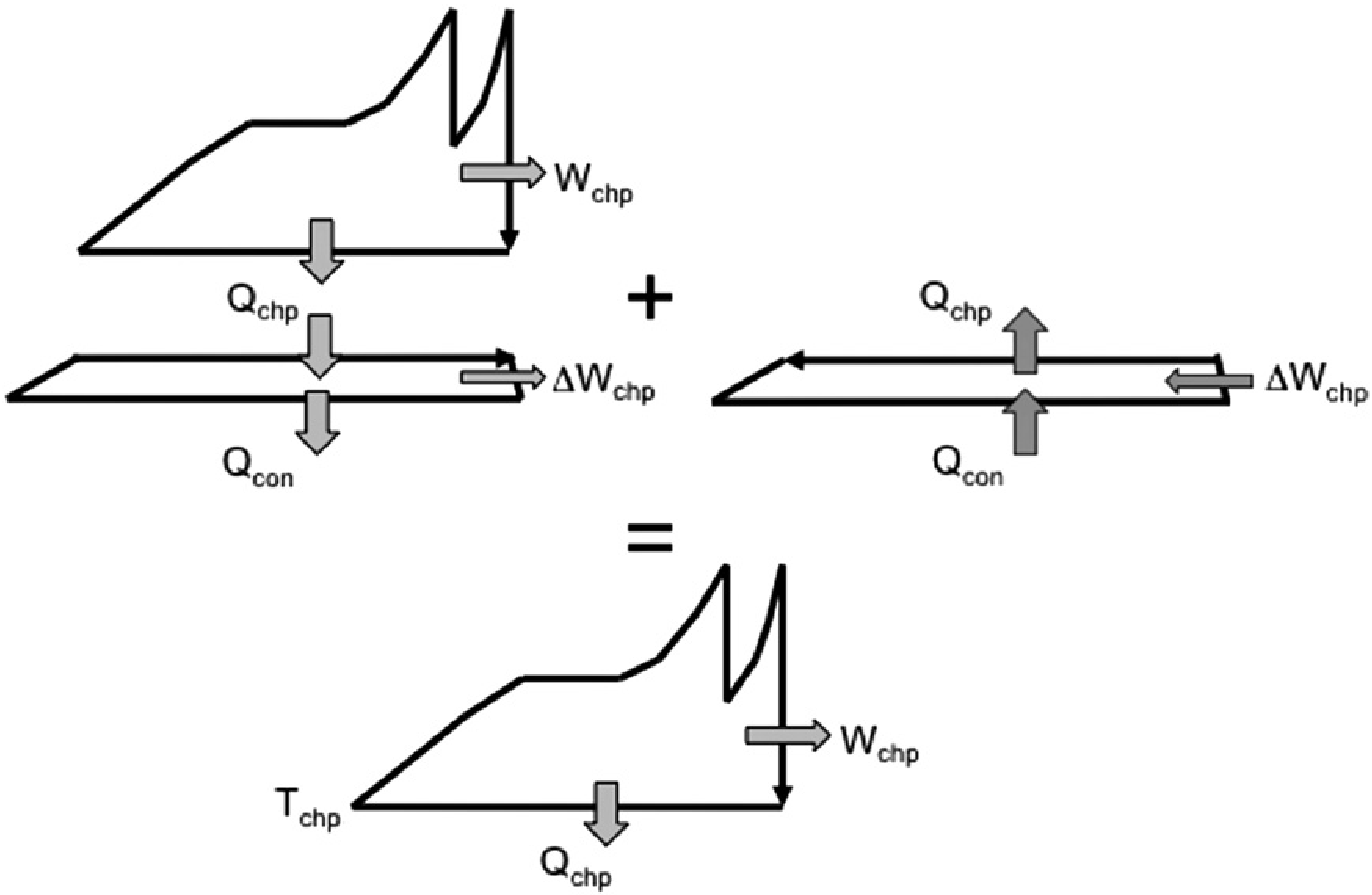
	China	Sweden
DH source share	Coal (91%) Oil products (4.5%) Natural gas (3%) Renewables (1.5%) in 2010 (IEA, 2011)	Biomass and waste (67%) Large heat pumps (10 %) Industrial heat recovery (8%) Fossil fuel (15%) in 2012
DH supply share in 2012	CHP (46%) Boilers (51%) Others (2%)	CHP (41%) Boilers (41 %) External heat (18%)
Annual average from/return temperature [°C]	90-130/60	86/47

Research Questions

- Is this Chinese concept concerning Combined Heat and Power (CHP) plants suitable for typical Swedish conditions with biomass as fuel?
- Will it be a path to transfer 3GDH to 4GDH? (No answer today)

Thermodynamic analysis

CHP vs CHP + Electric HP

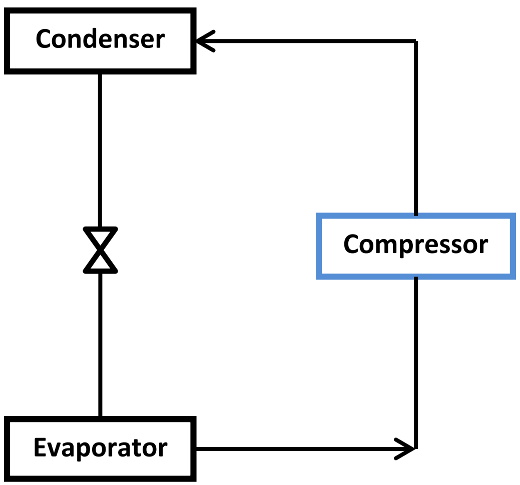


$COP_{reversible}$
$= Q_{chp}/\Delta W_{chp}$
$= T_{chp}/(T_{con}-T_{chp})$

Lowe, R. (2011). Combined heat and power considered as a virtual steam cycle heat pump. *Energy Policy, 39*(9), 5528-5534.

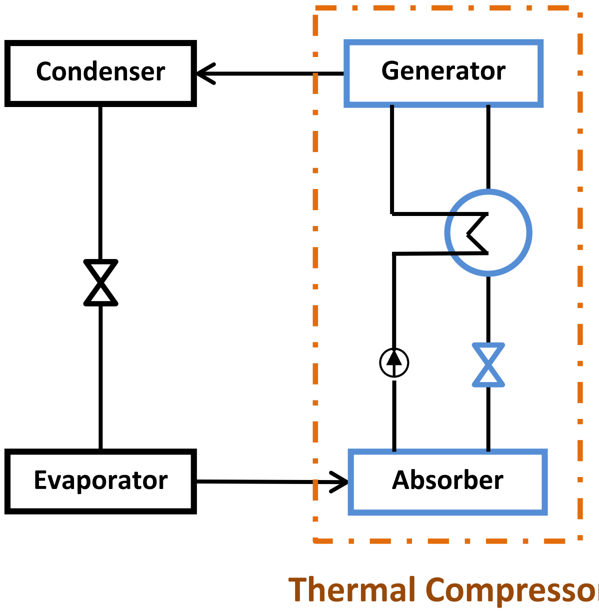
Heat pumps

Electric heat pump



$$\mathrm{COP}_{\mathrm{r,heat}} = \frac{\mathrm{heat}}{\mathrm{electrcity}} = \frac{T_h}{T_h - T_l}$$

Absorption heat pump



$$\mathrm{COP}_{\mathrm{r,heat}} = \frac{\mathrm{heat}}{\mathrm{driven\ heat}} = \frac{T_h}{T_h - T_l} \quad \frac{T_g - T_l}{T_g}$$

Carnot efficiency

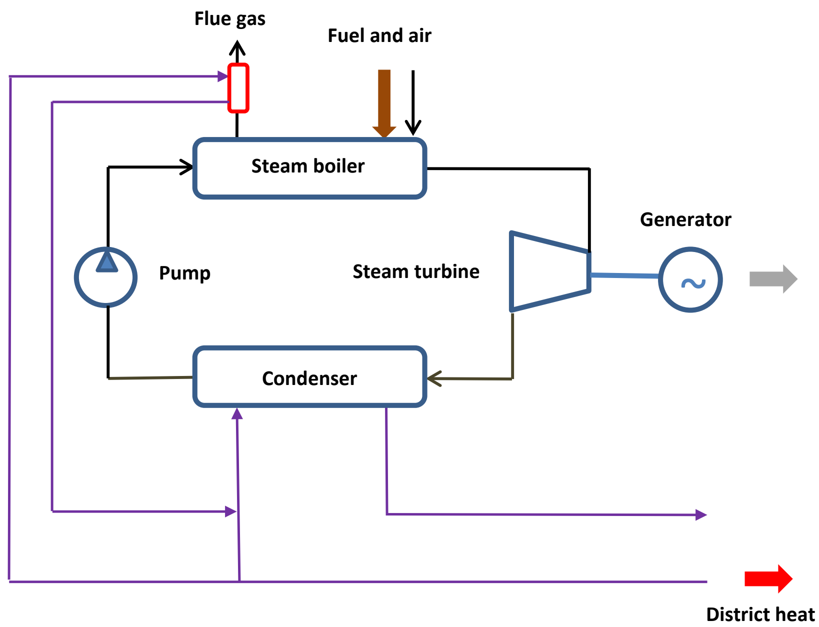
Case Study

The Örtofta CHP plant, outside Lund

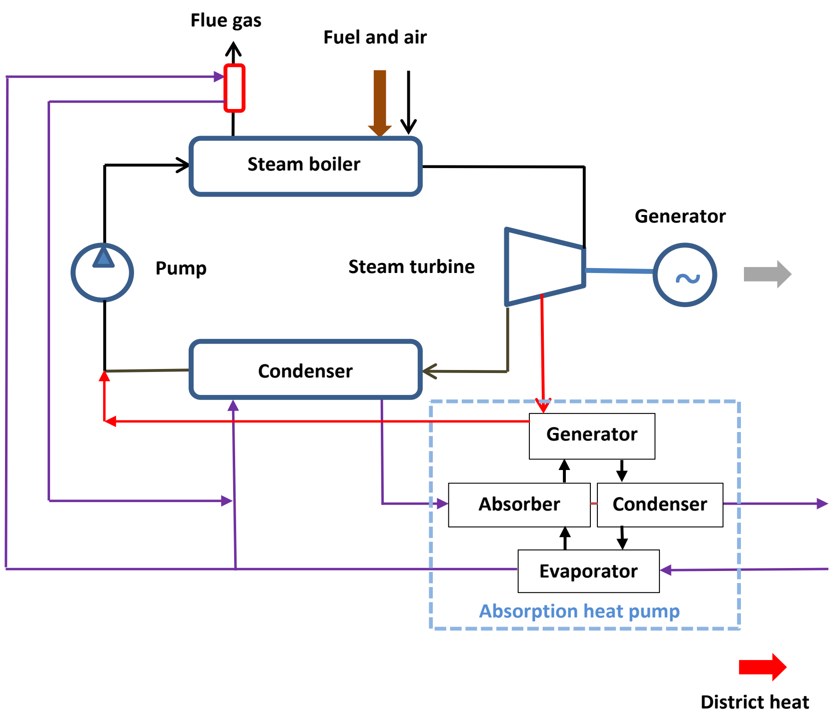
- 38 MW electricity
- 90 MW heat, including 16 MW from the FGC unit
- Biomass fuel input of 123 MW based on LHV.

Ideal

A simple CHP plant without AHP



A simple CHP plant with AHP



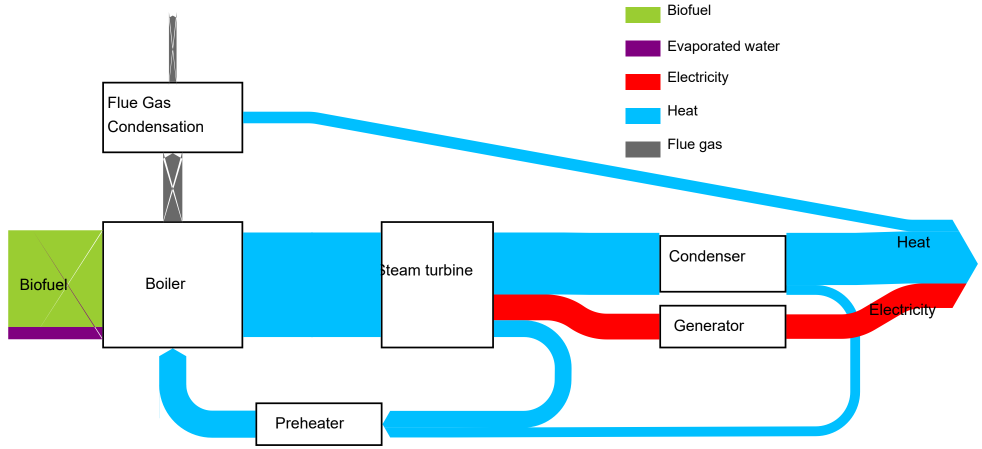
Overview of independent, fixed, and dependent variables in the simulation model

Independent variables	Fixed variables	Dependent variables
• Return temperature after AHP • Return temperature from DH network	• Fuel input: 141 MW in HHV • Conversion efficiency of boiler: 91.78% • Steam to turbine: 540 ^{o}C, 11.1 MPa, and 44 kg/s • Isentropic efficiency of turbine: 86.5% • Conversion efficiency of generator: 95% • Number of Thermal Units (NTU) of turbine condenser: 2.1 • Feed water pumping • Preheaters before boiler • DH mass flow of 532.1 kg/s • COP for AHP: 0.7	• Steam flow to AHP • Steam flow to condenser • Steam temperature in condenser • Steam flow to feed water tank • Electricity generated • Heat generated in FGC • Heat generated in condenser • Heat generated in AHP • Supply temperature to DH network

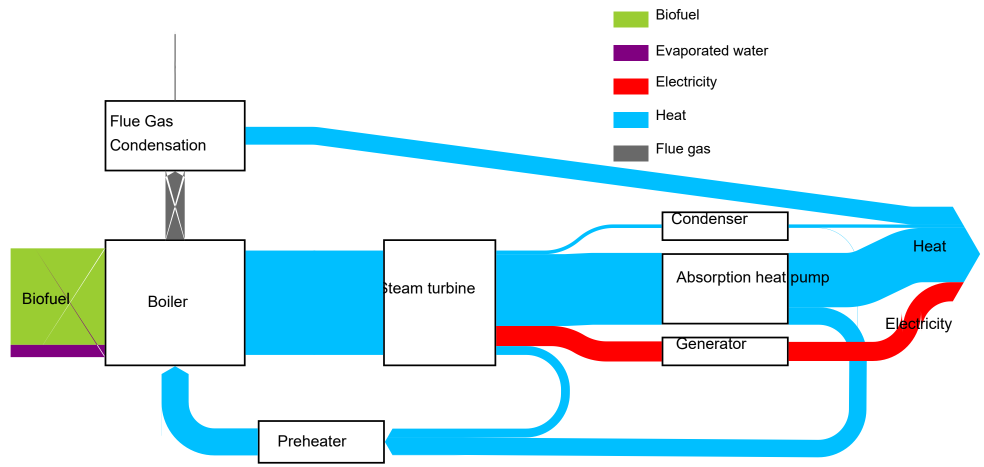
Overview of key parameters for the simulated case in the CHP plant

	Ref.	3GDH+AHP						4GDH		
DH circle										
Return temperature after AHP [ºC]	50	45	40	35	30	25	23.6	30	25	20
Supply temperature after condenser [ºC]	91.4	80.6	69.9	59.3	48.9	38.6	35.1	73.9	69.1	64.2
Supply temperature to DH network [ºC]	91.4	92.7	94.1	95.7	97.4	99.3	99.2	73.9	69.1	64.2
Steam circle										
Steam flow to AHP [kg/s]	-	7.5	14.9	22.4	29.9	37.4	39.4	-	-	-
Steam flow to condenser [kg/s]	35.6	28.4	21.5	14.9	8.5	2.3	-	34.5	34.2	33.9
Steam flow to feed water tank [kg/s]	4.5	4.2	3.6	2.8	1.7	0.4	-	5.5	5.8	6.1
Steam temperature in condenser [ºC]	96.2	84.4	72.7	61.3	50	38.9	-	78.5	73.7	68.7
Output										
Electricity generated [MW]	35.7	35.4	34.4	32.9	30.7	27.9	26.7	38.2	38.9	39.5
Heat generated in FGC [MW]	16.9	19.3	21.5	23.3	24.8	26.0	26.3	24.8	26.0	27.0
Heat generated in condenser [MW]	76.1	60.5	45.7	31.4	17.8	4.9	-	73.5	72.8	72.1
Heat generated in AHP [MW]		15.9	31.8	47.7	63.5	79.4	83.8	-	-	-
Total Heat generated [MW]	93	95.7	99	102.4	106.1	110.3	110.1	98.3	98.8	99.1

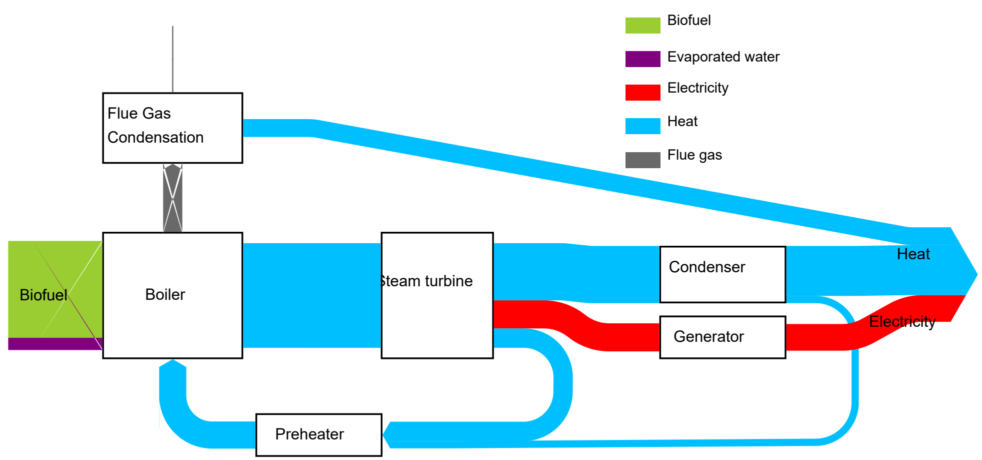
Sankey diagrams



Reference case

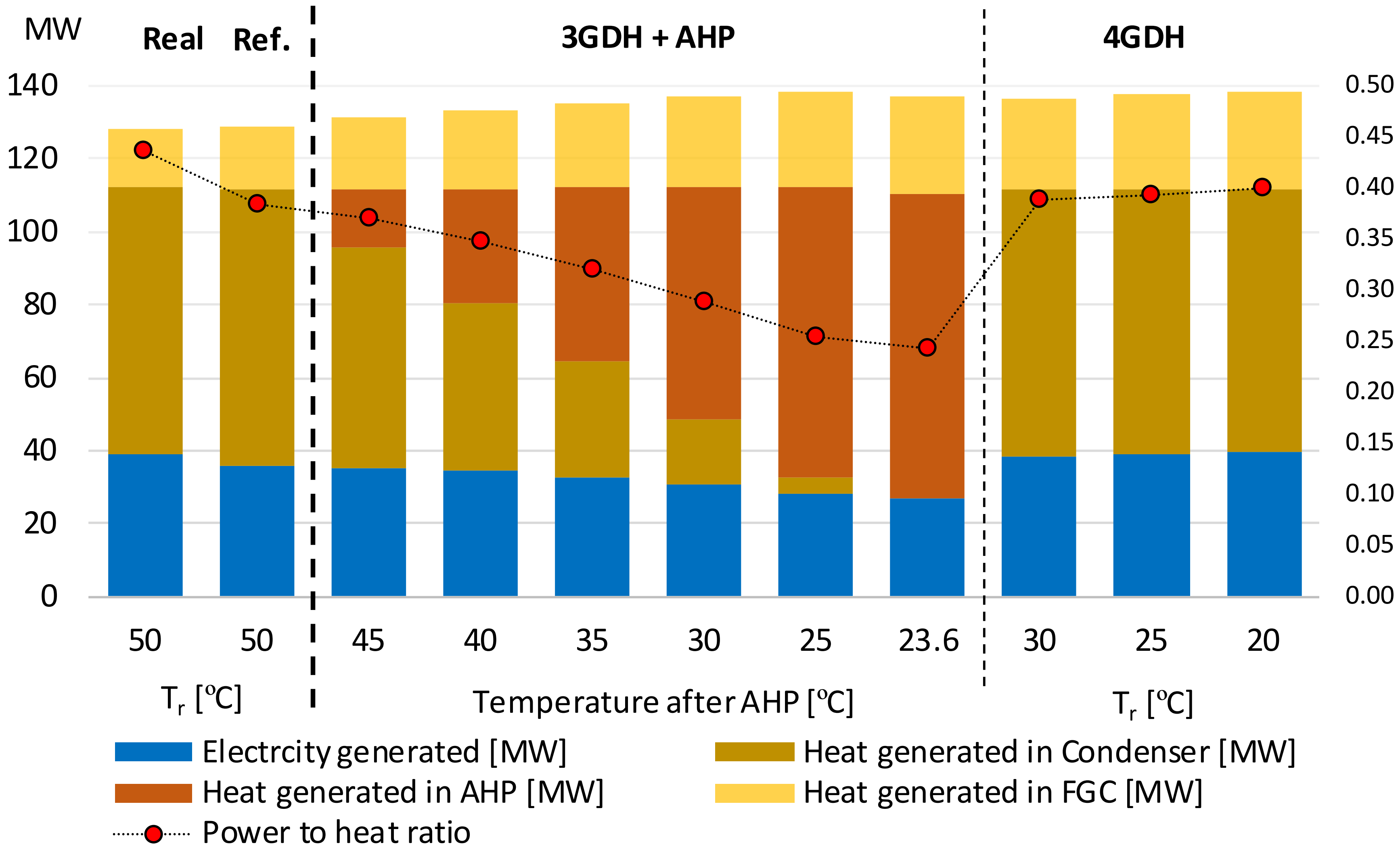


3GDH+AHP



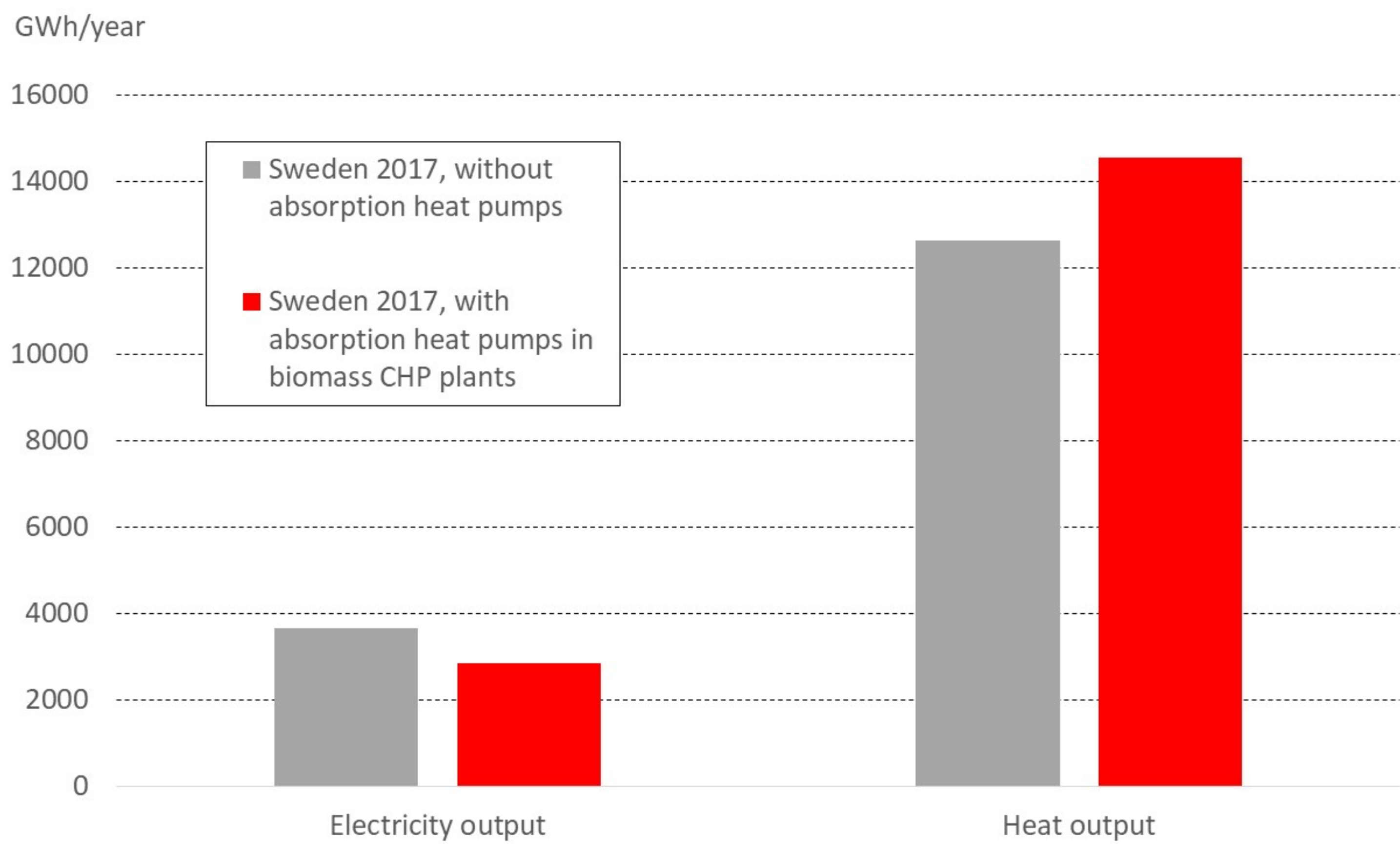
4GDH

Results

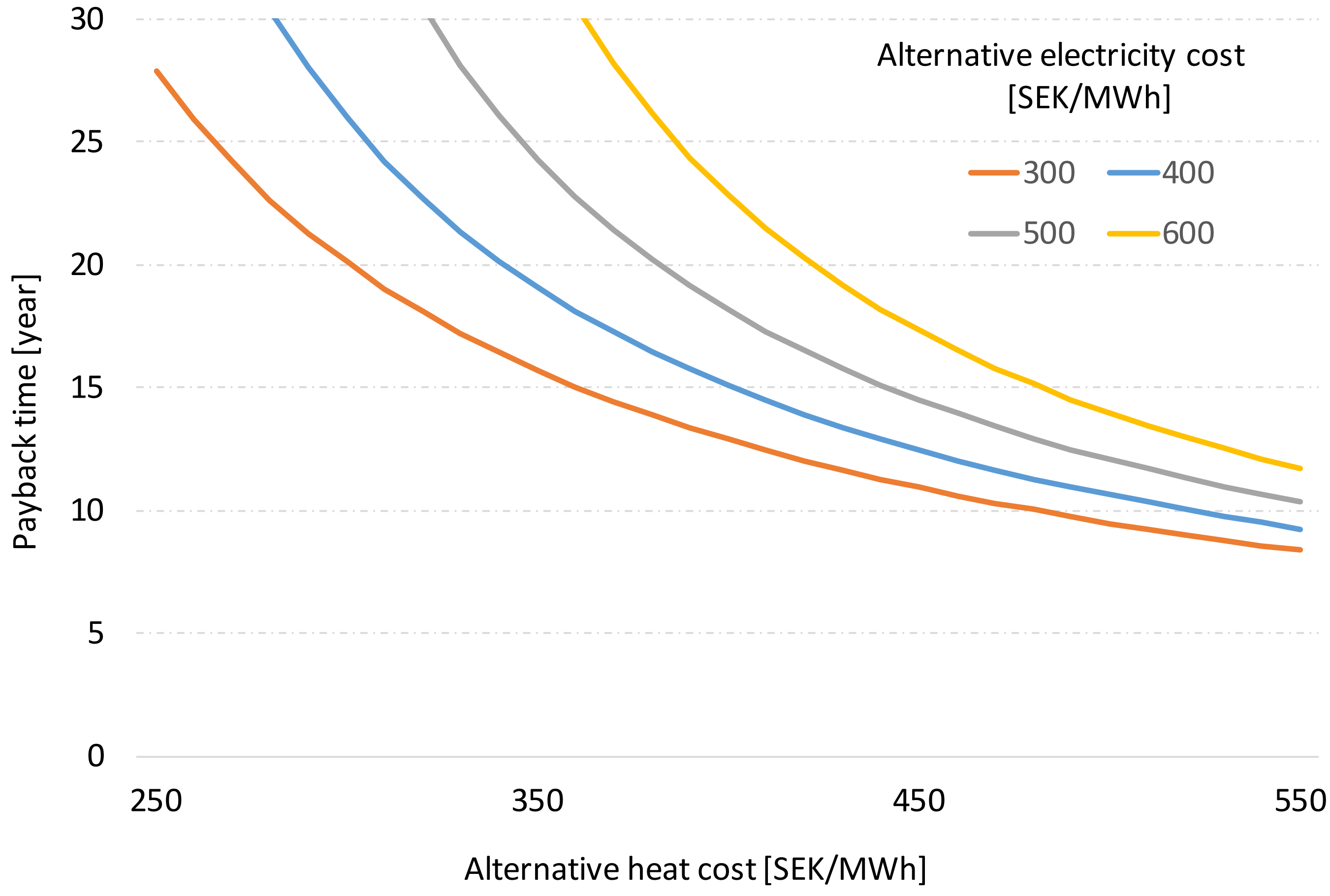


MW
Real
Ref.
3GDH + AHP
4GDH
140
120
100
80
60
40
20
0
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
50
50
45
40
35
30
25
23.6
30
25
20
T_r [ºC]
Temperature after AHP [ºC]
T_r [ºC]
Electrcity generated [MW]
Heat generated in Condenser [MW]
Heat generated in AHP [MW]
Heat generated in FGC [MW]
Power to heat ratio

Estimation of the electricity and the heat outputs



Payback times versus alternative heat and electricity costs



Conclusions

- It is less suitable for the Swedish context with biomass back-pressure CHP plants.
- The Chinese context with utilization of existing condensation turbines is still interesting, since condenser heat can be recycled without major modification of existing turbines.
- However, we intend to repeat the analysis for a modified system solution.

Questions?