A Program for first Estimation of Power Output, Costs and Profit of Geothermal Heat and Power Plants

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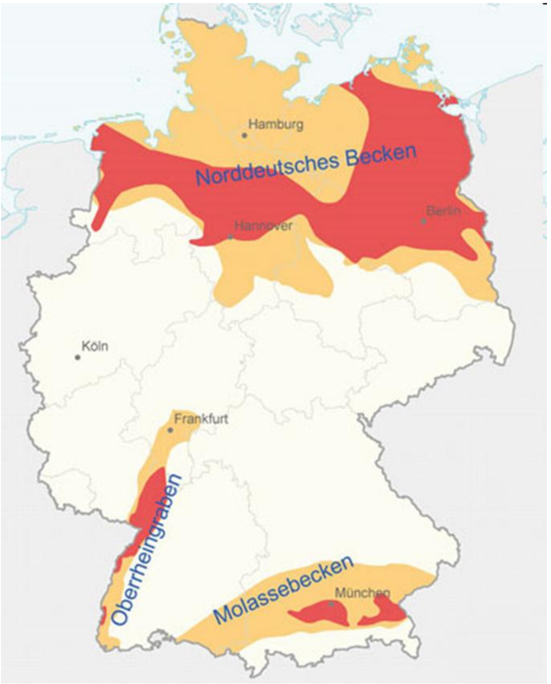
Motivation



- About 100 Geothermal heat and power projects are planned in Germany within the next years
- Investors and communities need a first estimation, if a new project will be profitable
- A program was developed, which gives a first estimation of profit with only a few, generally known input parameters

Program Overview

- Definition of simple input parameters
- Calculation of thermodynamic quantities
- Estimation of costs
- Estimation of earnings
- Calculation of amortization time

Input Data (1)

- Should be easily availabe for new locations
- Only a few values
  - Thermal water
    - Mass flow
    - Inlet and outlet temperatures
  - District Heating
    - Number of inhabitants of community
    - Length of waste water grid of community
    - Area and length/width ratio of community
  - Power plant
    - Some standard values for component efficiencies and cooling

Input Data (2)

- Example of input data

Sorry, but program description and figures currently only available in German

Thermalwasser	Massenstrom	m_B	150	kg/s
Förderbohrung	Temperatur	T_B1	150	°C
	Geschätzter Betriebsdruck =1,2*ps(T_B1)	p_B	5,7	bar
	Spez. Enthalpie	h_B1	632	kJ/kg
	Dichte	rho_B1	917,1	kg/m3
	Volumenstrom	V_B1	164	l/s
Injektionsbohrung	Temperatur	T_B3	60	°C
	Spez. Enthalpie	h_B3	252	kJ/kg
	Zur Verfügung stehender Wärmestrom	Q_B	57.104	kW

Heizwerk	Einwohner Kommune	EW	20.000	Personen
	Anschlußgrad	AG	50	%
	Gleichzeitigkeitsfaktor	GF	50	%
	Wärmemenge pro Person und Jahr	Q_P	34	MWh/a/Pers
	Wärmestrom maximal	Q_HWm	76.484	kW
	Benötigter Wärmestrom für Nahwärmenetz	Q_HW	19.121	kW
	länge Abwassernetz berichtigt		62.000	m
	Verhältnis Länge/Breite		1,18	
	Fläche der Gemeinde		24.590.000	m2

Kraftwerk	Wärmestrom ins Kraftwerk	Q_KW	37.983	kW
	Isentroper Wirkungsgrad Pumpe	etas_P	80	%
	Isentroper Wirkungsgrad Turbine	etas_T	80	%
	Min. Temperaturdifferenz Wärmezufuhr	DTmin_zu	5	°C
	Min. Temperaturdifferenz Wärmeabfuhr	DTmin_ab	7	°C
Kühlwasser	Betriebsdruck	p_K	2,0	bar
	Temperatur Kühlwassereintritt	T_K1	15	°C
	Spez. Enthalpie Kühlwassereintritt	h_K1	63	kJ/kg
	Temperatur Kühlwasseraustritt	T_K3	20	°C
	Spez. Enthalpie Kühlwasseraustritt	h_K3	84	kJ/kg
Reihenschaltung	Spez. Enthalpie Thermalwasser Austritt KW	h_KW	379	kJ/kg
	Temperatur Thermalwasser Austritt KW	T_KW	90	°C
Parallelschaltung	Massenstrom Thermalwasser KW	m_KW	100	kg/s
	Massenstrom Thermalwasser HW	m_HW	50	kg/s

Thermodynamics (1)

- Calculation of heat transfer rates
  - Available heat from thermal water

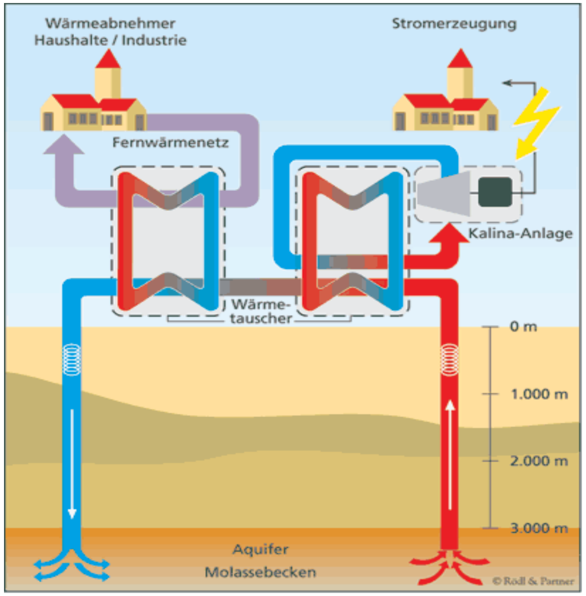
$$\dot{Q}_B = \dot{m}_B \cdot (h_{B1} - h_{B3})$$

  - Needed heat for district heating

$$\dot{Q}_{HW} = AG * GF * EW * \dot{Q}_P$$

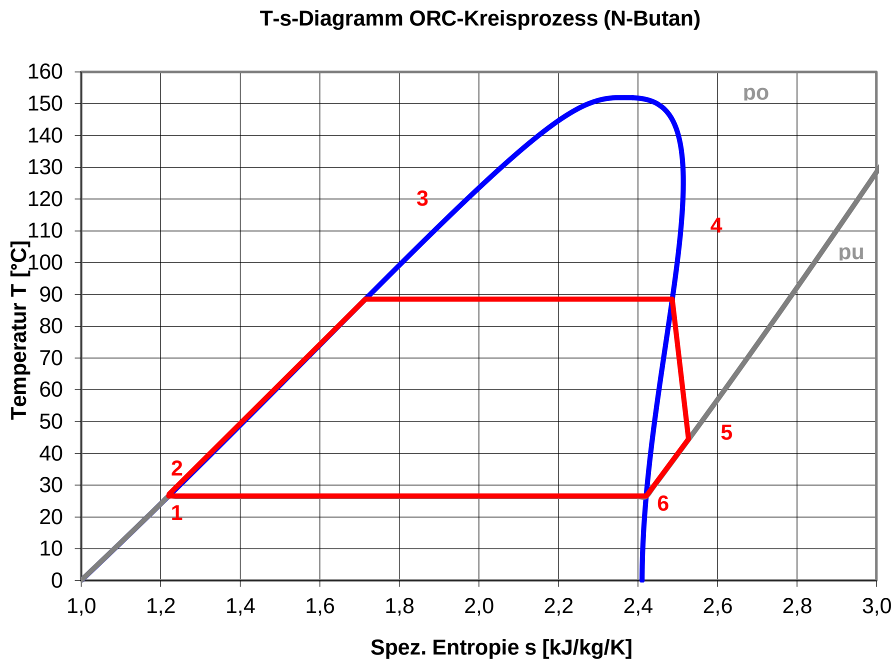
  - Available heat for power generation

$$\dot{Q}_{KW} = \dot{Q}_B - \dot{Q}_{HW}$$



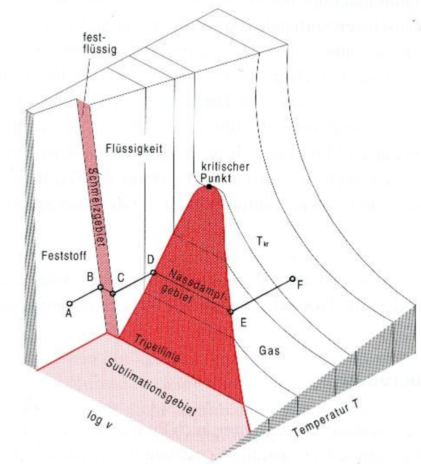
Thermodynamics (2)

- Calculation of power cycles
  - Organic Rankine cycle with various organic fluids
  - Kalina cycle



Thermodynamics (3)

- Power cycle with real fluid quantities (h,v,s)
  - FluidEXL Graphics libraries are used [1]
  - Currently available fluid libraries
    - N- and Iso-Butan
    - Propan
    - R134a
    - Water and air
    - Ammonia-Water mixture
    - Water-Lithiumbromid mixture

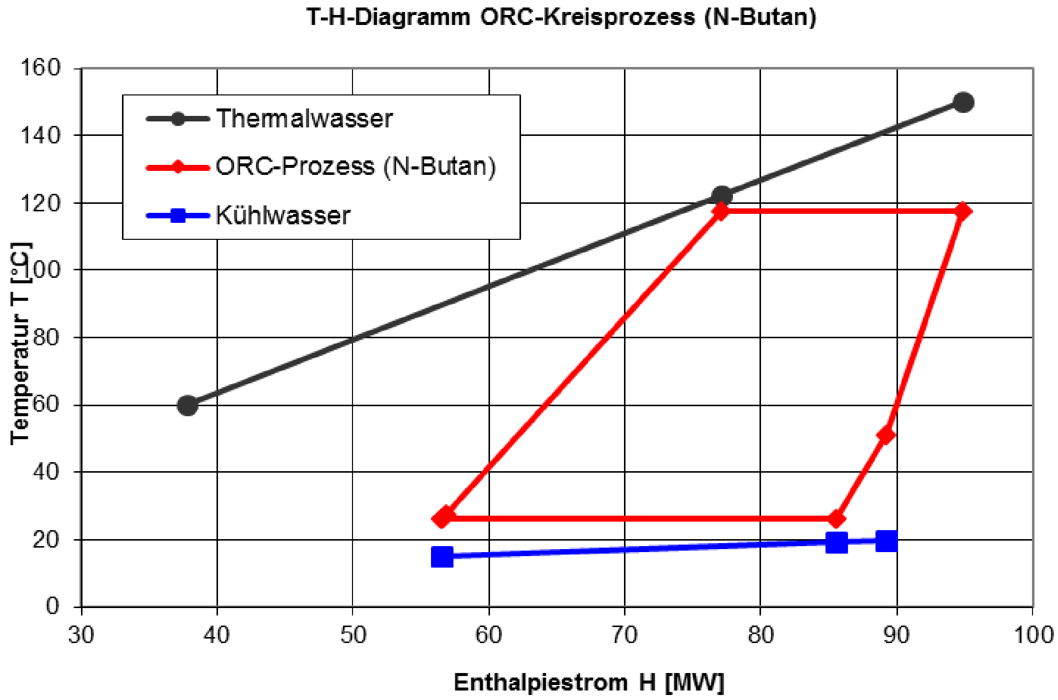


  - Other fluid libraries can be easily implemented if an Excel add-in is available

[1] FluidEXL Graphics, H.-J. Kretzschmar, Hochschule Zittau/Görlitz Germany, http://thermodynamics.hs-zigr.de

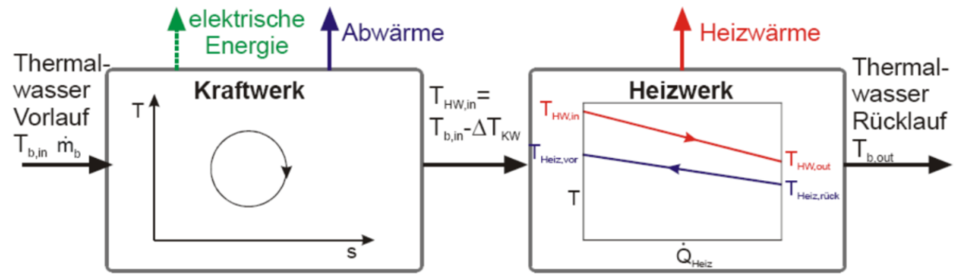
Thermodynamics (4)

- Optimization of power cycle
  - Cycle is automatically optimized to given temperature levels of thermal water and cooling water/air

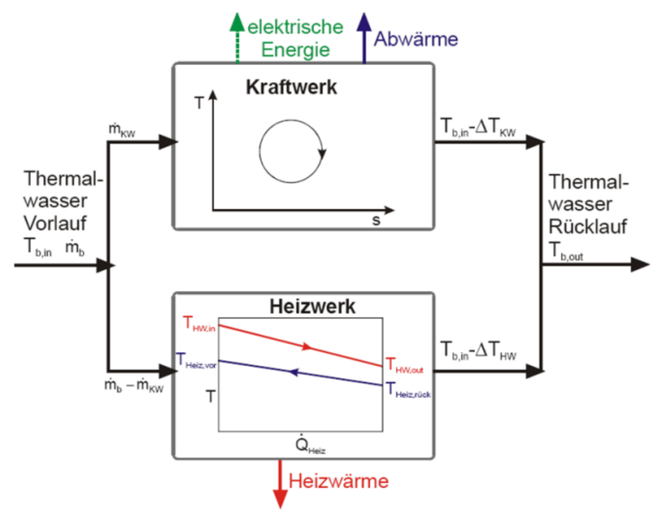


Thermodynamics (5)

- Two operation modes for coupling of heat and power station are implemented
  - Serial Mode

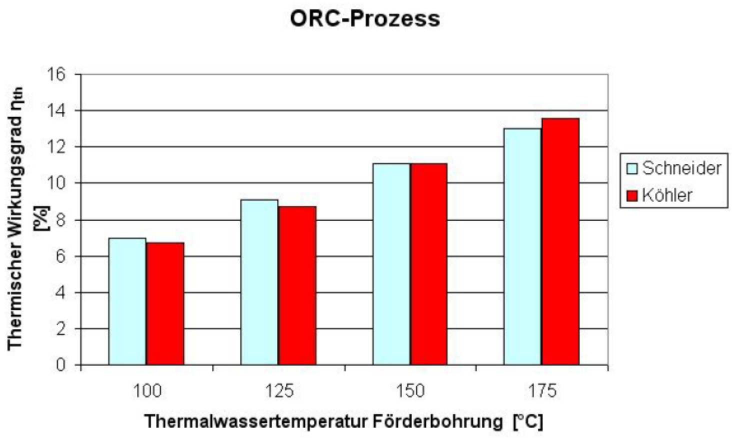


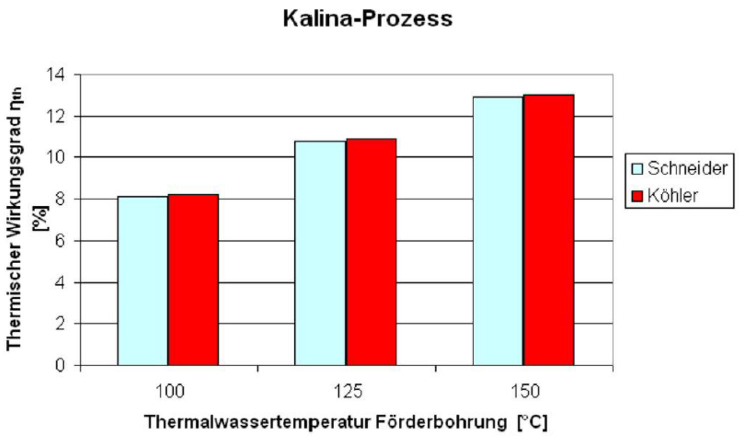
  - Parallel mode



Thermodynamics (6)

- Validation of power cycles
  - Done for ORC-Process with N-Butane and Kalina-Process KCS34
  - Comparison to results from literature i.e. [2]
  - Agreement is very good for Kalina and ORC at 150°C (for ORC at 100, 125, 175°C Köhler used different fluids)





[2] Köhler Silke, Geothermisch angetriebene Dampfkraftprozesse, Dissertation am GeoForschungszentrum Potsdam, 2006

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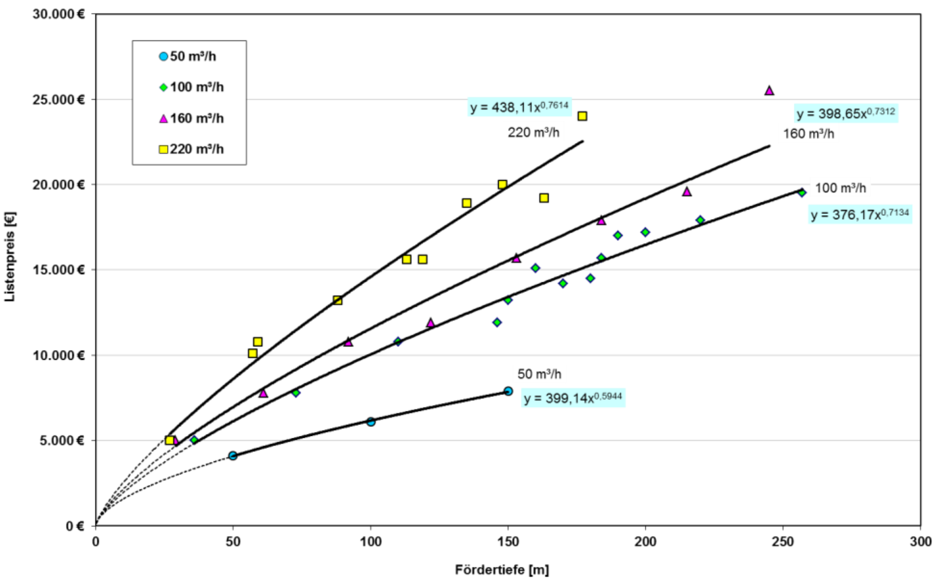
Investment Costs (1)

- Investment costs C_I are estimated from thermodynmic quantities X_I via cost functions [3]

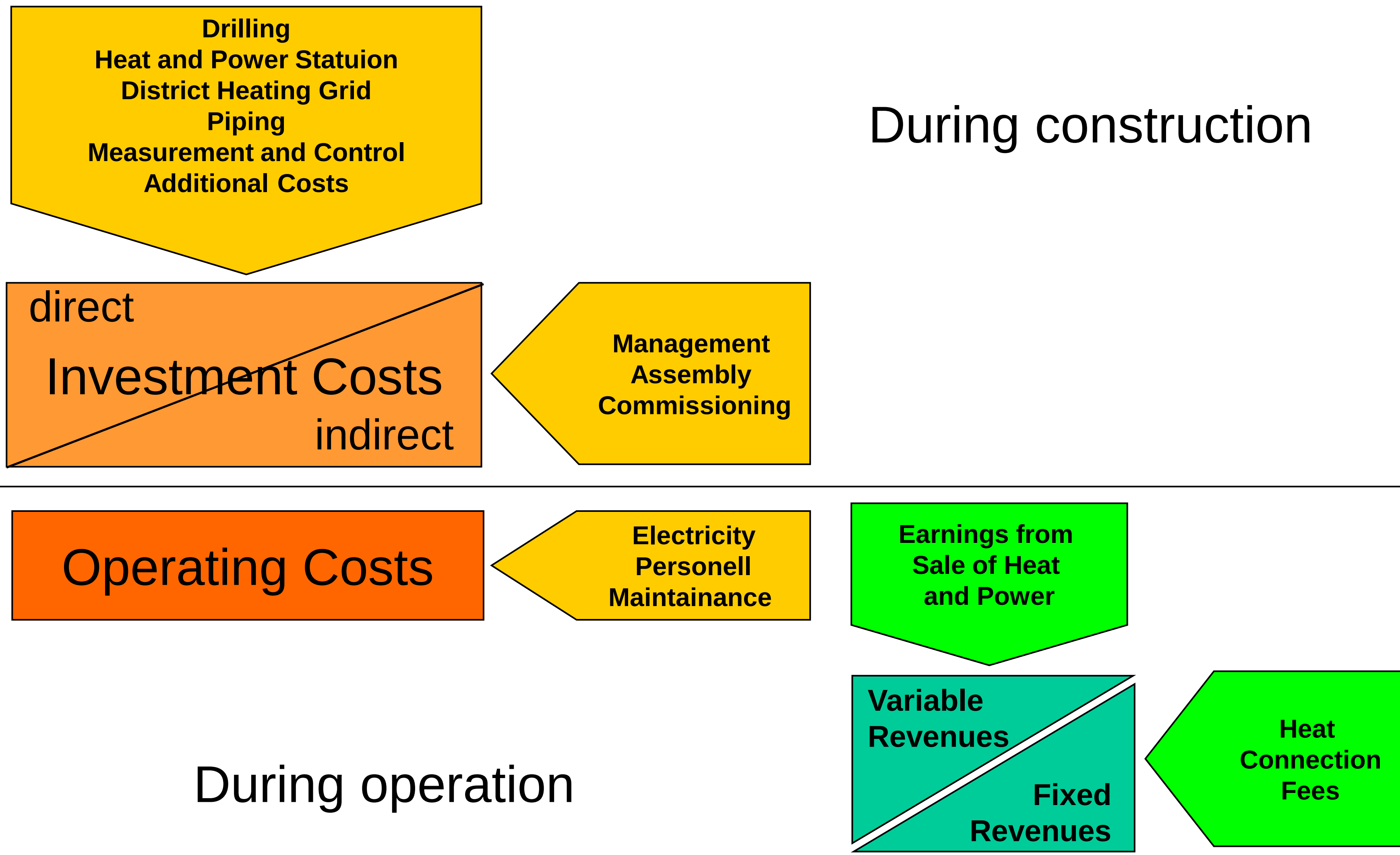
$$C_I = C_O \cdot \left(\frac{X_I}{X_O}\right)^{\alpha}$$

- Coefficients C_O, X_O, α are evaluated from literature or existing projects via curve fits



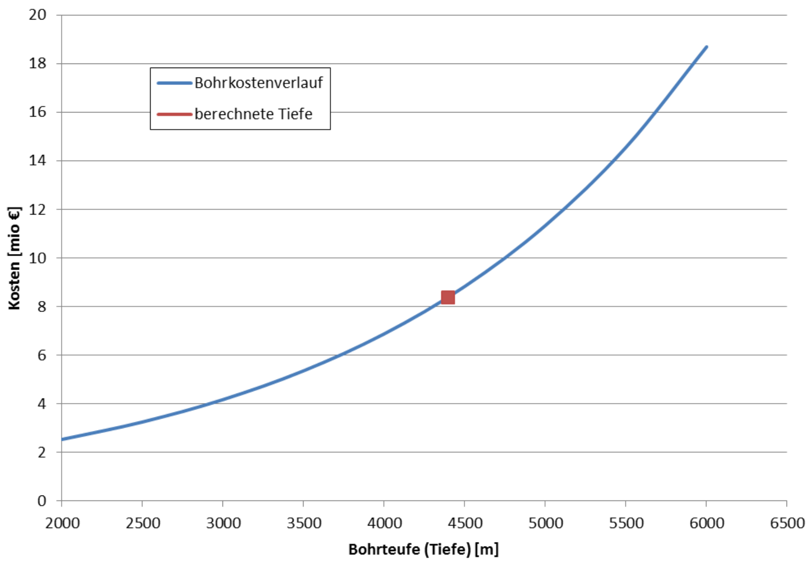
[3] Bejan, Tsarsaronis, Moran, Thermal Design & Optimization, Wiley&Sons

Investment Costs (2)



Investment Costs (3)

- Drilling costs
  - Curve fit from existing geothermal projects
  - Costs as function of drilling depth



- Inflation rate is taken into account for all costs

Investment Costs (4)

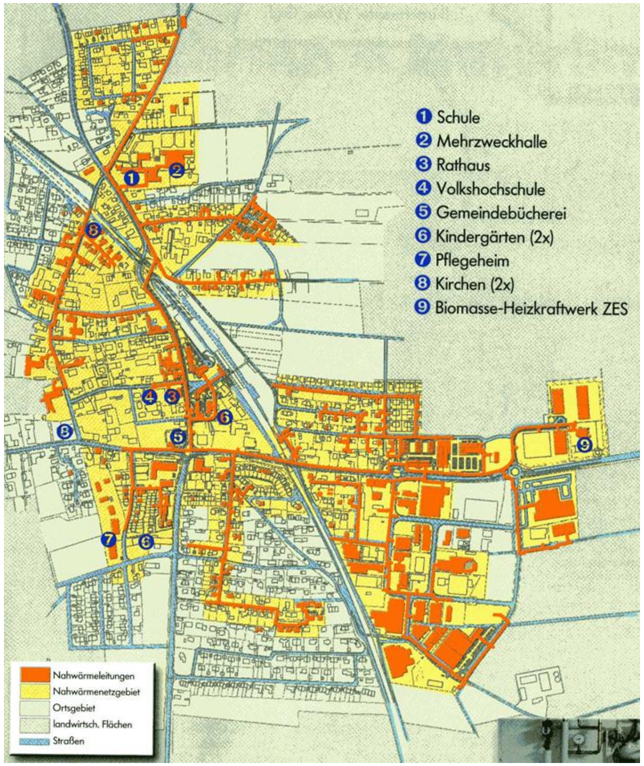
- Components of heat and power station
  - Direct Costs for components
    - Heat exchangers
    - Pumps
    - Turbine

      C_C
    - Piping $0.66 * C_C$
    - Measurement and Control $0.1 * C_C$
    - Miscellaneous $0.2 * C_C$

      C_D
  - Indirect costs
    - Management $0.8 * C_D$
    - Assemly $0.15 * C_D$
    - Commissioning

Investment Costs (5)

- District heating grid
  - Data used from 14 existing district heating grids to define simple input parameters and cost functions
  - Calculation of heating pipe length from length of waste water grid
  - Calculation of costs from
    - Number of connected people
    - Shape of the Community (area, length/width ratio)



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Earnings

- From sale of heat
  - Typically 2000 to 4000 OH/year
  - Typically ~40 €/MWh

- From sale of renewable electricity
  - Typically 8000 OH/year
  - Currently ~220 €/MWh in Germany due to EEG

Amortisation Time (1)

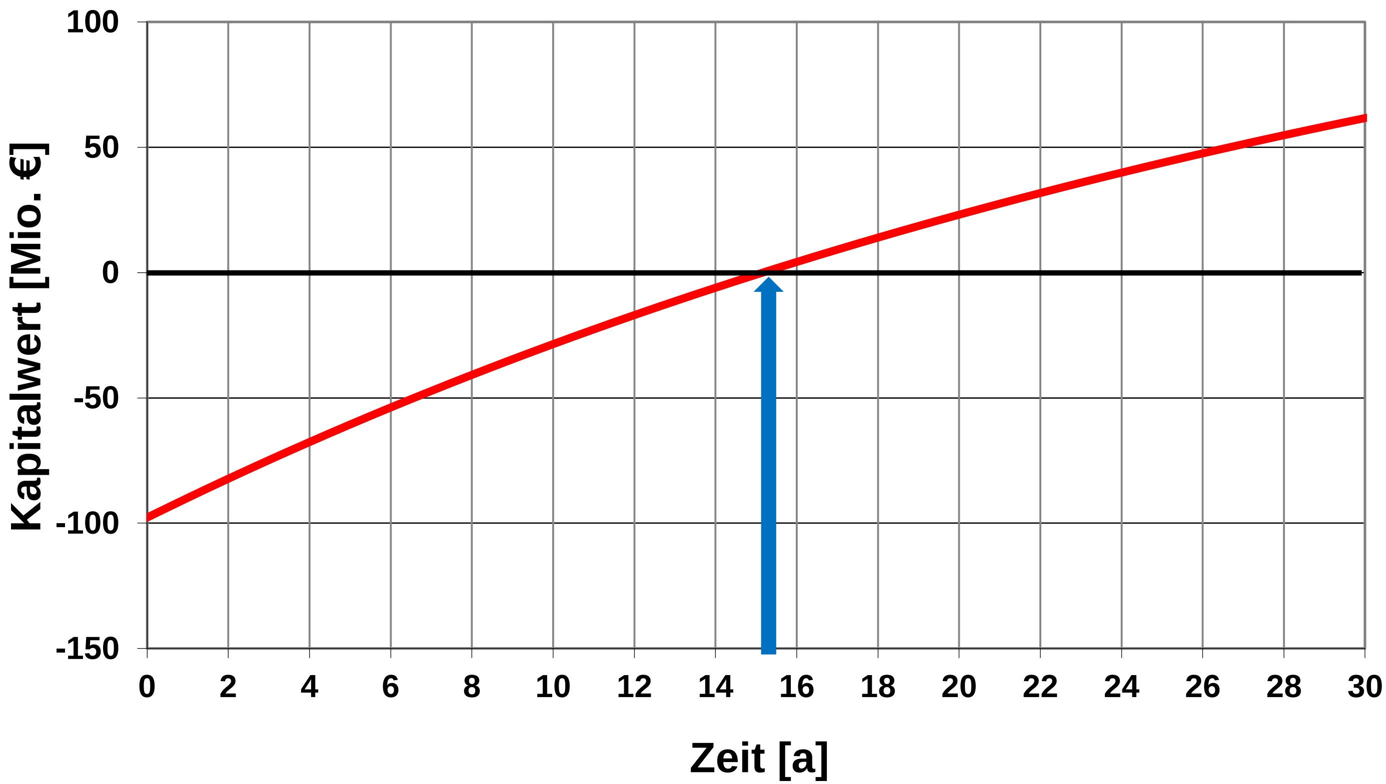
- Net present value method is used

$$K_0 = \sum_{t=1}^{n} \underbrace{\left(I_n - E_n\right)}_{\text{Income - Expenses}} * \underbrace{\frac{1}{q^n}}_{\text{Discount Factor}}$$

  - $K_0 > 0$ Profitable
  - $K_0 \leq 0$ Nonprofitable

Amortisation Time (2)

- Example: Profitable $(K_0 > 0)$ after 16 years



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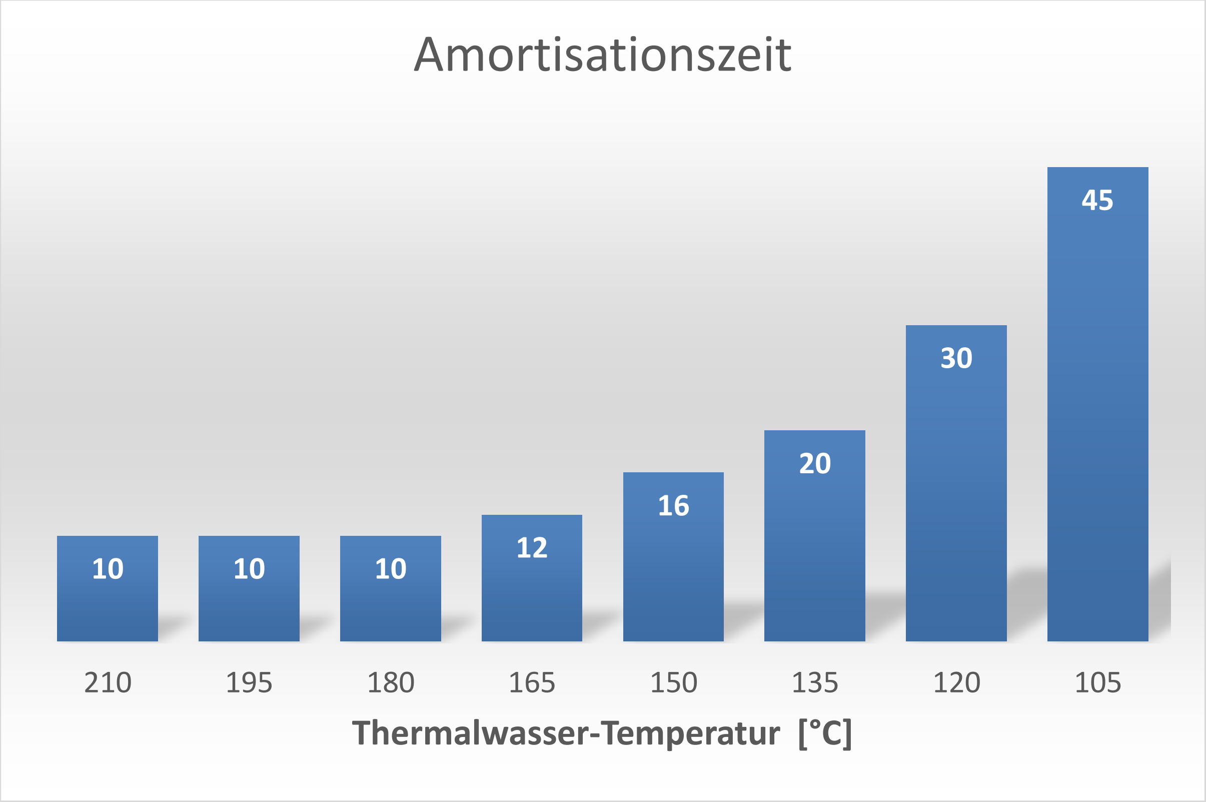
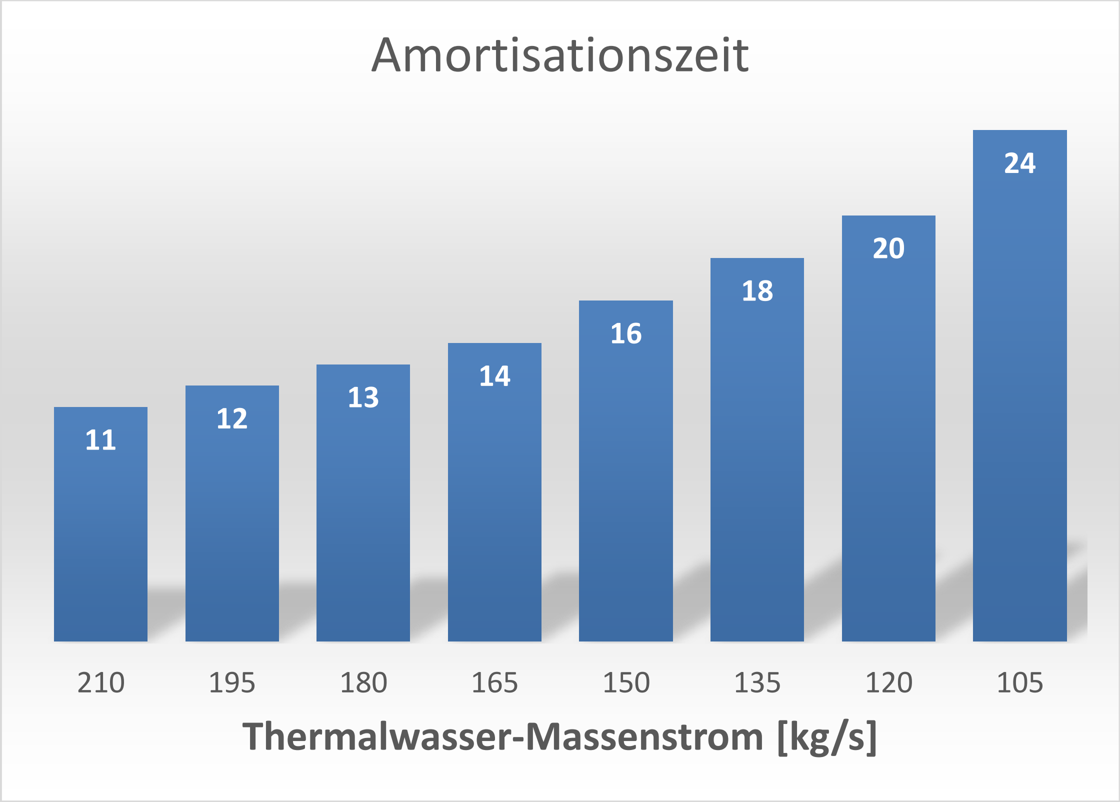
Sensitivity Analysis (1)

- Amortisation time versus thermal water temperature



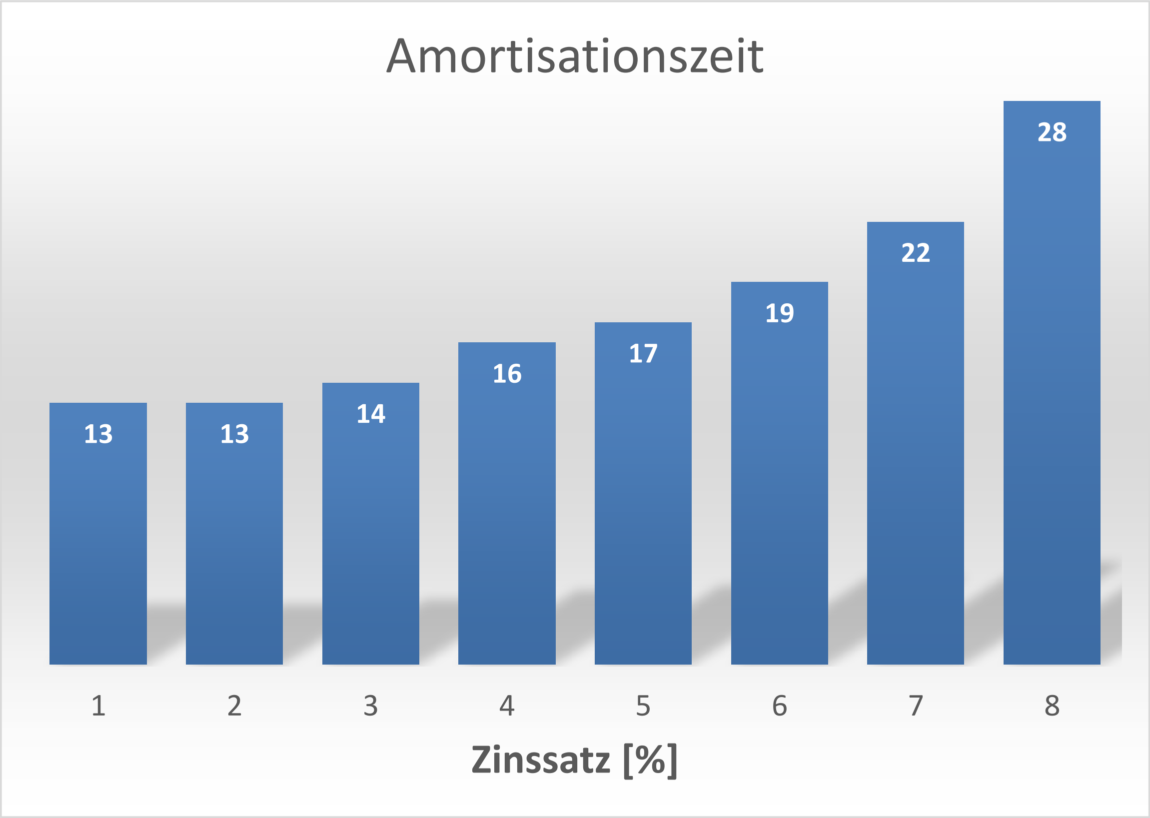
Sensitivity Analysis (2)

- Amortisation time versus thermal water mass flow



Sensitivity Analysis (3)

- Amortisation time versus interest rate



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Conclusions

- Excel programs were developed for easy and fast estimation of amortisation times for geothermal projects (ORC, Kalina, heat pumps)
- They can be used for a first estimation at new locations with only a few available input data
- Data from a few existing projects are used for cost functions
- More validation data are needed for component costs of real geothermal projects!

Acknowledgement

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  - Mr. Jens Junkerdorf (Diploma thesis 2007)
  - Mr. Jens Reichert (Diploma thesis 2008)
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