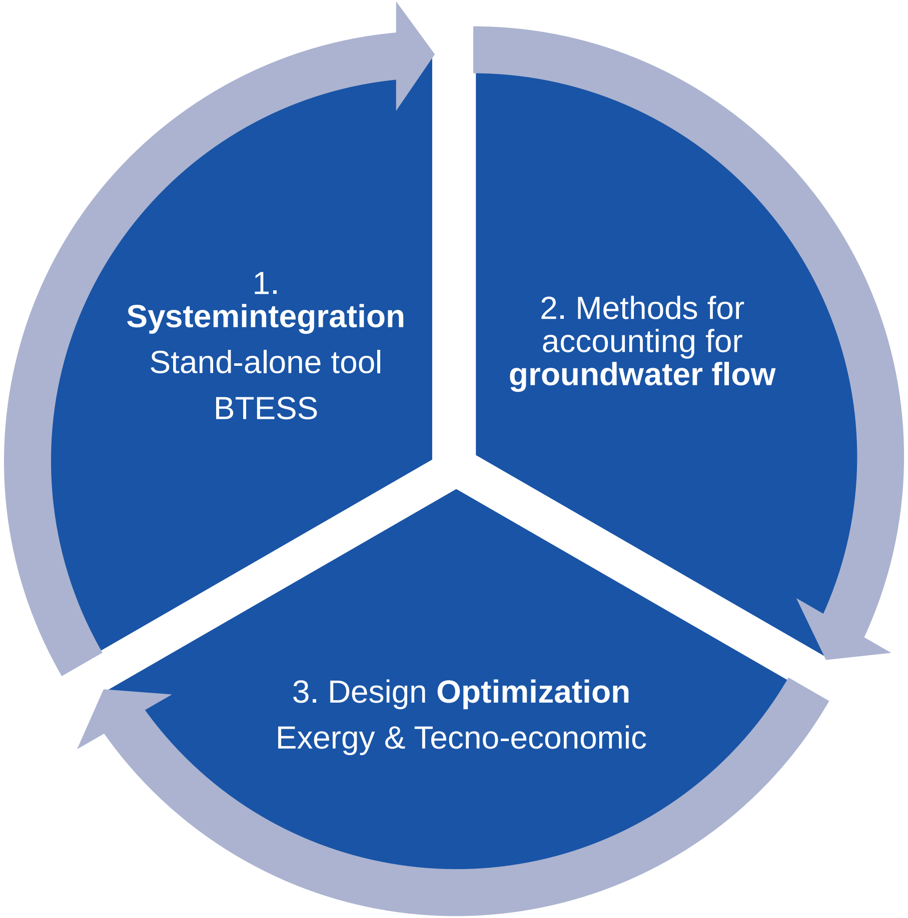
WP3.1:
Kraftvärme i samspel med borrhålslager

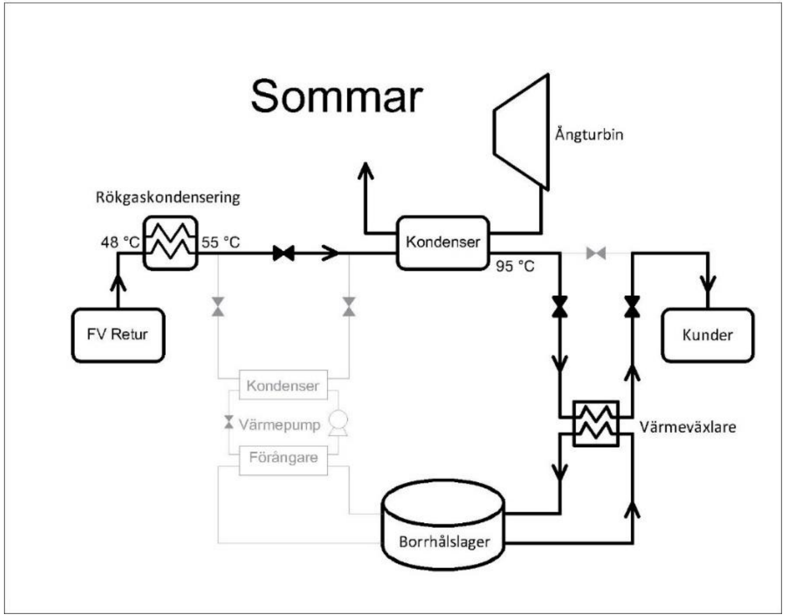
WP3.1:

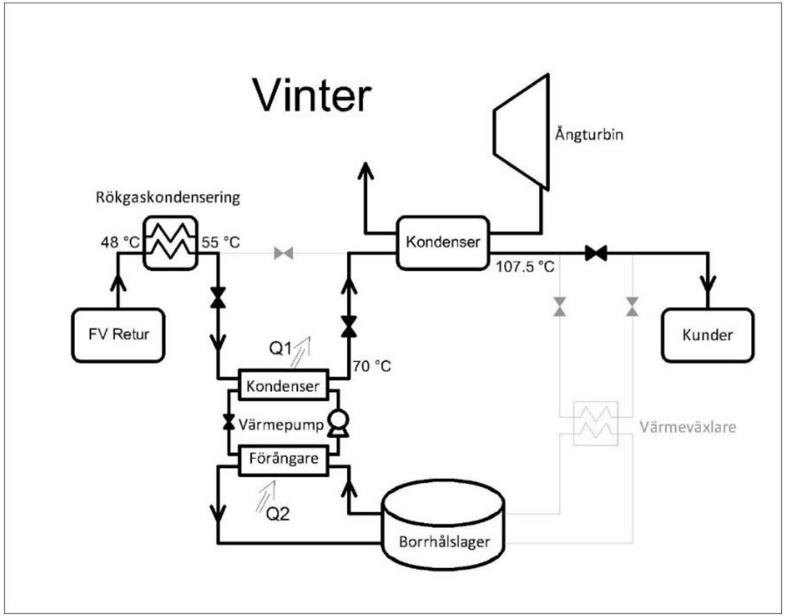
- Kraftvärme i samspel med borrhålslager
- = Combined heat and power plants with borehole thermal energy storage



Stand-alone tool, BTESS

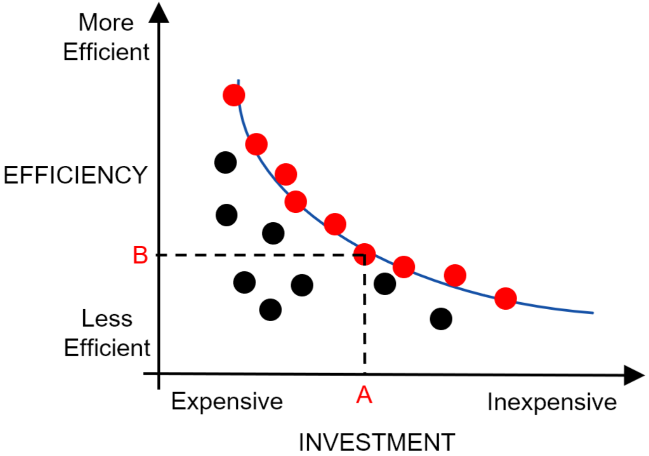
- For evaluating system’s performance
- Flexible for handling any particular study case (data required)

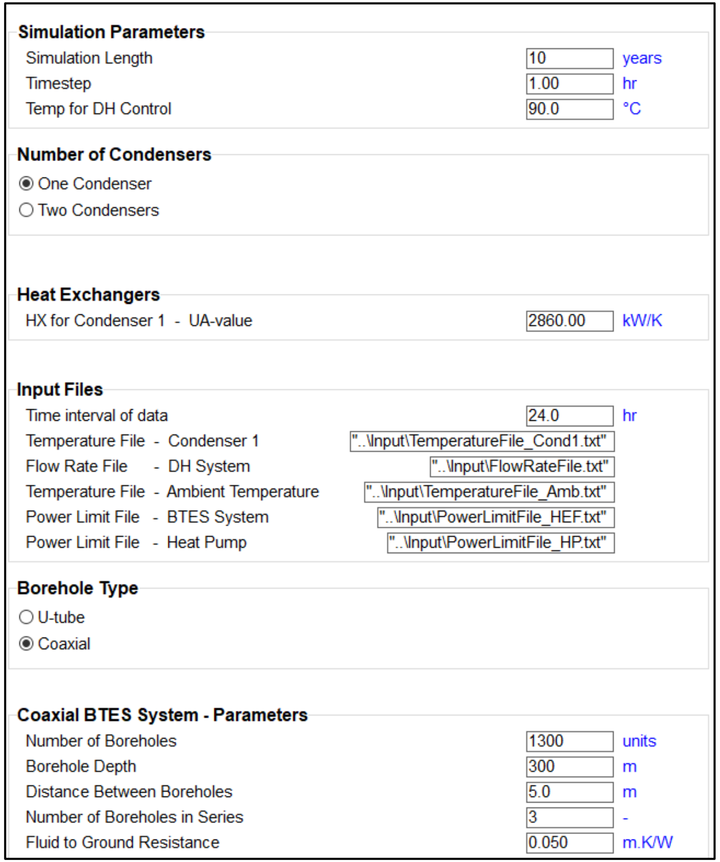




Stand-alone tool, BTESS

User friendly, quick, simple, no need of license





Simulation Parameters

Simulation Length	10	years
Timestep	1.00	hr
Temp for DH Control	90.0	°C

Number of Condensers

- (•) One Condenser
- ( ) Two Condensers

Heat Exchangers

HX for Condenser 1 - UA-value	2860.00	kW/K

Input Files

Time interval of data	24.0	hr
Temperature File - Condenser 1	"..\Input\TemperatureFile_Cond1.txt"	
Flow Rate File - DH System	"..\Input\FlowRateFile.txt"	
Temperature File - Ambient Temperature	"..\Input\TemperatureFile_Amb.txt"	
Power Limit File - BTES System	"..\Input\PowerLimitFile_HEF.txt"	
Power Limit File - Heat Pump	"..\Input\PowerLimitFile_HP.txt"	

Borehole Type

- ( ) U-tube
- (•) Coaxial

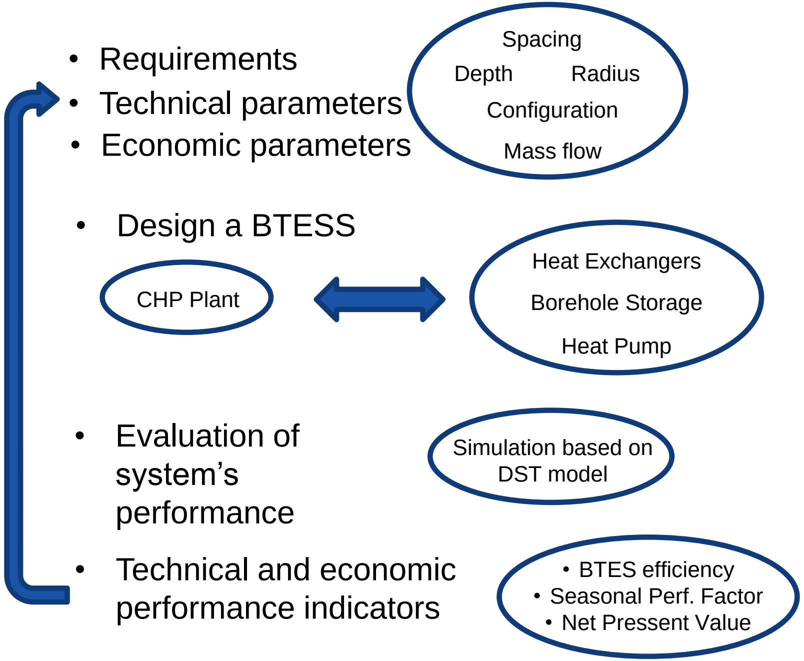
Coaxial BTES System - Parameters

Number of Boreholes	1300	units
Borehole Depth	300	m
Distance Between Boreholes	5.0	m
Number of Boreholes in Series	3	-
Fluid to Ground Resistance	0.050	m.K/W

BTESS

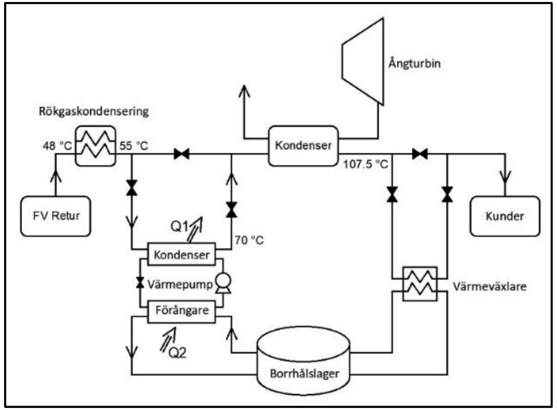
- Multi objective optimization
- System Design
- Simulation / Performance
- Test different technical parameters
- Identify a conflicting objectives
- Establish a Pareto front

Optimization Process



BTESS

- Simplified version of DST
- Iterative design process



BTESS Design Process

- Requirements
- Technical parameters

Spacing
Depth Radius
Configuration
Mass flow

- First guess of BTES size (# boreholes)
- Design of auxiliary components

Heat Exchangers
Heat Pump

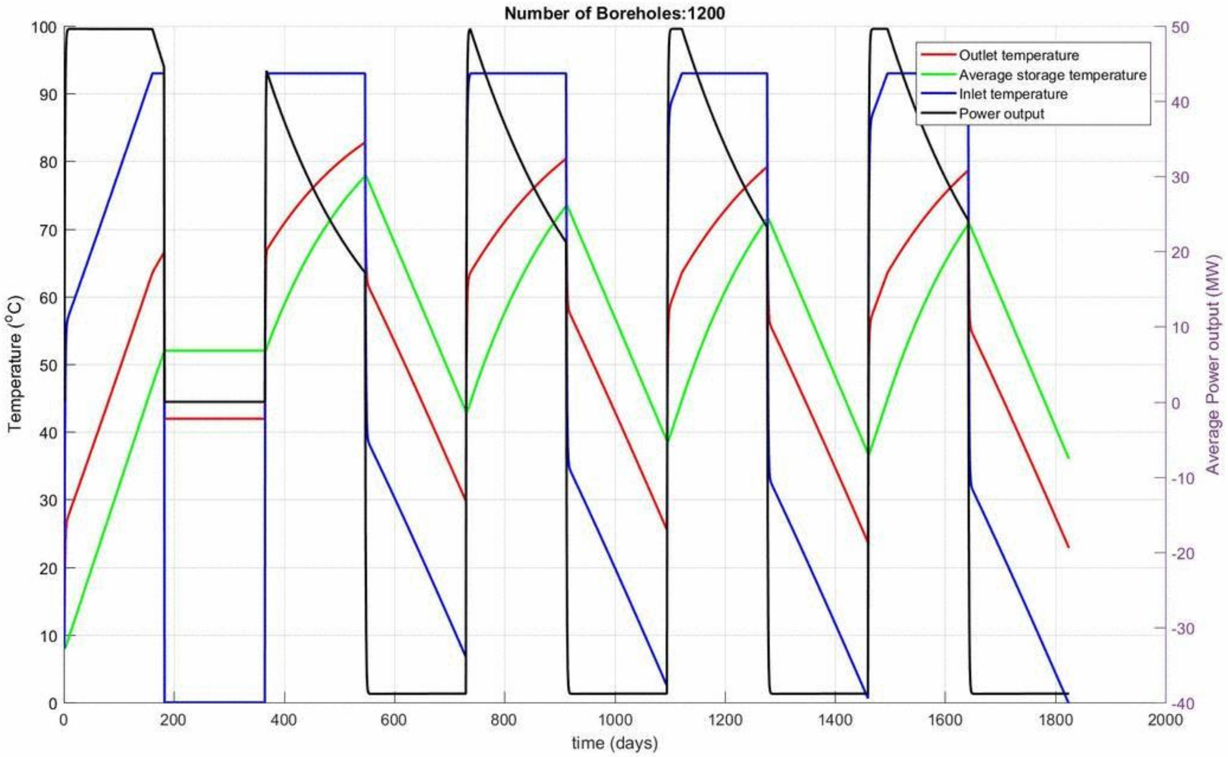
- Estimation of BTES performance

- Simplified DST model
- 5 years of operation

BTESS designed

Full simulation continues

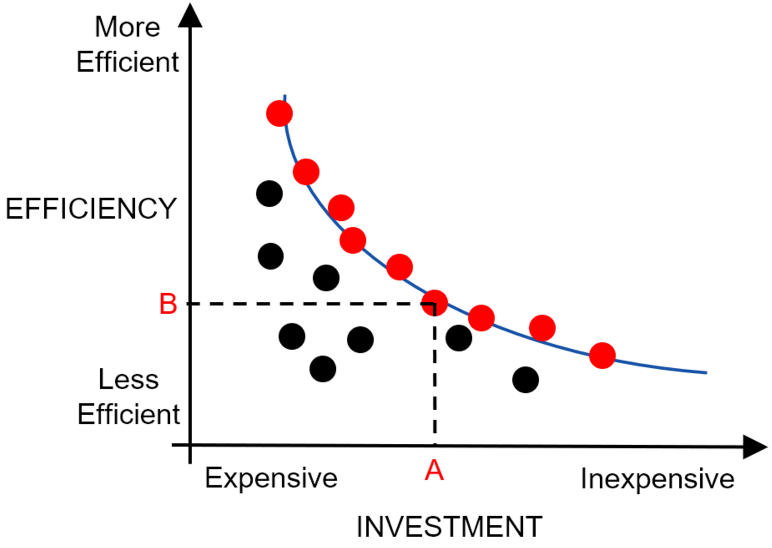
Example



Number of Boreholes:1200
Outlet temperature
Average storage temperature
Inlet temperature
Power output
Temperature (°C)
Average Power output (MW)
time (days)
100
90
80
70
60
50
40
30
20
10
0
50
40
30
20
10
0
-10
-20
-30
-40
0
200
400
600
800
1000
1200
1400
1600
1800
2000

Example, optimization

- Two conflicting objectives, efficiency and investment cost
- Each point is a system with a different and unique combination of parameters
- Consider a system that requires an investment A and performs with an efficiency B



- Part of the Pareto front (blue curve) because it is the less expensive system able to perform at an efficiency B.
- A more efficient system would be more expensive.
- A lower cost system would not be as efficient

Optimization: What performance indicators do we use in the BTESS tool?

Lack of satisfying KPIs for BTES systems

The main performance measure used nowadays to evaluate borehole systems is the so called “energy efficiency” $\eta = \frac{\mathrm{Q_d}}{\mathrm{Q_c}}$

Q_d : heat extracted during the **discharging** season.

Q_c : heat injected during the **charging** season.

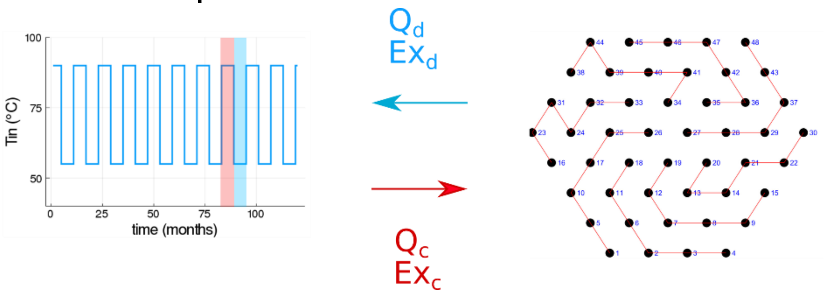
This parameter does not tell the **full story**

We cannot easily compare two systems where energy injection and extraction is performed at different temperatures levels.

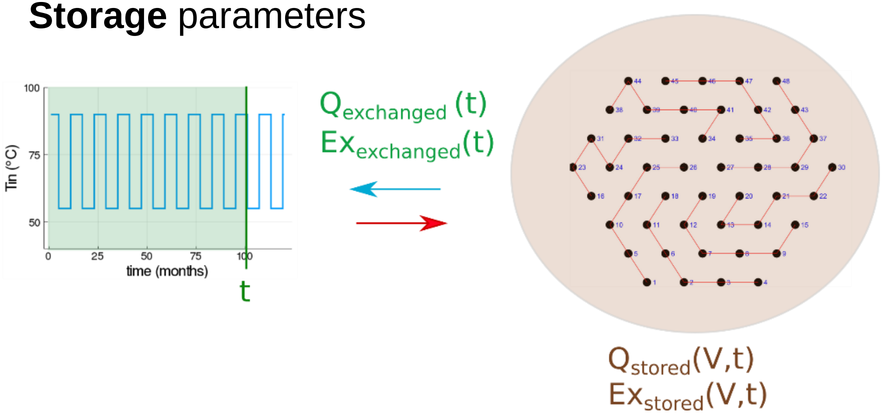
Performance indicators

Seasonal parameters	Energy	$\eta = \frac{Q_d}{Q_c}$	✓
	Exergy	$\psi = \frac{Ex_d}{Ex_c}$	✗
Storage parameters	Energy	$\eta_{\text{storage}}(V,t) = \frac{Q_{\text{stored}}(V,t)}{Q_{\text{exchanged}}(t)}$	✗
	Exergy	$\psi_{\text{storage}}(V,t) = \frac{Ex_{\text{stored}}(V,t)}{Ex_{\text{exchanged}}(t)}$	✗

Seasonal parameters



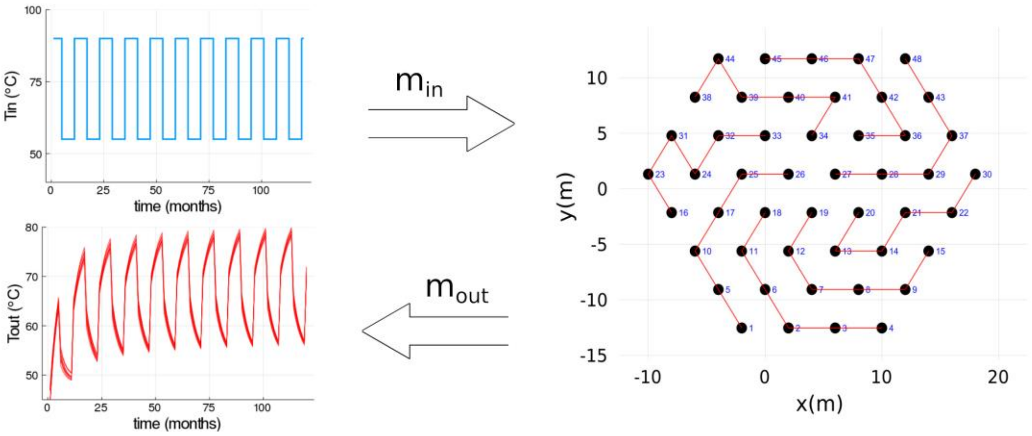
Storage parameters



Application to high temperature borehole storage

Model requirement for the study

- **Flexible** hydraulic connections.
- Feed borehole with **inlet temperatures** and mass **flow rates**.
- **Reverse** the flow between seasons.
- Computation of **energy and exergy stored** in the ground

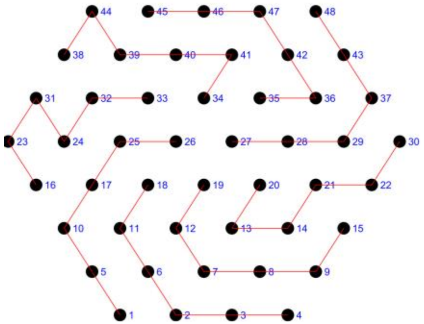


We made a custom model with these characteristics

Configuration 0: reference case

Table 1: Properties utilized to define the reference case configuration case 0.

Property	Symbol	Value	Units
borehole radius	r_b	0.0575	m
borehole length	H	100	m
ground conductivity	k_g	3	W/m K)
ground heat capacity	C_g	$1.875 \cdot 10^6$	J/(m³ K)
grout conductivity	k_b	1.5	W/(m K)
grout heat capacity	C_b	$3.1 \cdot 10^6$	J/(m³ K)
minimum boreholes distance	B	4	m
mass flow rate per loop	$\dot{m}$	0.5	kg/s
density fluid	ρ_f	1000	
specific heat capacity fluid	cp_f	4182	J/(kg K)
arrangement	-	series	-
inlet temperature summer time	$T_{in,s}$	90	℃
inlet temperature winter time	$T_{in,w}$	55	℃
Undisturbed temperature	T_0	8	℃



Test cases

Table 1: Properties utilized to define the reference case configuration case 0.

Property	Symbol	Value	Units
borehole radius	r_b	0.0575	m
borehole length	H	100	m
ground conductivity	k_g	3	W/m K)
ground heat capacity	C_g	$1.875 \cdot 10^6$	J/(m³ K)
grout conductivity	k_b	1.5	W/(m K)
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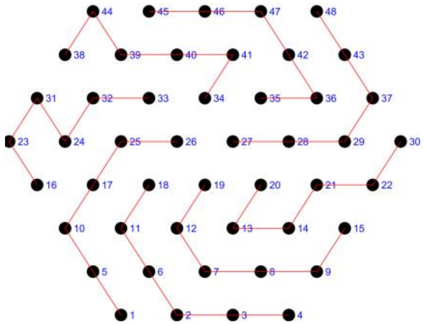
minimum boreholes distance	B	4	m
mass flow rate per loop	$\dot{m}$	0.5	kg/s
density fluid	ρ_f	1000	
specific heat capacity fluid	cp_f	4182	J/(kg K)
arrangement	-	series	-
inlet temperature summer time	$T_{in,s}$	90	℃
inlet temperature winter time	$T_{in,w}$	55	℃
Undisturbed temperature	T_0	8	℃



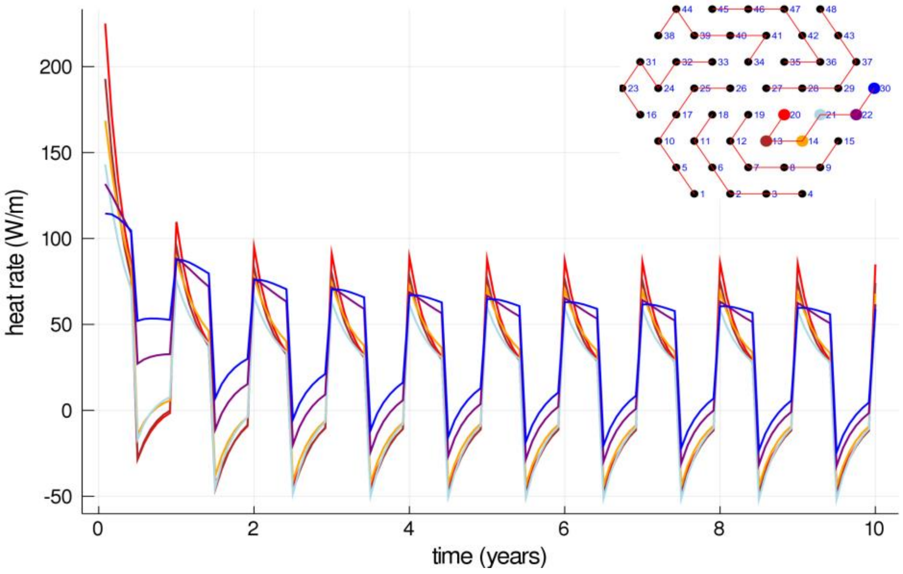
	arrangement	k_b (W/(mK))	$\dot{m}$ (kg/s)
case 0	series	1.5	0.5
case 1	parallel	1.5	0.5
case 2	series	2.5	0.5
case 3	parallel	2.5	0.5
case 4	series	2.5	1
case 5	parallel	2.5	1

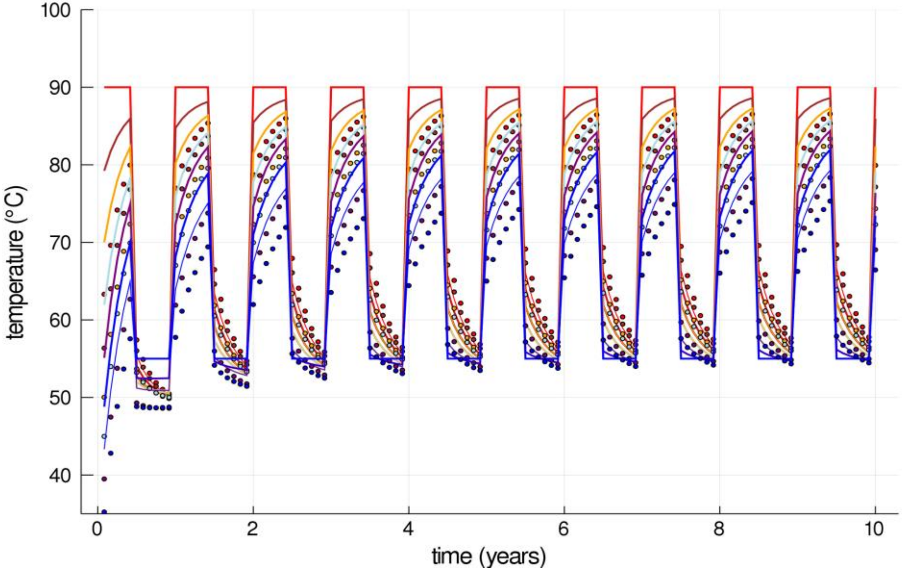
Simulation results

Heat flows and **temperatures** for **each** borehole in the field.

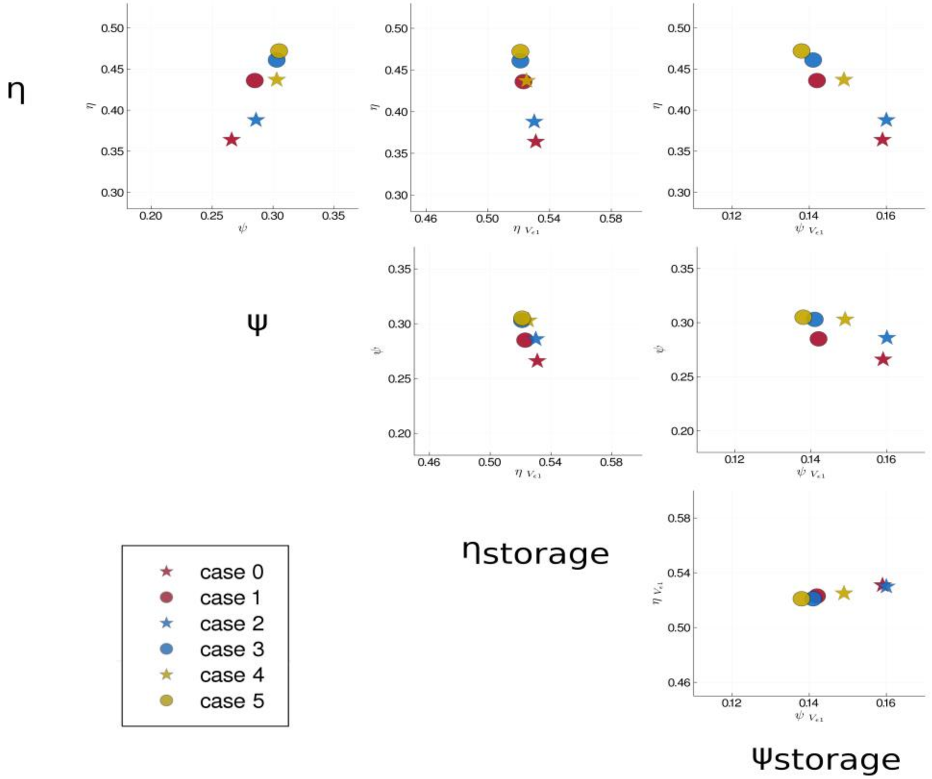
Temperature plots Cheat sheet

- Inlet temperature
  continuous thick line
- Outlet temperature
  continuous thin line
- Dotted line
  borehole temperature





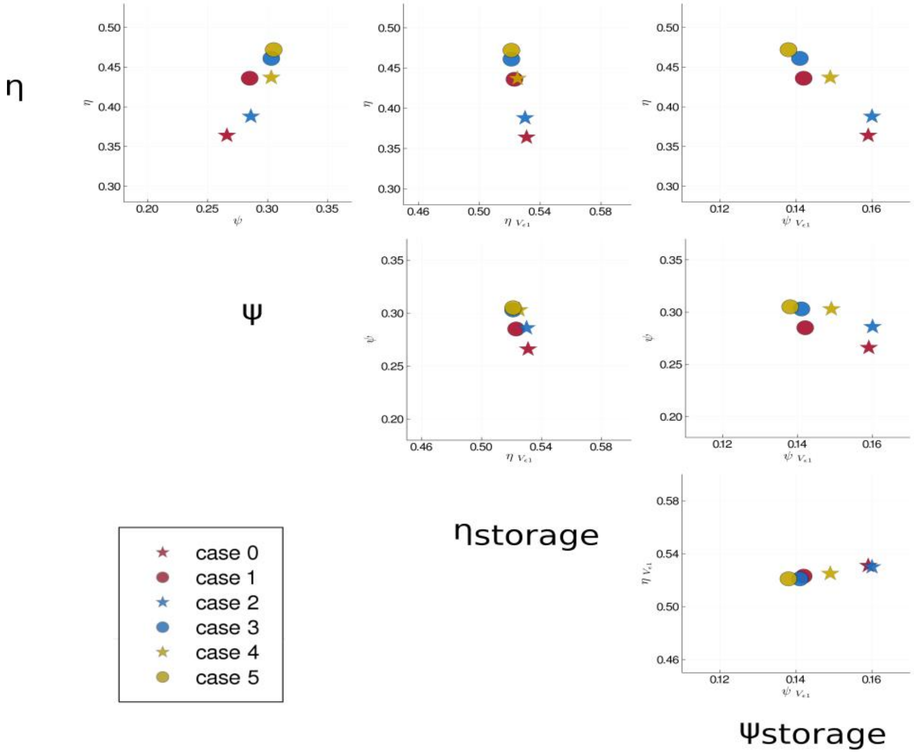
Storage performance after 10 years of operation



Comparison and remarks for the study cases investigated

- Large spread in terms of seasonal energy efficiency η.
- The spread is reduced when we take a look at seasonal exergy efficiency ψ.
- The energy storage efficiency η_{storage} is almost identical for all the systems.
- Systems with worse seasonal efficiency η are the one performing best in terms of ψ_{storage}.

Storage performance after 10 years of operation



- **Lower** seasonal energy efficiency ***η*** **does not** necessarily **mean higher heat losses** from the storage volume.

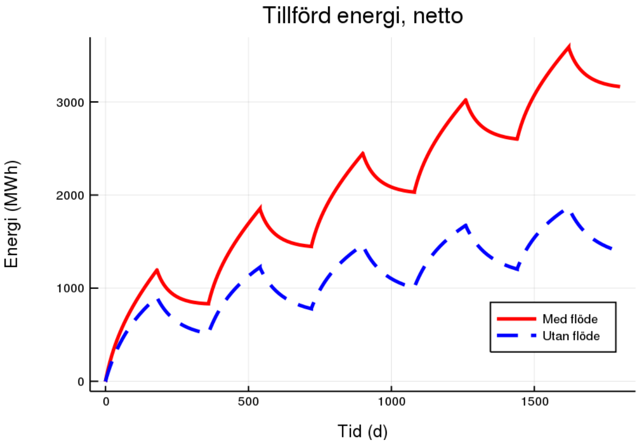
- The **performance indicators** investigated **can help improve the design** of borehole heat storage systems, (BTESS)

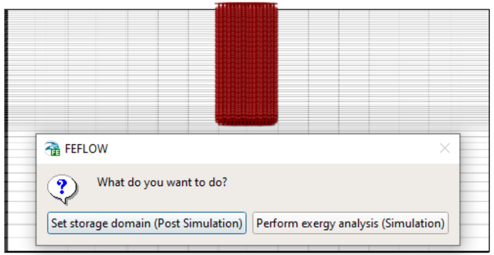
- Looking at several parameters **provides** a **better understanding** of the processes of **exchange and storage** of heat with borehole field system**.**

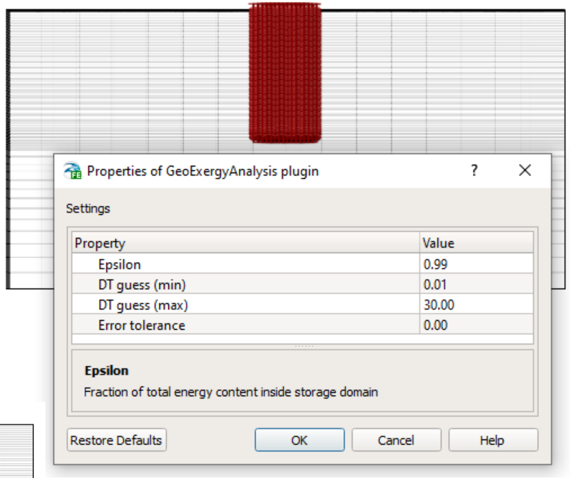
How do we measure exergy performance under the presence of groundwater flow?

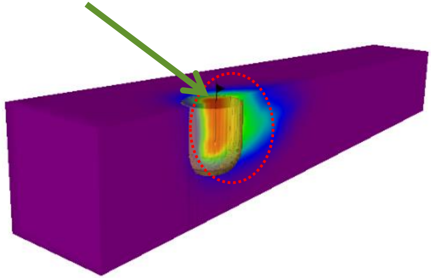
Performance influenced by groundwater flow

- We are developing a plug in to FEFLOW, based on the same exergy approach but numerically and 3D

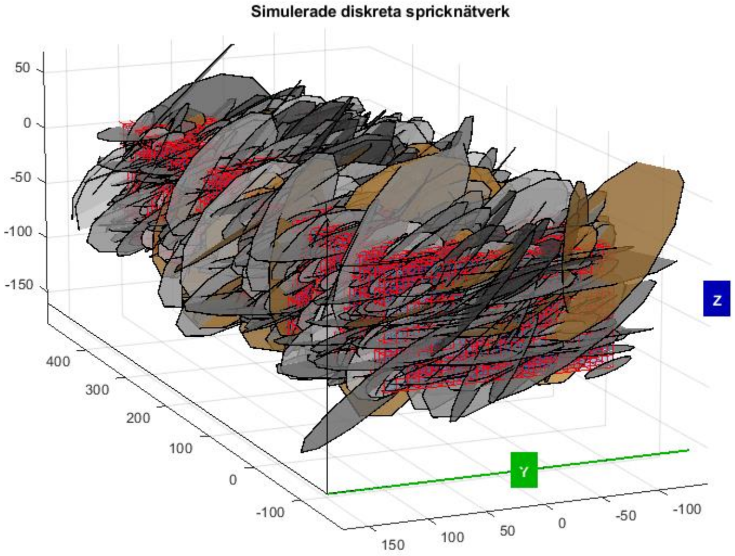








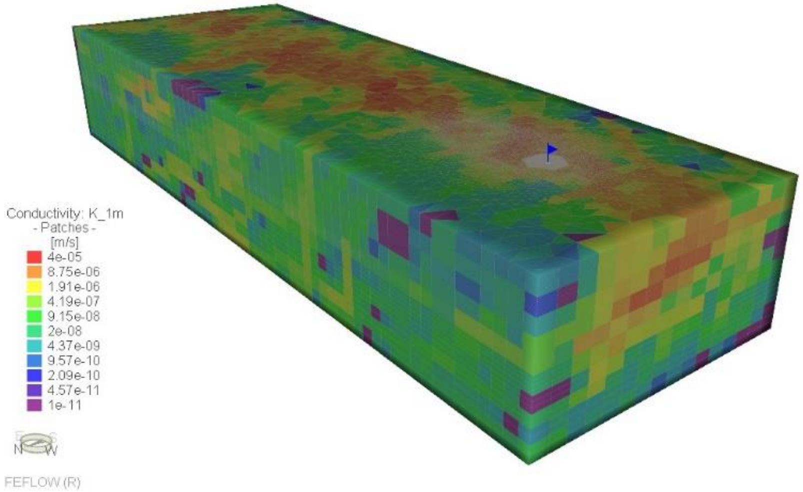
Continues representation of fracture networks



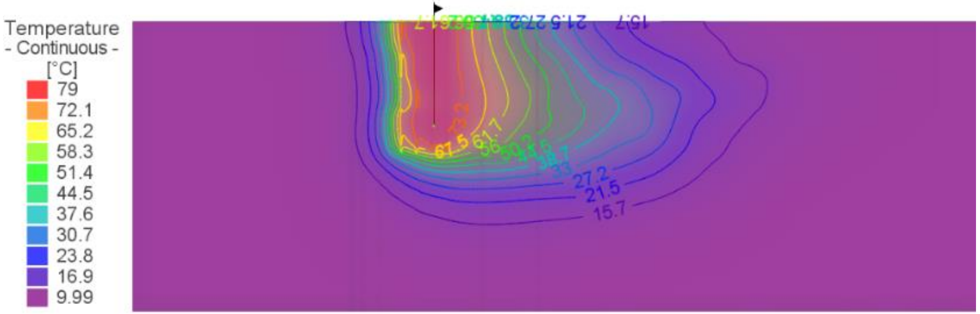
Properties of discret fractures (geometry, fracture density, fracture size, hydraulic connection through fractures etc.)

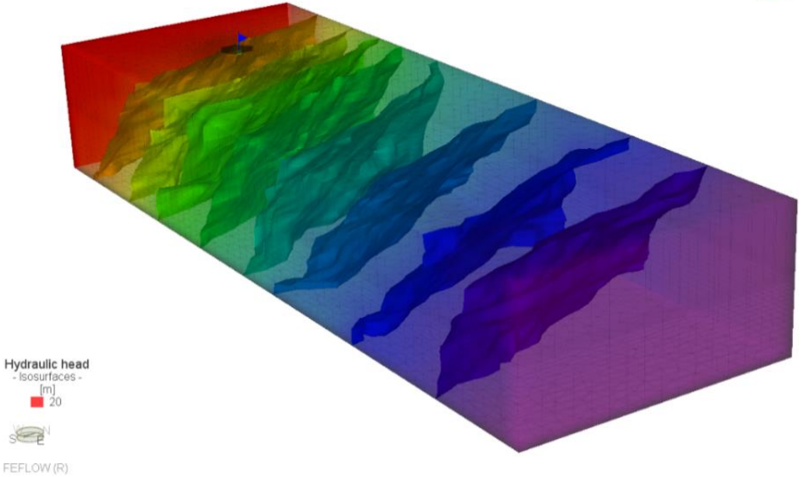
upscaling

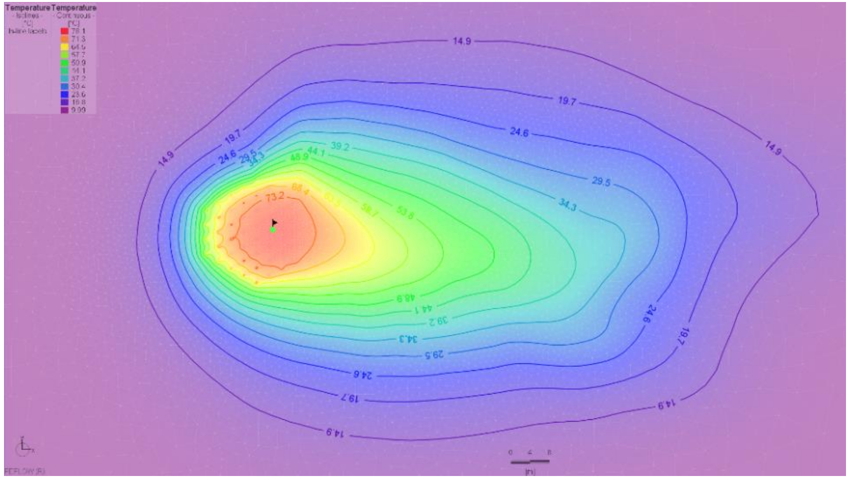
Properties of an equivalent porous media in block volumes (porosity, hydraulic conductivity etc.)



- Allows the use of existing and availble approaches for porous media (FEFLOW, MODFLOW, OpenGeoSys m.m.) – publication in the pipeline





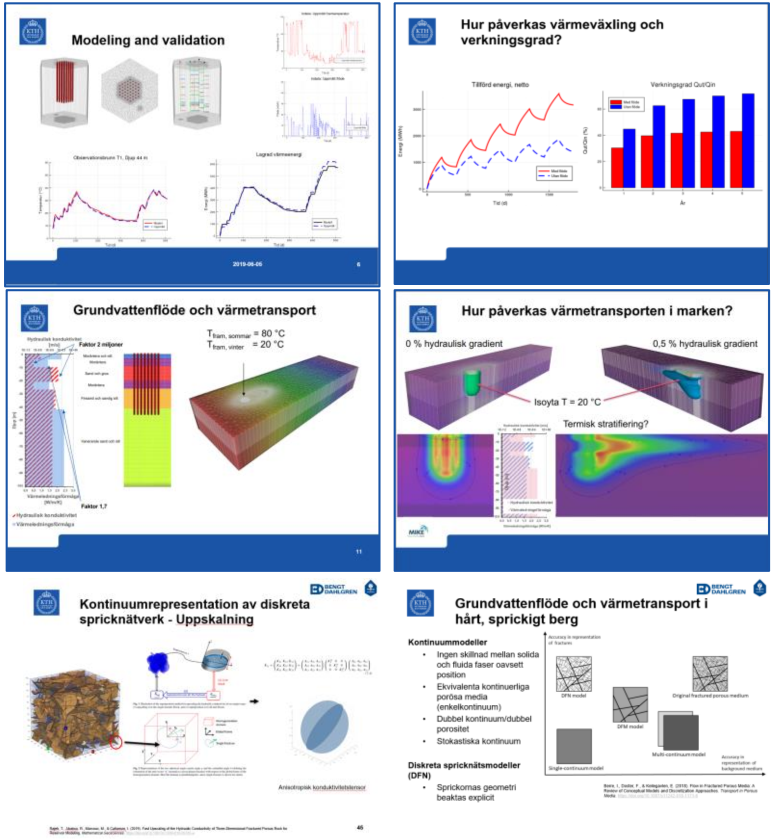


Influence of groundwater flow

- Continues representation of **discret fracture network**

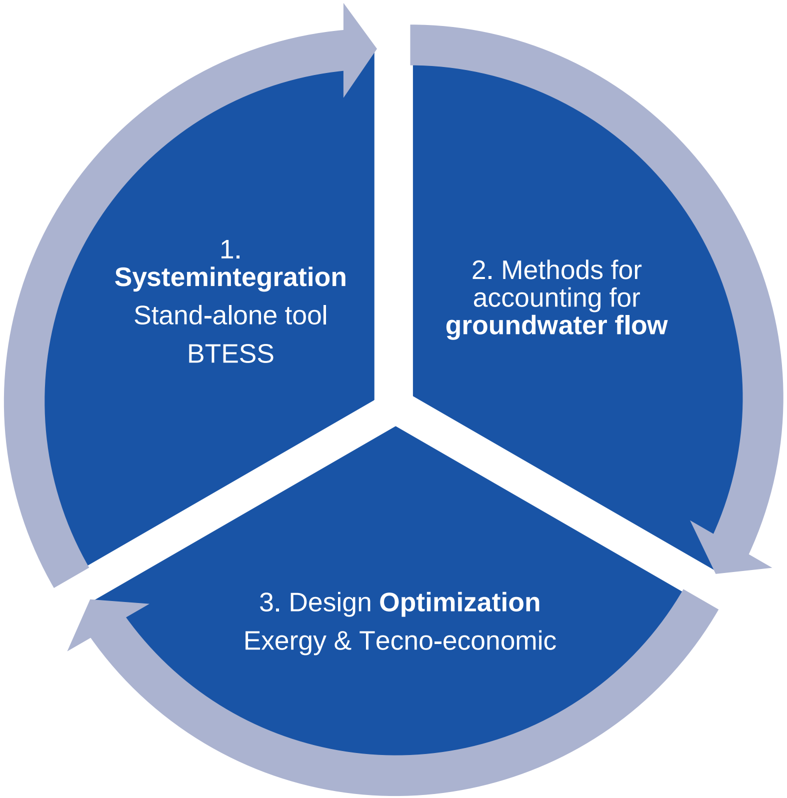
- Modelling of heat transport in hard fractured rock

- Numerical method for **energy- and exergy analysis** of BTES under the influence of groudwater flow



Conclusions

1. Simple and flexible stand-alone design tool under development
2. Methods to do energy- and exergy analysis of BTES systems have been proposed as optimization indicators
3. A method for modelling heat transport in hard fractured rock accounting for continues representation of discret fracture networks has been suggested
4. Lower seasonal energy efficiency does not necessarily mean higher heat losses from the storage volume.



Thank you!