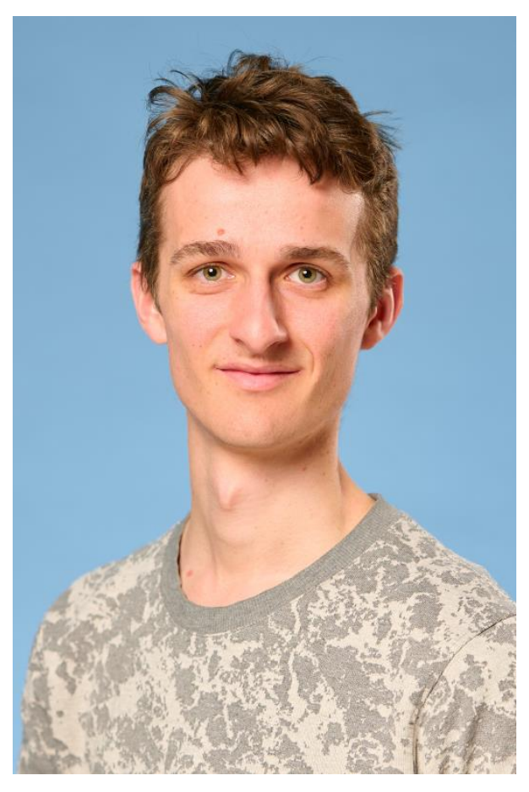

Copernicus Institute of
Sustainable Development

The PUSH-IT project is funded to develop and demonstrate high temperature heat storage for seasonal purposes using multiple storage technologies in three different locations.

Recovery efficiency estimation in High-Temperature ATES

Analysing simulation model results

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Why HT-ATES?

To reduce global warming, the EU aims to have a net-zero greenhouse gas economy by 2050. At present, heating and cooling represent around half of the final energy demand in Europe To achieve EU ambitions, is therefore essential to move to low-carbon heating and cooling. HT-ATES stores excess energy to be used when needed. Preventing the use of back-up fossil fuel boilers.

Definition Recovery Efficiency (η)

Ratio of extracted heat to injected heat:

$$\eta = \frac{E_{out}}{E_{in}} = \frac{T_{out} - T_{ground}}{T_{in} - T_{ground}}$$

Why this work

We generated data to quickly identify the efficiency of the HT-ATES system, which can be used in larger system modelling. We also looked into the correct way to use a subsurface model, showing differences between different model configurations.

Aim

The aim of this work is threefold:

1. Find differences between axisymmetrical (AXI) grid and 3D grid, to compare them and use the right configuration of the subsurface model.
2. Verify whether placing two ATES wells apart by 3 times the thermal radius is the correct distance within the model to prevent interaction.
3. Find an analytical relation between recovery efficiency and subsurface and operation parameters, which can be used for larger system modelling.

How?

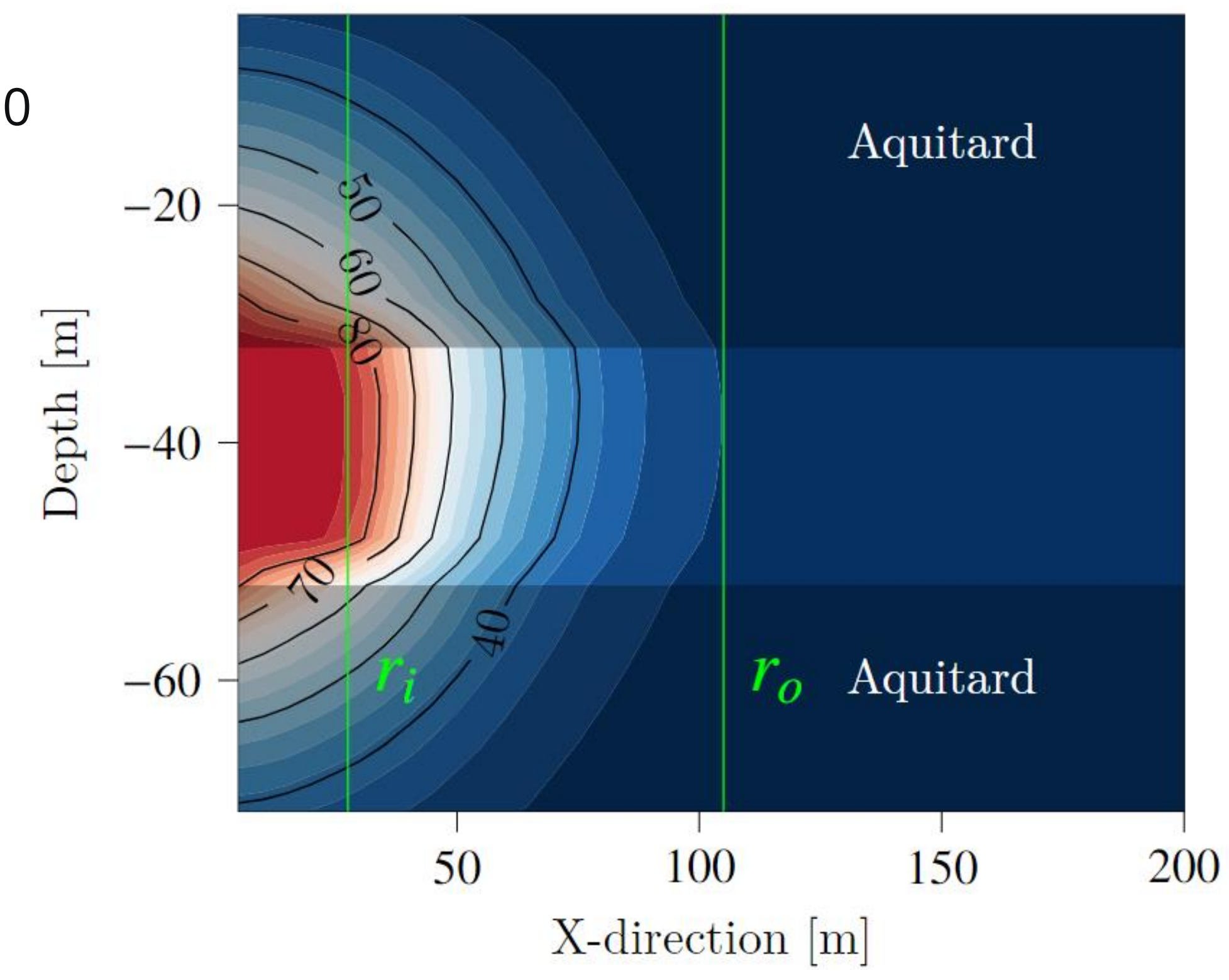
A MODFLOW model was build and run repeatedly, using design of experiment, which uses extreme values of the parameters. This created ~4500 data points.

Method aim 1:

Compare the results of Sheldon et al (2021)[1] using MOOSE software and AXI grid with MODFLOW AXI grid output and MODFLOW 3D grid. Eight scenarios were compared with different aquifer characteristics and operation characteristics.

Method aim 2:

Calculate the thermal radius for the 4500 data points and compare the inner and outer thermal radius (r_i and r_o respectively) with the analytical thermal radius (r_{th}) defined in Bloemendal et al. (2018)[2]. Then modelling different distances between cold and hot well to see the effect of changing this distance on the recovery efficiency.

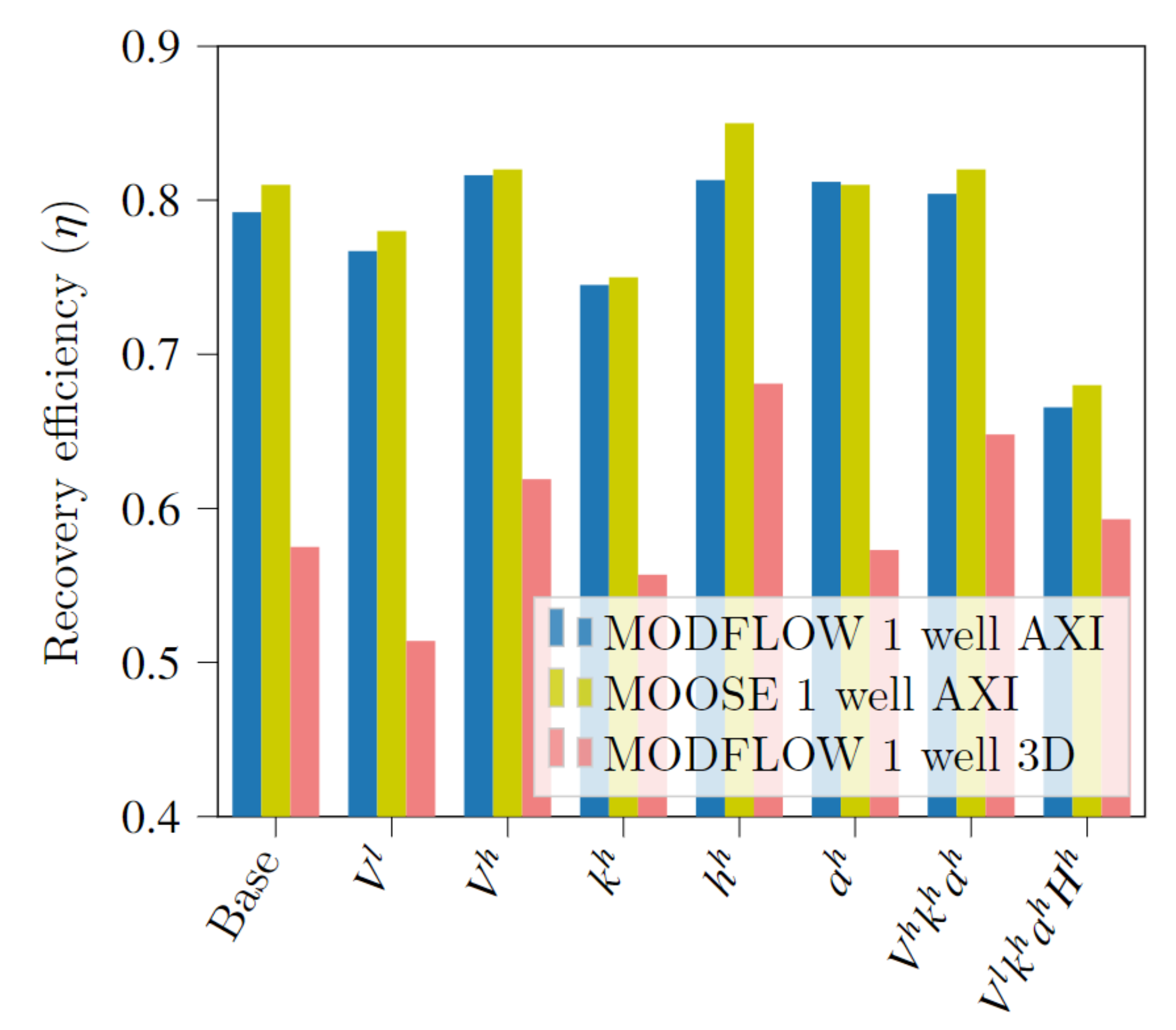


Method aim 3:

Fit a curve through the data points to find the relation between input and output parameters only taking into account parameters that significantly reduce the error of the fitted curve.

Results

Aim 1:

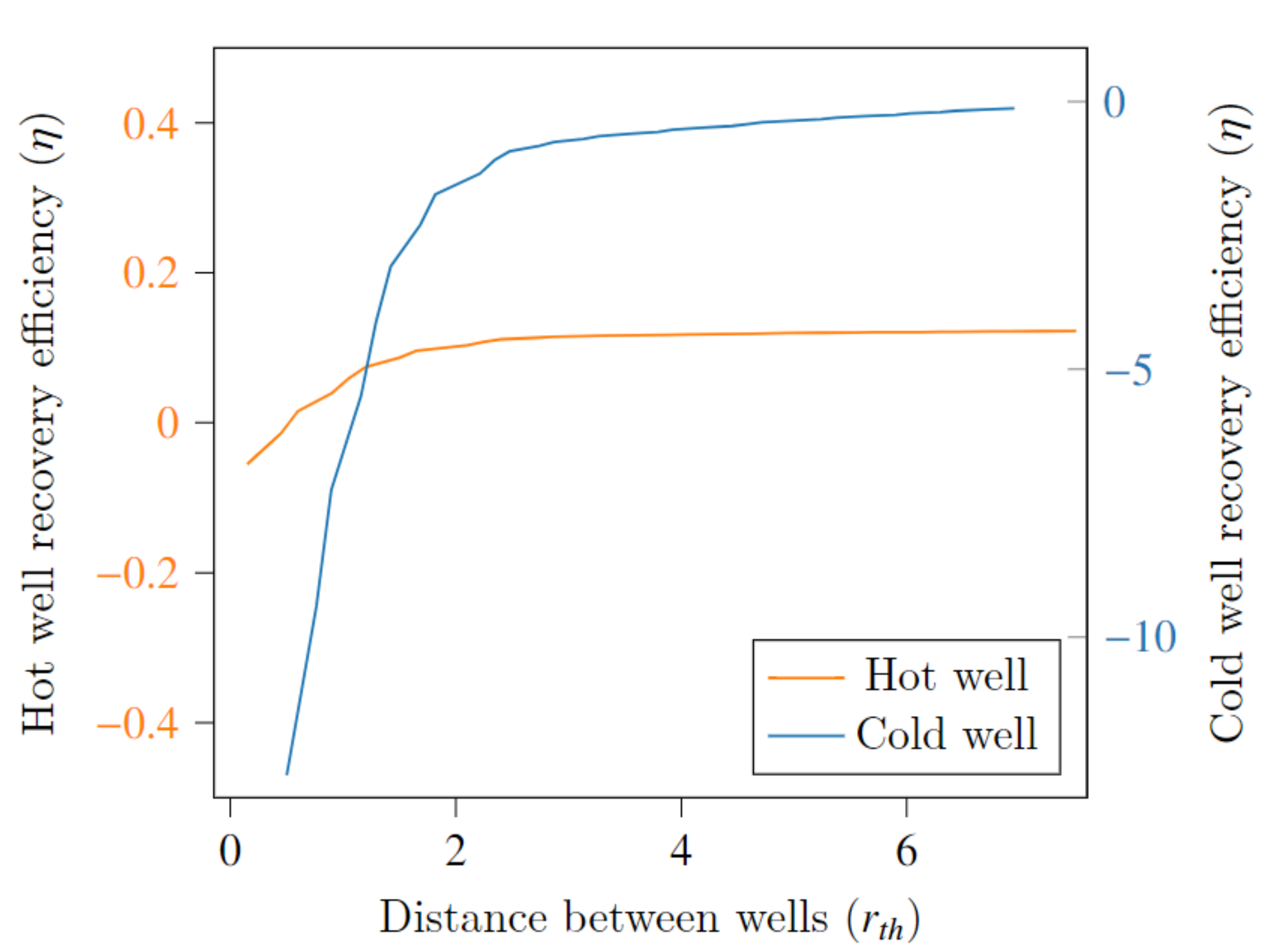


Conclusions

1. MODFLOW and MOOSE software do not significantly differ in terms of results recovery efficiency, when using the same type of grid.
2. AXI and 3D grid differ significantly from each other. This is caused by the larger dispersion in the 3D grid. Which brings up the question, which discretization is correct?

Aim 2:

The outer thermal radius differs significantly from the analytical thermal radius in most data points analysed. Below the effect of distance on the recovery efficiency of the different wells can be found.



Conclusions

For the hot well the effect of the cold well becomes negligible after 2*r_{th}. The cold keeps being influenced by the hot well even after a distance of 7 * r_{th}

Aim 3:

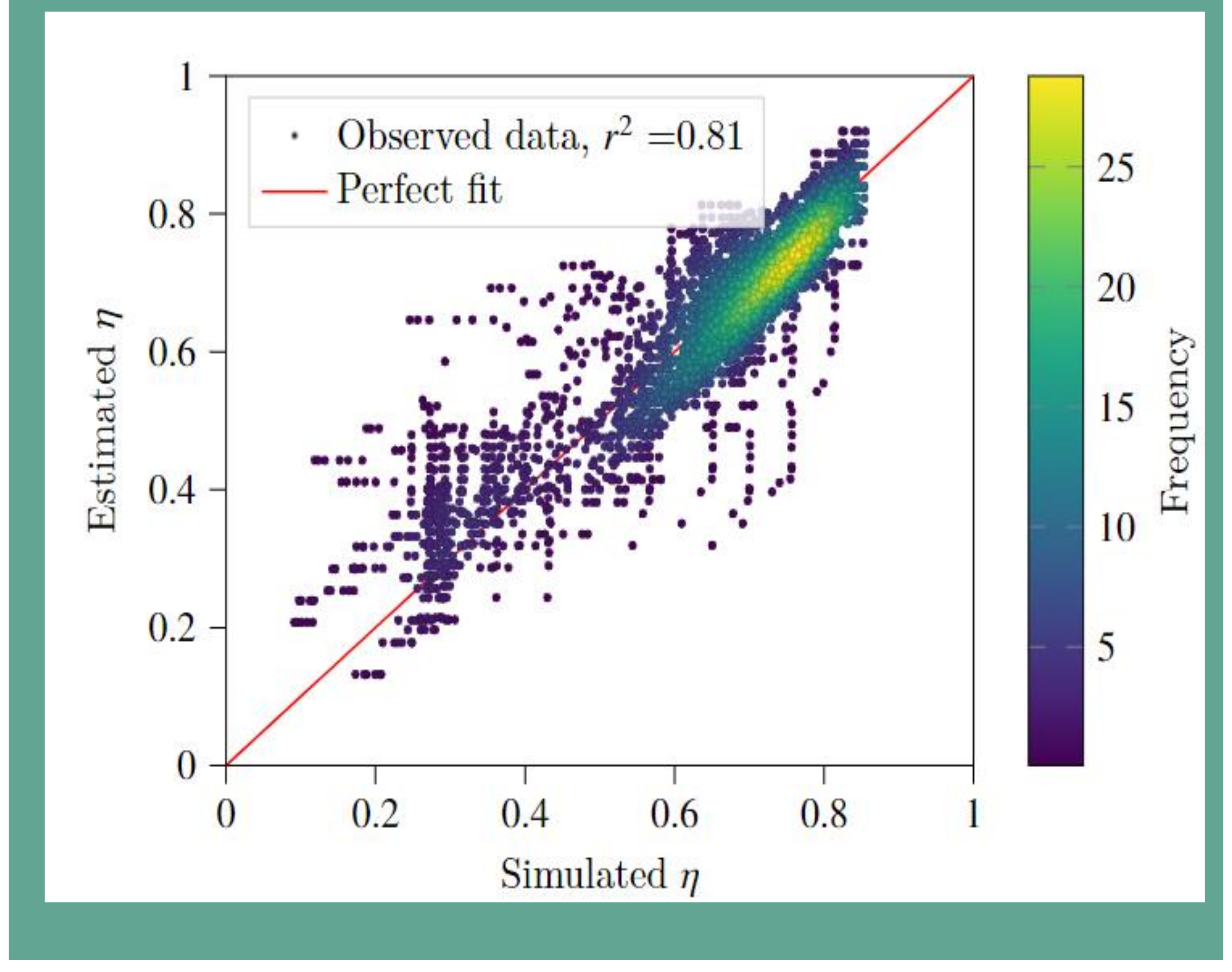
R² was used to find significance of the effect that each parameter has on the recovery efficiency. Showing that injected yearly volume is the most important parameter. When only including significant effects the following equation was created:

$$\eta = 1.8E3 + 1.3E3 * V_i^{6.7E-5} - 2.7E-7 * T_i^{2.9}$$
$$+300 * H^{2.2E-4} - 3.2E-4 * k_h^{1.2} + 150 * a^{1.8E-4}$$

V_i= Injected yearly volume
T_i= Injected temperature
H= Thickness aquifer
k_h=Horizontal hydraulic conductivity
a= Anisotropy = k_h/k_v

Accuracy of prediction

R² of this formula was 0.81, the error in the predictions is shown below. Showing that with higher efficiencies the error is generally lower.



Future work

1. Implement ATES in a larger system perspective in a computational efficient way.
2. Figure out the whether the storage component is economically viable, using the levelized cost of heat (LCOH).
3. Verify the created energy system model using the data from sites in the PUSH-IT project.

Research questions:

1. How can the ATES system be optimally implemented within a district heating system?
2. What effect does the ATES have on the CO2 emissions of the district heating system.

References

1. H. A. Sheldon, A. Wilkins, and C. P. Green, "Recovery efficiency in high-temperature aquifer thermal energy storage systems," Geothermics, vol. 96, p. 102173,
2. M. Bloemendal and N. Hartog, "Analysis of the impact of storage conditions on the thermal recovery efficiency of low-temperature ates systems," Geothermics, vol. 71, pp. 306–319, 2018

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