How useful is heat storage? Techno-economic analysis of HT-ATES

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Main research question of PhD research:

How can high-temperature aquifer thermal energy storage (HT-ATES) be computationally efficiently modeled, integrated, and optimally sized within district heating systems to support their cost-effective and sustainable decarbonization?

Method

HT-ATES model [2]

An HT-ATES model was developed, which improved computational speed compared to full numerical models but remains accurate. We created a data-driven model (DDM) [2]

Comparison

Required output: Temperature profile
Compared to the numerical model:
Time: From 601 min → 0.5 sec
Root mean square error: 1.22 ℃
Efficiency RMSE: 1.4 percentage point

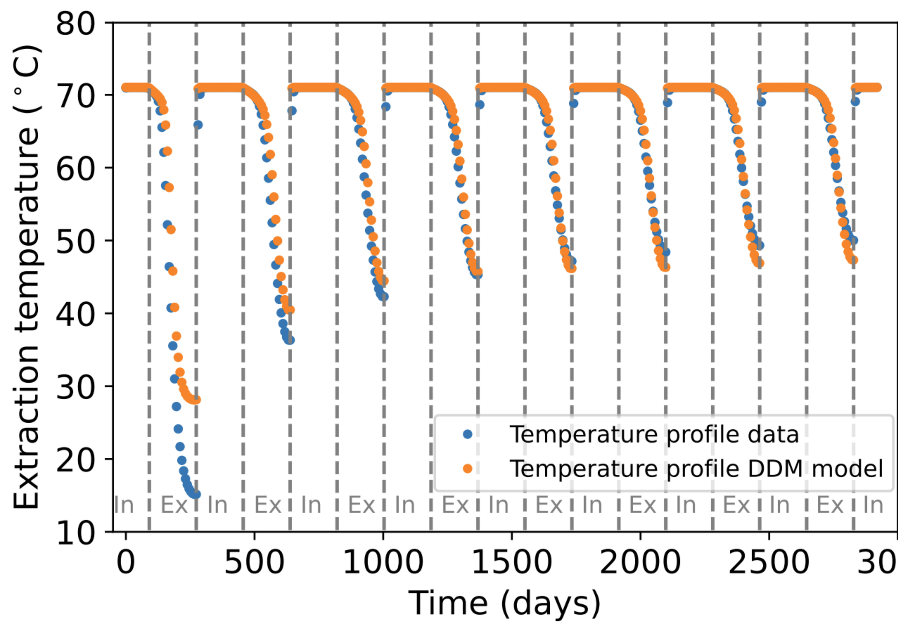


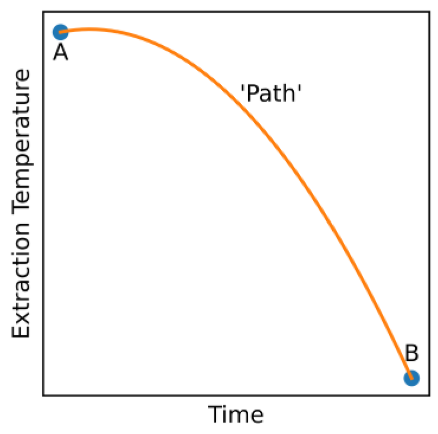
Figure: Comparison between numerical model and DDM with error of 1.22℃

Method

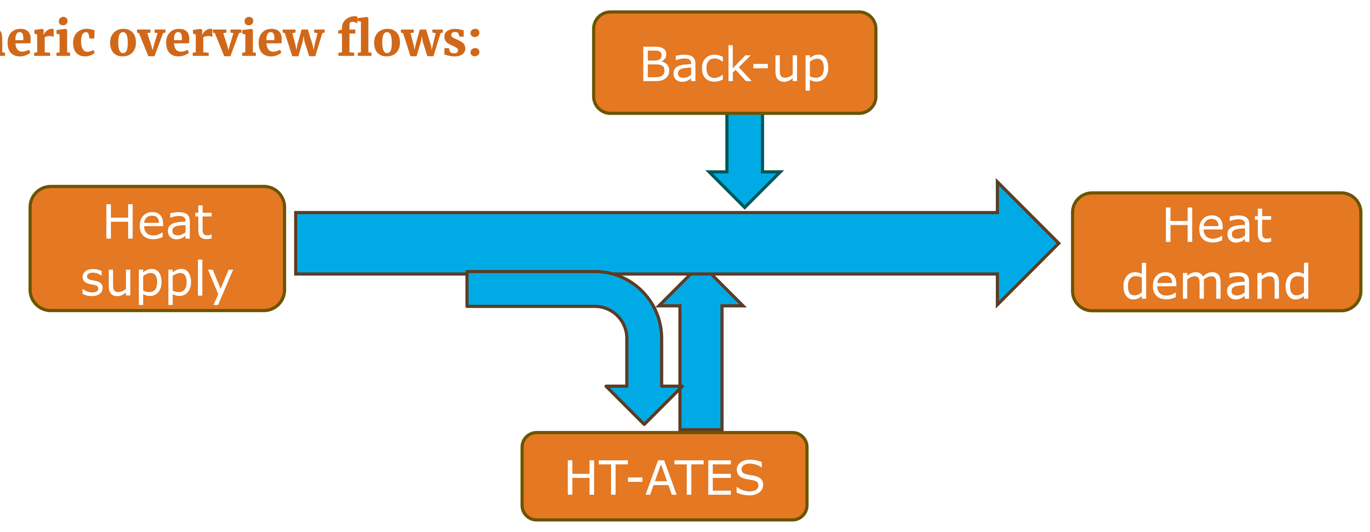
1. Generate/load Data
   See my first paper [1].
2. Predict the efficiency of HT-ATES
3. Nearest neighbour search: search for the most suitable temperature profile in the dataset based on efficiency and other parameters
4. Temperature profile adaptation: Adapt temperature profile to fit

Reasoning

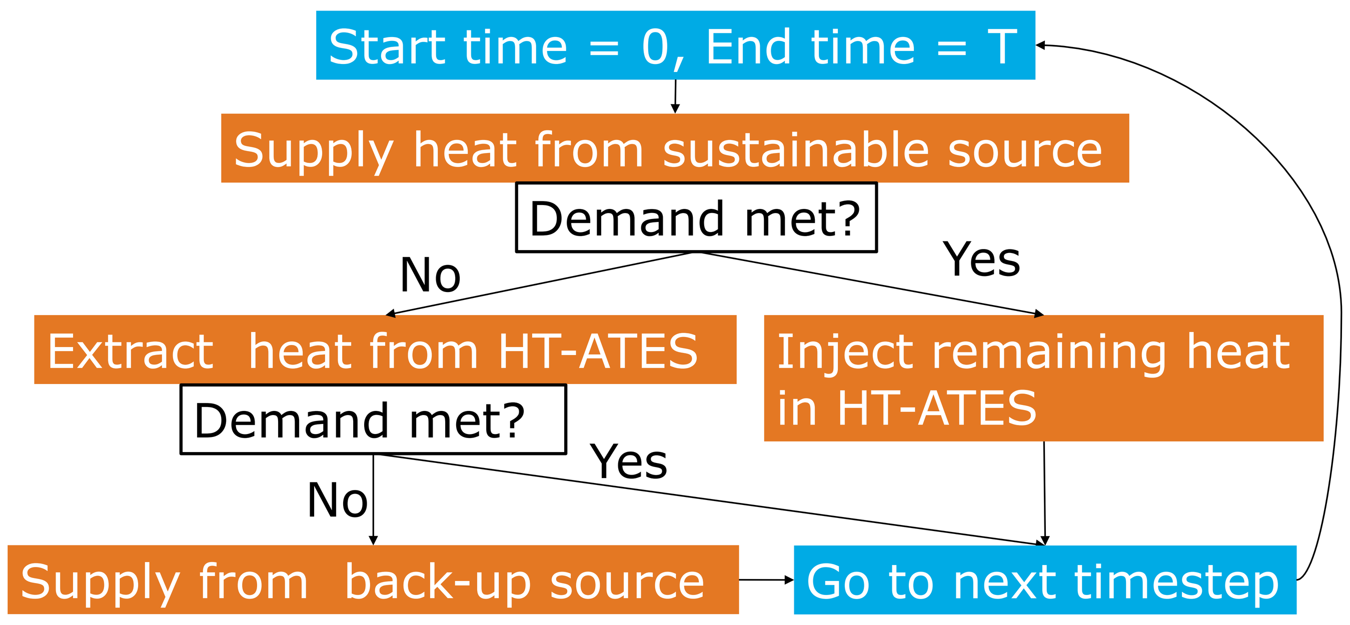
We need the temperature profile, defined by the points A and B and the path between them. A is the same as the injected temperature (assumed constant), and B can be approximated by the ground temperature. The path is summarized in efficiency. Therefore, we predict efficiency and search for the closest data point with that efficiency, injected temperature, and ground temperature.



Generic overview flows:



Techno-economic model control system [3]:

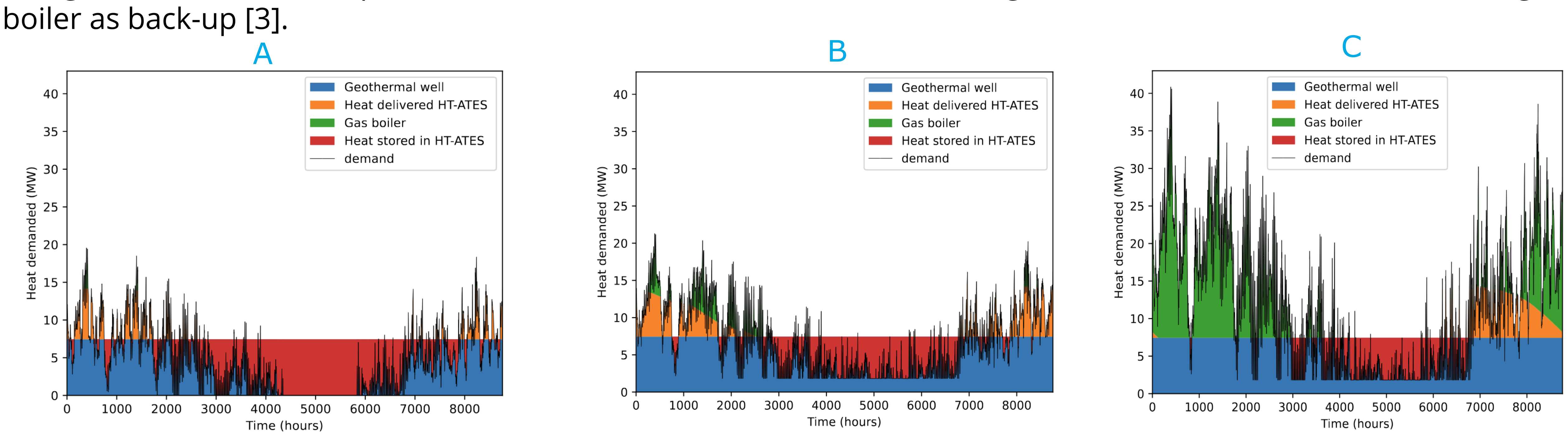


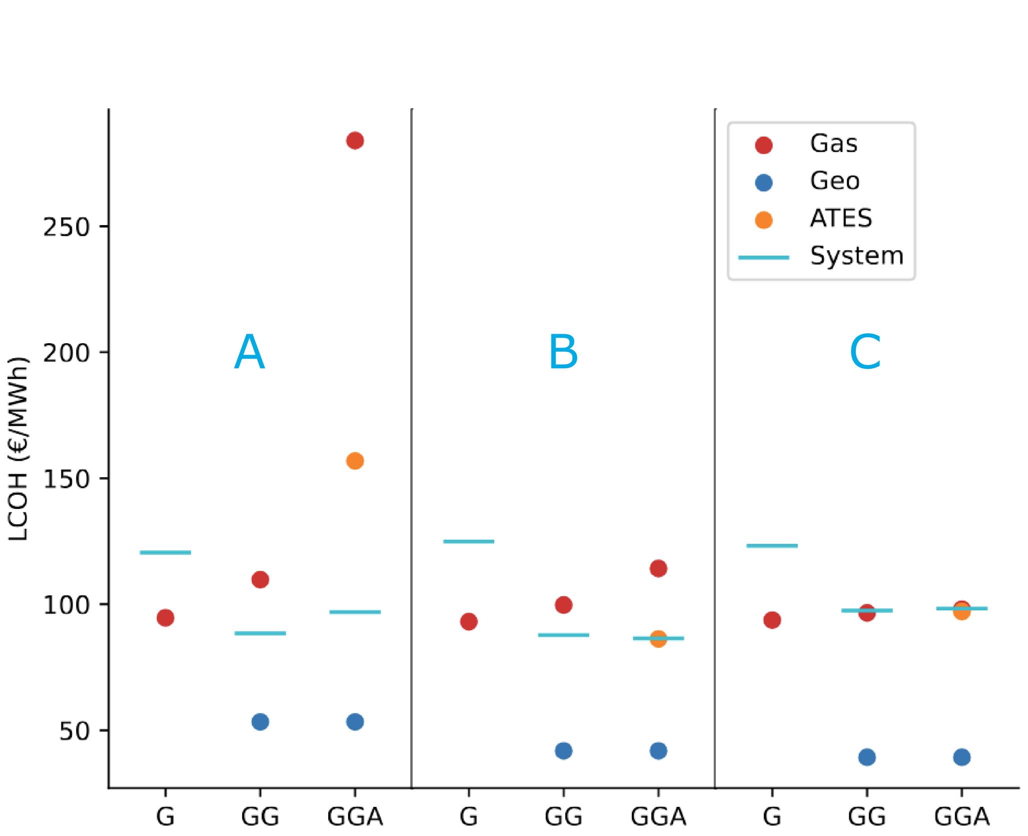
The used metrics are the following: Levelized cost of heat (LCOH); Carbon Abatement Cost (CAC); Renewable Energy Share (RES)

$$LCOH = \frac{\sum_{t=1}^{n} \frac{I_t + O\&M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad EF = \frac{\sum_{t=1}^{n} \frac{CO_{2,t}}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \qquad CAC = \frac{LCOH_{s1}}{EF_{s1}} - \frac{LCOH_{s2}}{EF_{s2}}$$

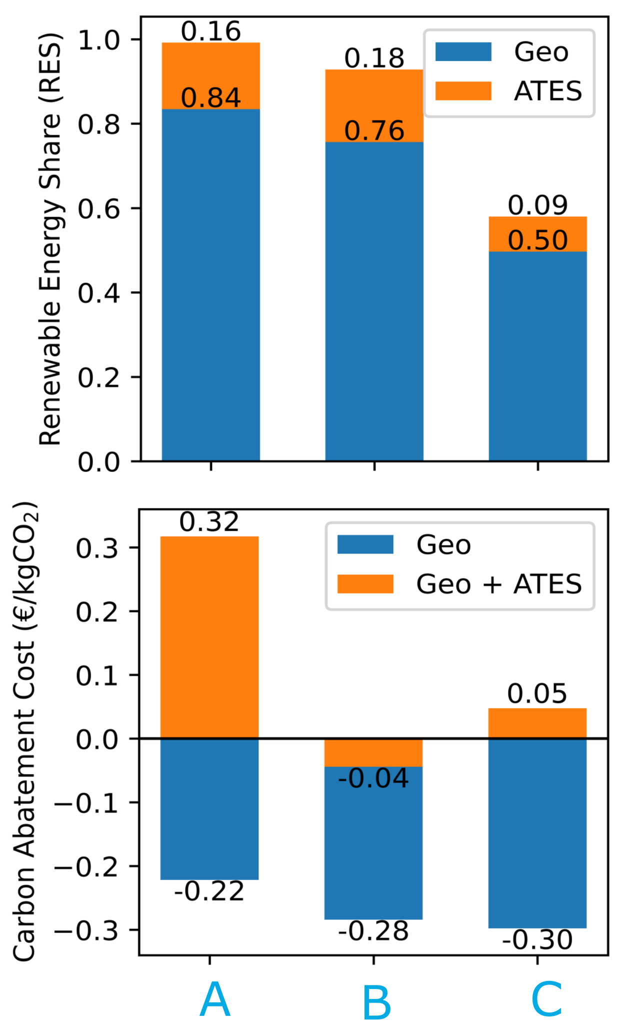
Results

Using 3 different demand profiles (case A, B, and C) with the same size of geothermal well and HT-ATES. With a gas boiler as back-up [3].





Figures: LCOH & CAC & RES of components and system.
G is only gas boilers; GG is gas + geothermal;
GGA is GG+HT-ATES



The geothermal well is highly cost-efficient, with the HT-ATES being beneficial in case B. The lowest system LCOH is found in this case with the GGA configuration at 87 €/MWh.

The CAC is negative for HT-ATES only in the B case, and positive in the others, noting an increase in costs for the carbon abated.

When the RES is close to 100%, the LCOH increases significantly, due to the large required capacity. Lower RES targets are more cost-effective.

Outlook

In future work, the sizing of DH components is going to be optimized. We will optimise the sizing of geothermal/solar collectors + HT-ATES to find the sizing with the lowest LCOH and how to improve RES most cost-effectively. See the figure for a sneak peek of this work [4].
These four papers will be used to form my PhD thesis (see references).

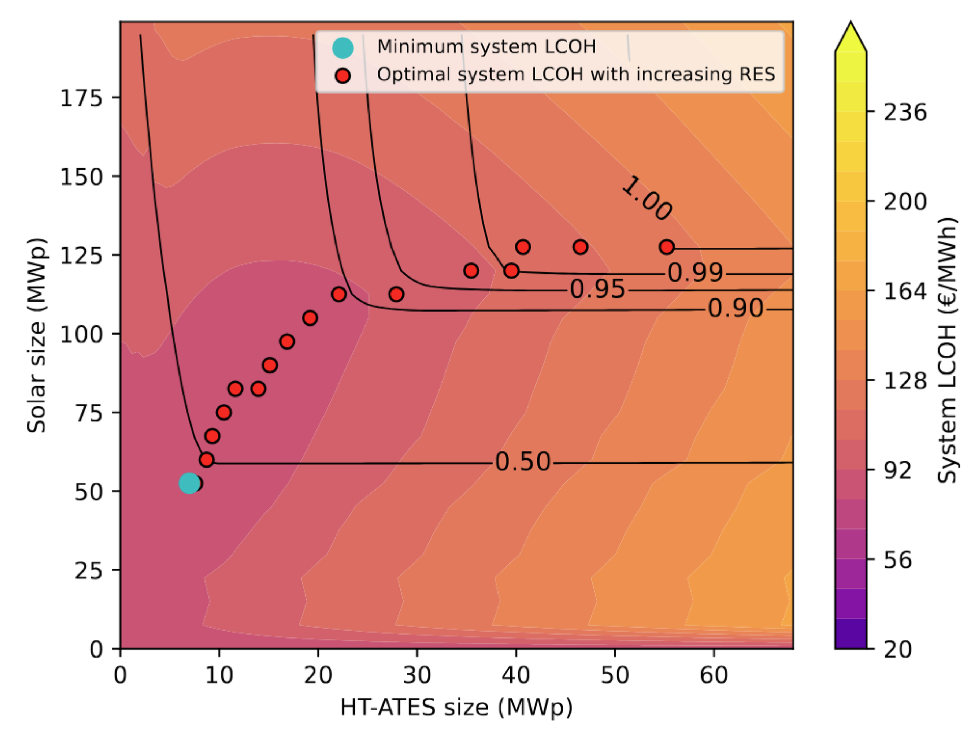


Figure: Solar + HT-ATES/ The lines in the plots correspond with the RES.

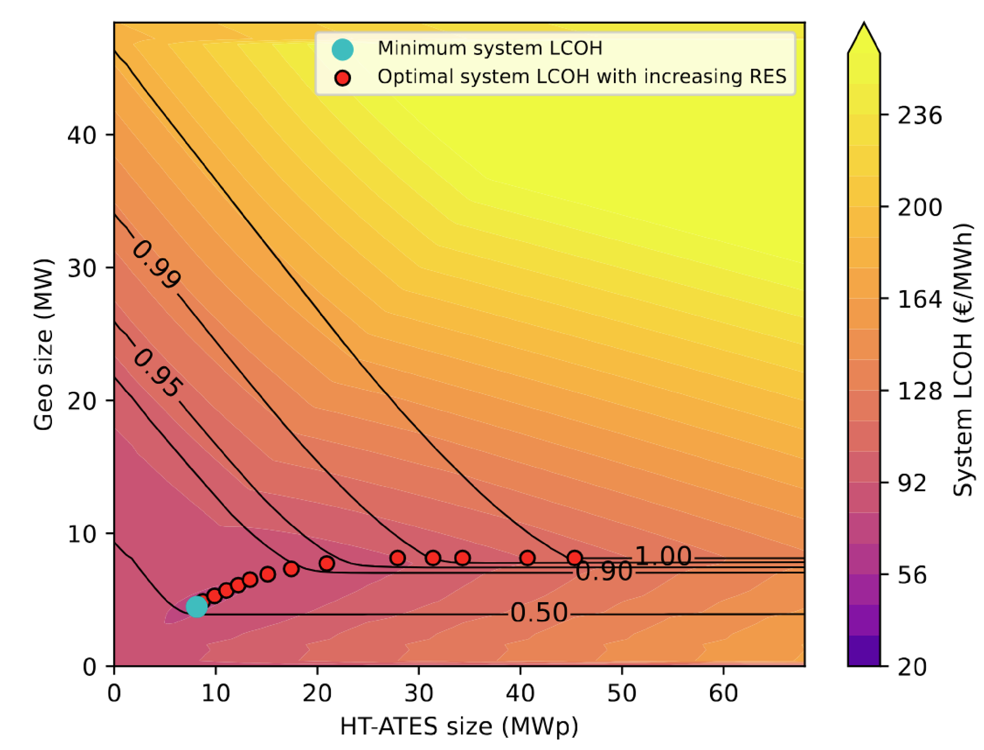


Figure: Geothermal + HT-ATES/ The lines in the plots correspond with the RES.

Conclusion

HT-ATES has its role in cost-effectively increasing RES and was also shown to be very efficient in reaching higher RES shares. However, the sizing of HT-UTES needs to be optimized together with the sustainable heat supply source. The cost-effectiveness is highly dependent on the sizing of all components (see outlook)

References

1. D. Geerts, A. Daniilidis, G. J. Kramer, M. Bloemendal, and W. Liu, "Analytically estimating the recovery efficiency for high temperature aquifer thermal energy storage using two-well simulations." *Geothermal energy*, 2025
2. D. Geerts, A. Daniilidis, and W. Liu, "A fast and accurate data-driven model for high-temperature aquifer thermal energy storage," Under Review at *Applied Thermal Engineering*, 2025.
3. D. Geerts, W. Liu, A. Daniilidis, P. Vardon, and G. J. Kramer, "Techno-economic analysis of high-temperature aquifer thermal energy storage in district heating systems." Under Review at *Energy*, 2025.
4. D. Geerts, A. Daniilidis, G. J. Kramer, and W. Liu, "Sizing optimization of district heating components with High-Temperature Aquifer Thermal Energy Storage: Techno-economic analysis," To be submitted, 2025.

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