# Demonstrating Low Temperature Grids: ATES as Flexibility for the E-Grid

Additional Information

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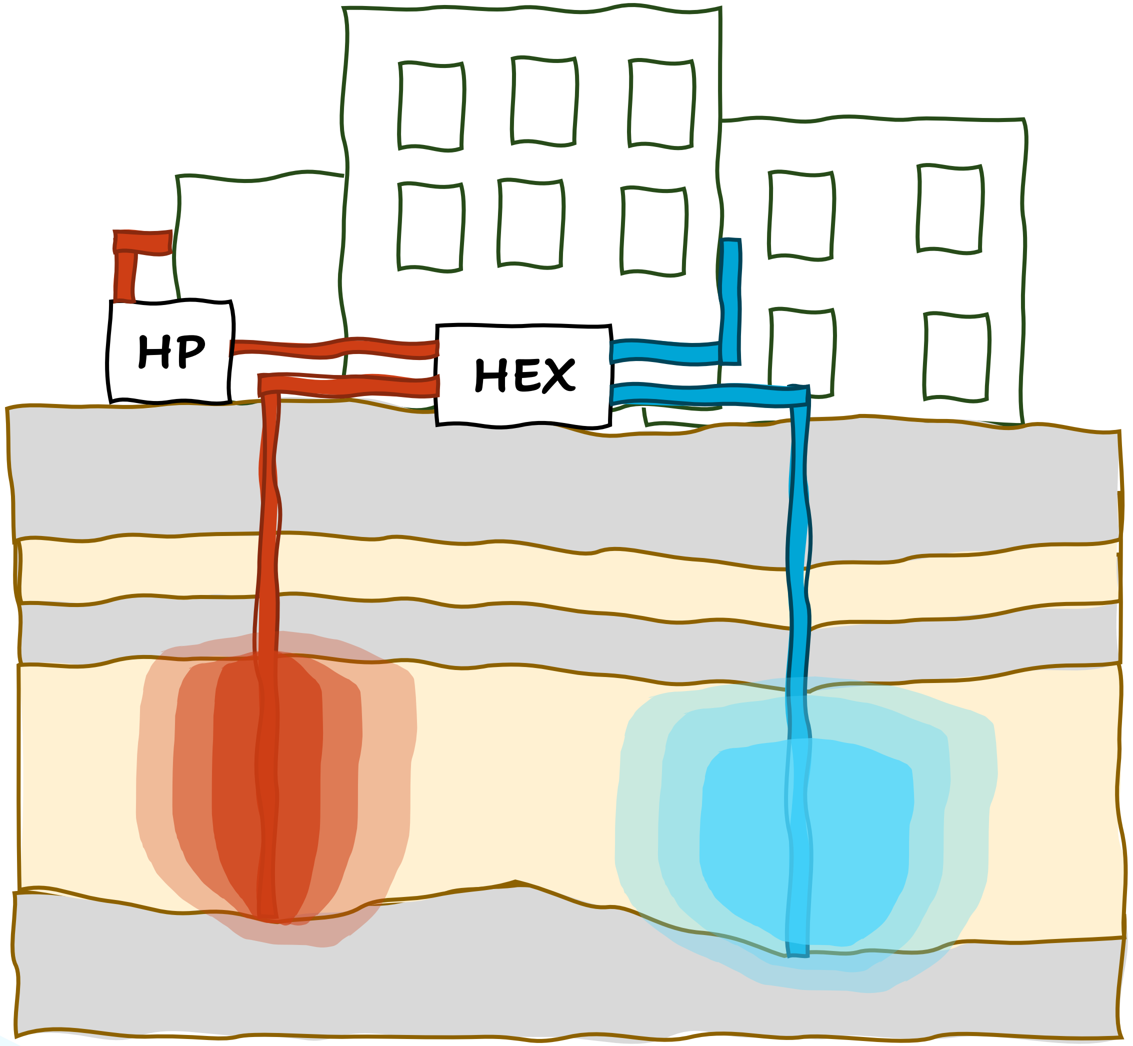


# Content

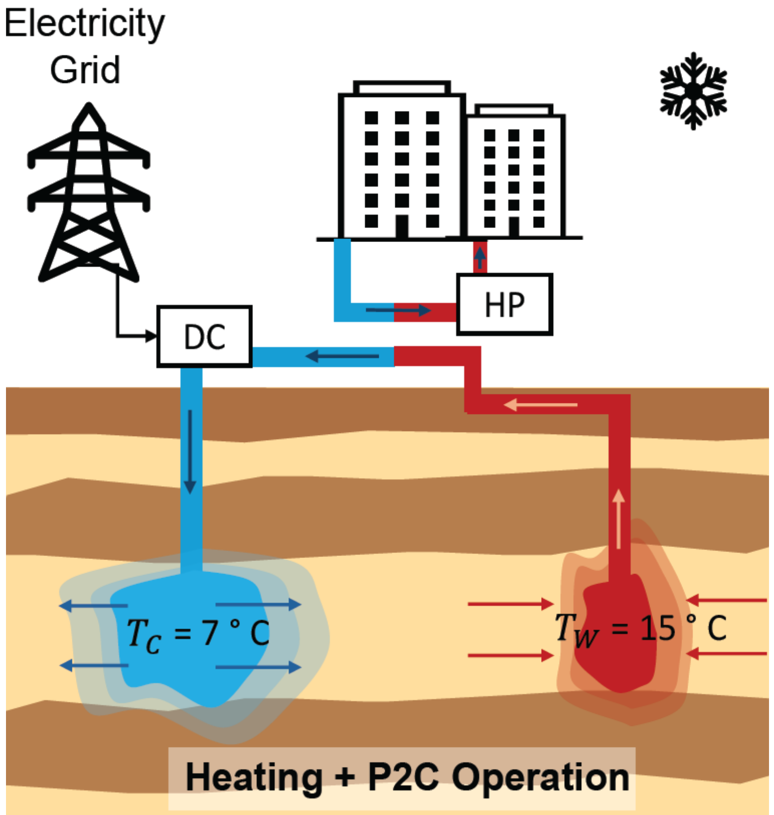
# Introduction

Case Study and Methodology

# Introduction

- **Problem**: heating and cooling systems contribute to congestion risk in electricity grids
- **Idea**: generate and store thermal energy when there is excess electricity (shift consumption to off-peak hours)

Supply-driven Power-to-heat (P2H) and Power-to-cooling (P2C) with ATES

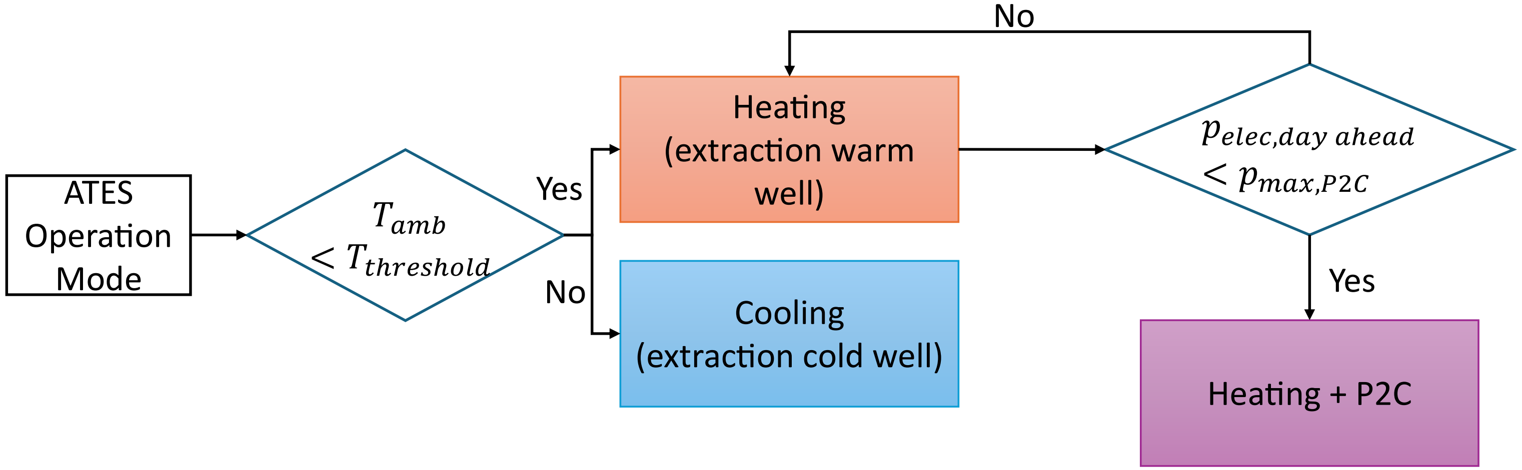


# Case Study: Delft Campus Zuid

- Cooling dominated system: $Demand_{cooling} > Demand_{heating}$

  → Apply Power-to-cooling

- Rule-based operation of the ATES:
  - Temperature threshold $T_{threshold}$: decides if heating or cooling mode
  - Price threshold $p_{max,P2C}$: decides if P2C is applied (when in heating mode)



# Methodology

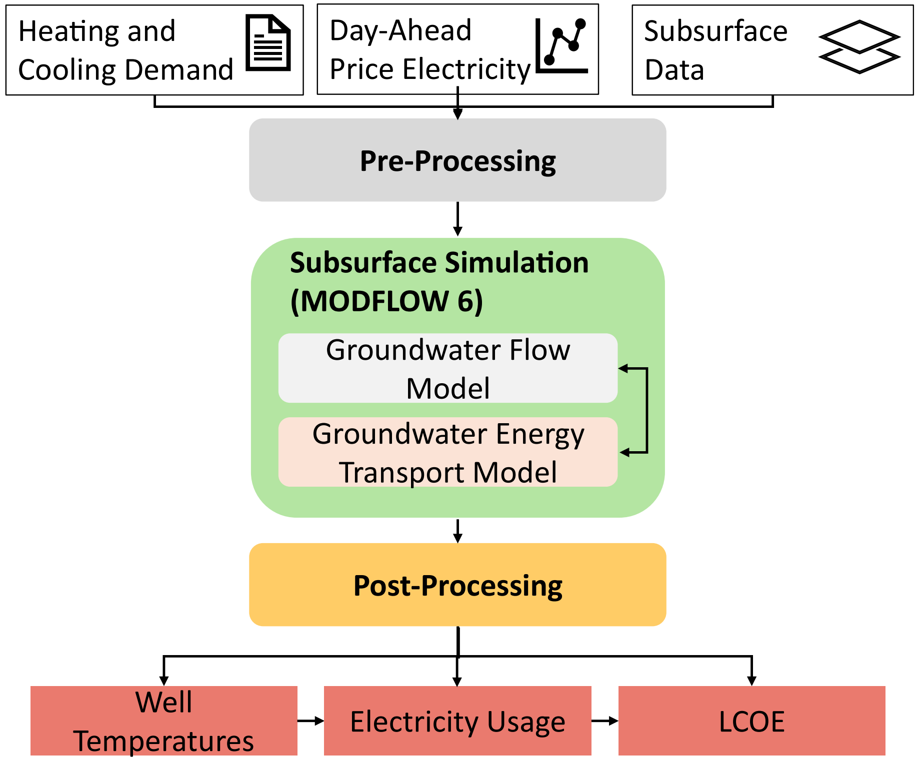
**Preprocessing:**

- Input = yearly heating and cooling demand
- *Degree Hour Method* example calculation heating demand $Q_{heat}$ in hour $h$:

$$Q_{heat}(h) = \frac{\max(T_{ref} - T_{amb}(h), 0)}{\sum_{i=0}^{8760} \max(T_{ref} - T_{amb}(i), 0)} \cdot Q_{year}$$

$T_{ref}$: reference temperature, $T_{amb}$: ambient temperature

- Injection and extraction flowrates based on hourly demand
- Restrictions: Maximum flow : 300 $\frac{m^3}{h}$

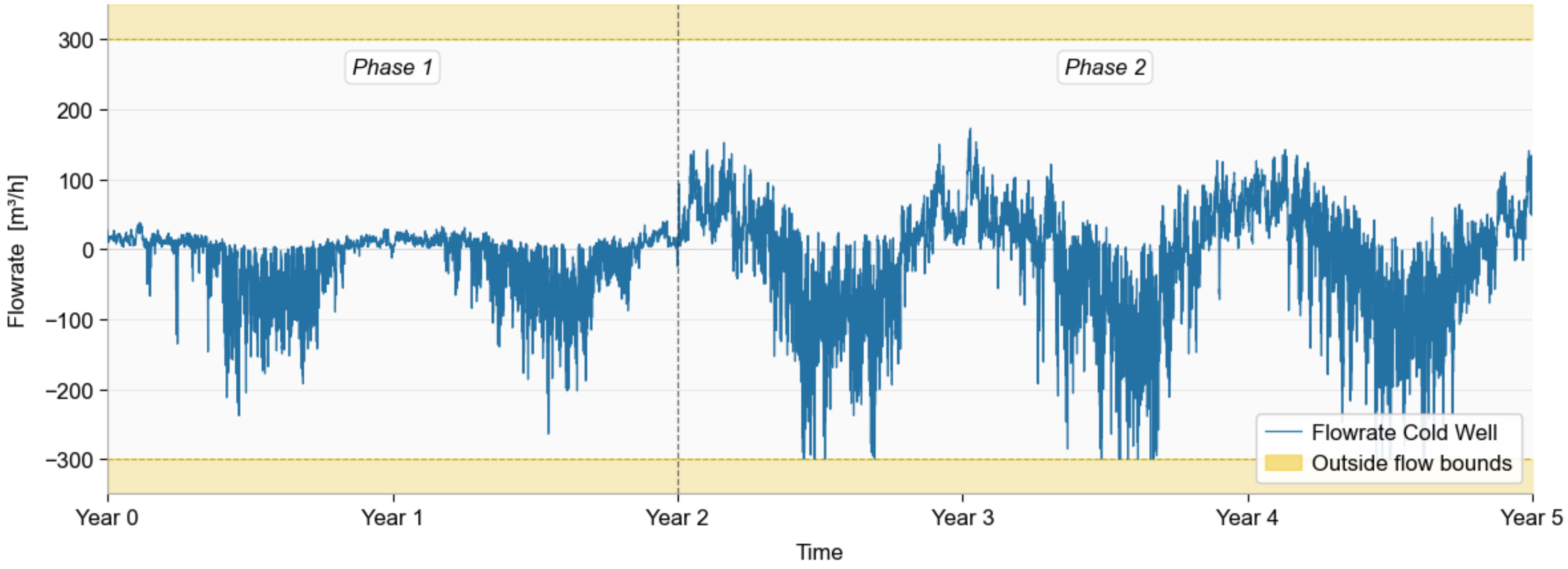



**Modflow 6 ATES Model**

- Separate axisymmetric models cold and warm wells
- Inputs: injection/extraction flowrates & injection temperature

# Flowrates and Injection Temperature

**Figure 1:** Demand based flowrates for the cold ATES well




- Two phases: higher demand after two years of operation
- Negative flowrates = extraction from the cold well

**Table 1:** Injection temperatures

| | Cold Well | Warm Well |
|---|---|---|
| T_inj (°C) | 7 | 15 |
| T_inj P2C (°C) | 5 | - |

Regeneration required
(imbalance extraction and injection)

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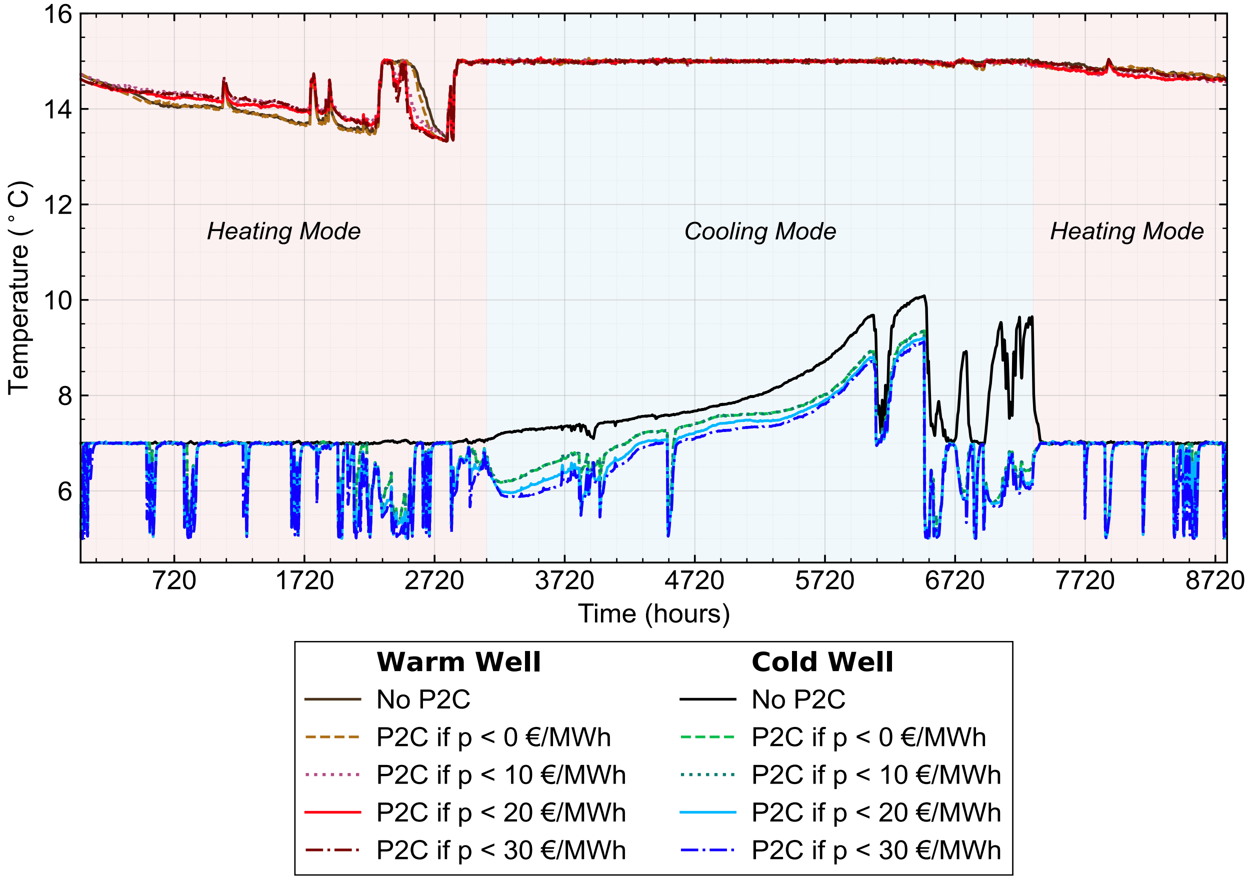
# ATES as Flexibility with P2C

Additional Graphics and Observations

# Well Temperature

**Figure 2:** Temperature at cold and warm well in year 4



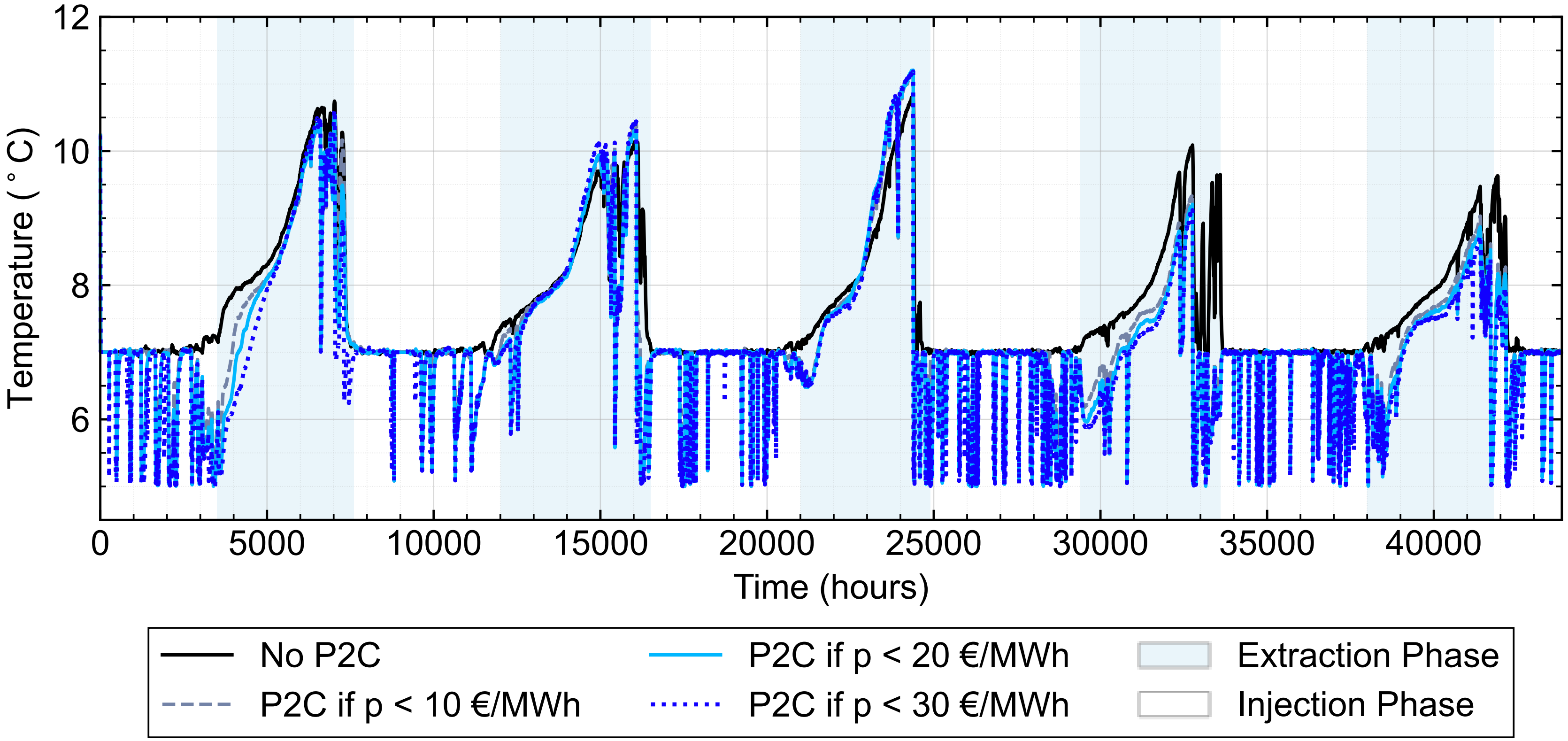

**Cooling Mode**: lower extraction temperatures at the cold well

**Price threshold**:

- Biggest difference from no P2C to P2C if p < 0 €/MWh
- Small additional reduction of cold well temperature by increasing price threshold

# ATES with P2C over 5 Years 1/3

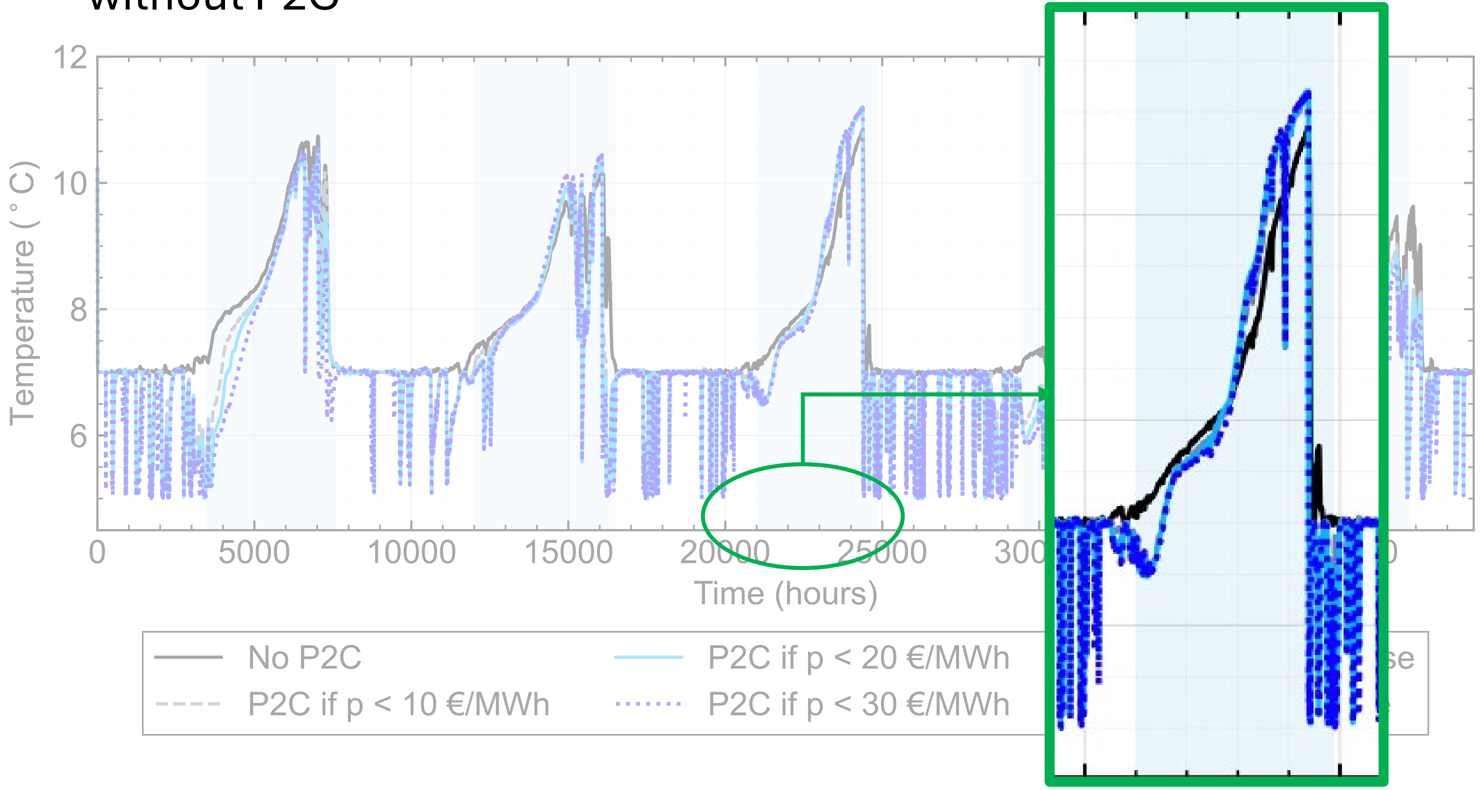
**Figure 3:** Temperature 1m from cold well over 5 years of operation with and without P2C




- P2C leads to mostly lower extraction temperatures during cooling season
- For 10, 20 and 30 €/MWh the cold well temperature in summer is similar, slightly lower for higher prices

# ATES with P2C over 5 Years 2/3

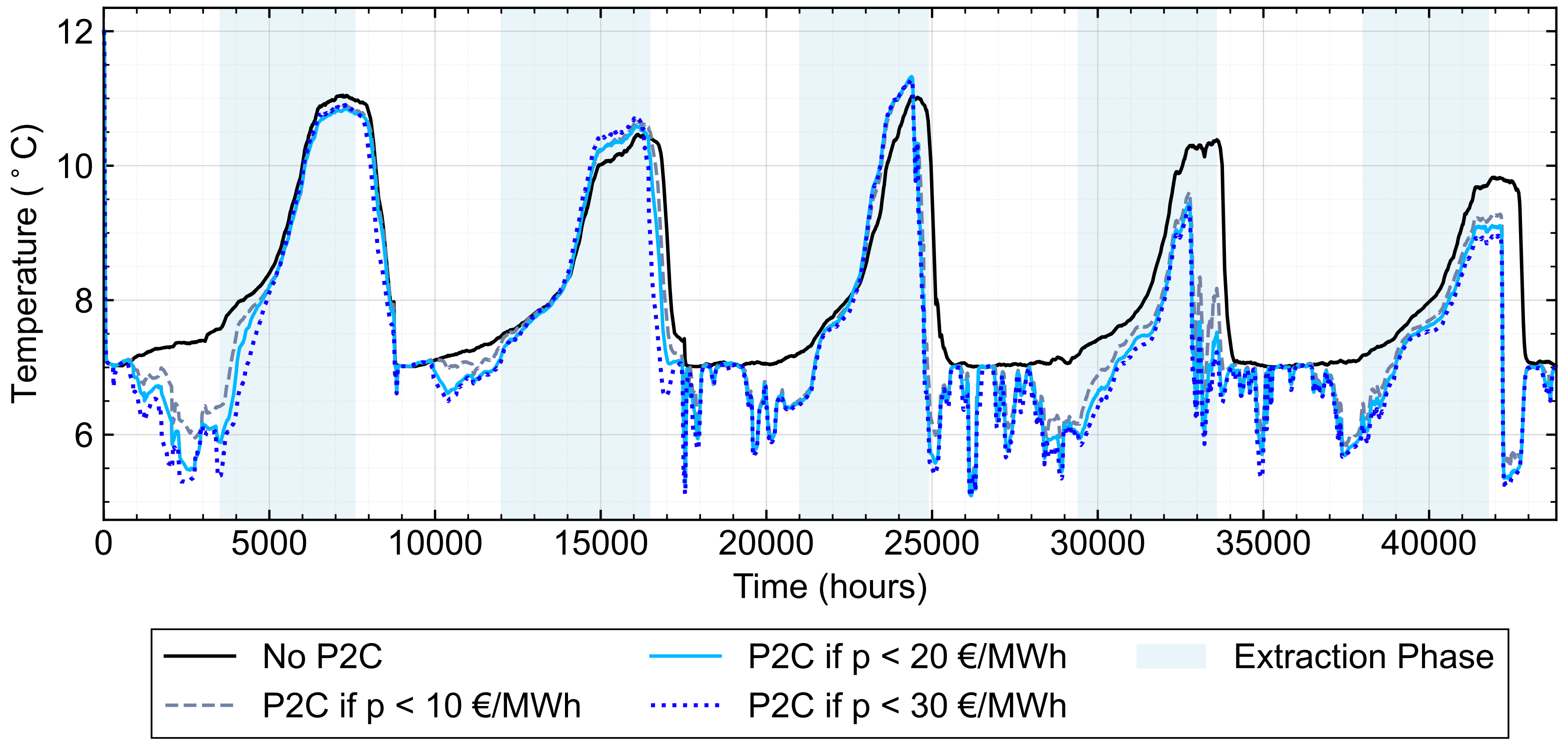
**Figure 3:** Temperature 1m from cold well over 5 years of operation with and without P2C




- If not enough P2C and additional regeneration before cooling season: **temperature spikes at cold well during summer**
- Regeneration cannot solely be planned based on electricity price

# ATES with P2C over 5 Years 3/3

**Figure 4:** Temperature 10m from cold well over 5 years of operation with and without P2C

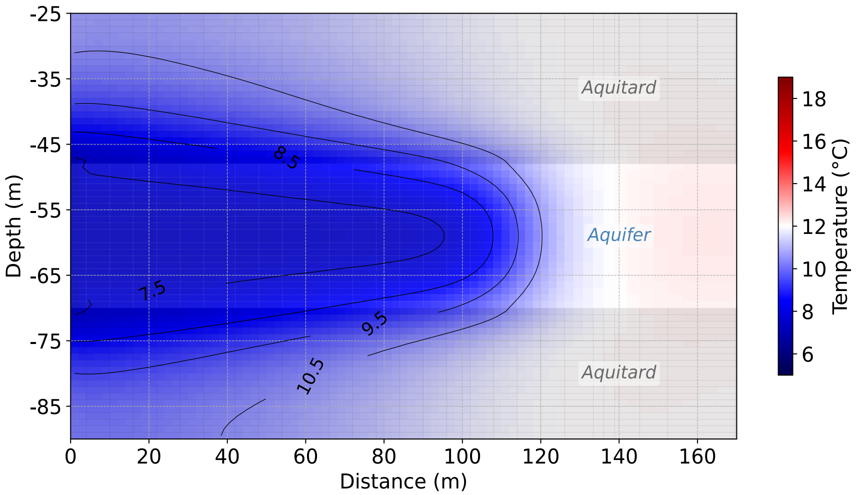



Further from the well: less fluctuations in temperature due to injection

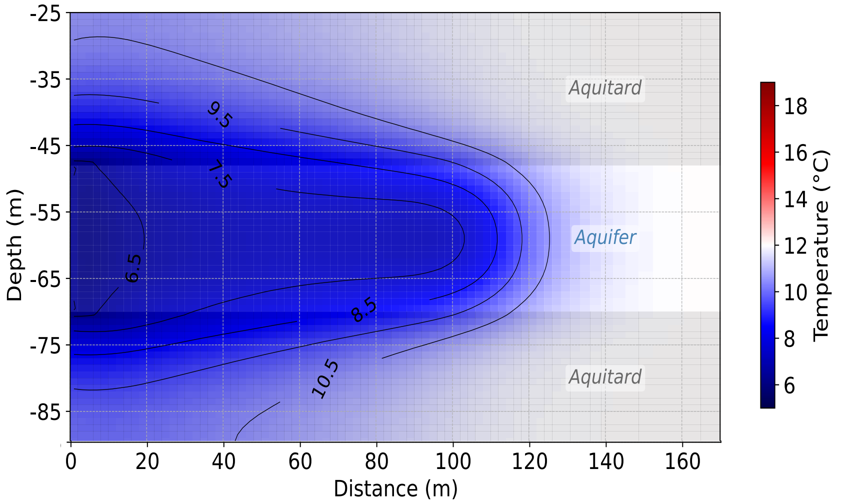
# Thermal Distribution in the Subsurface

**Figure 5:** Cold well cross section May year 5

**a)** Without P2C




**b)** With P2C, if p < 10 €/MWh

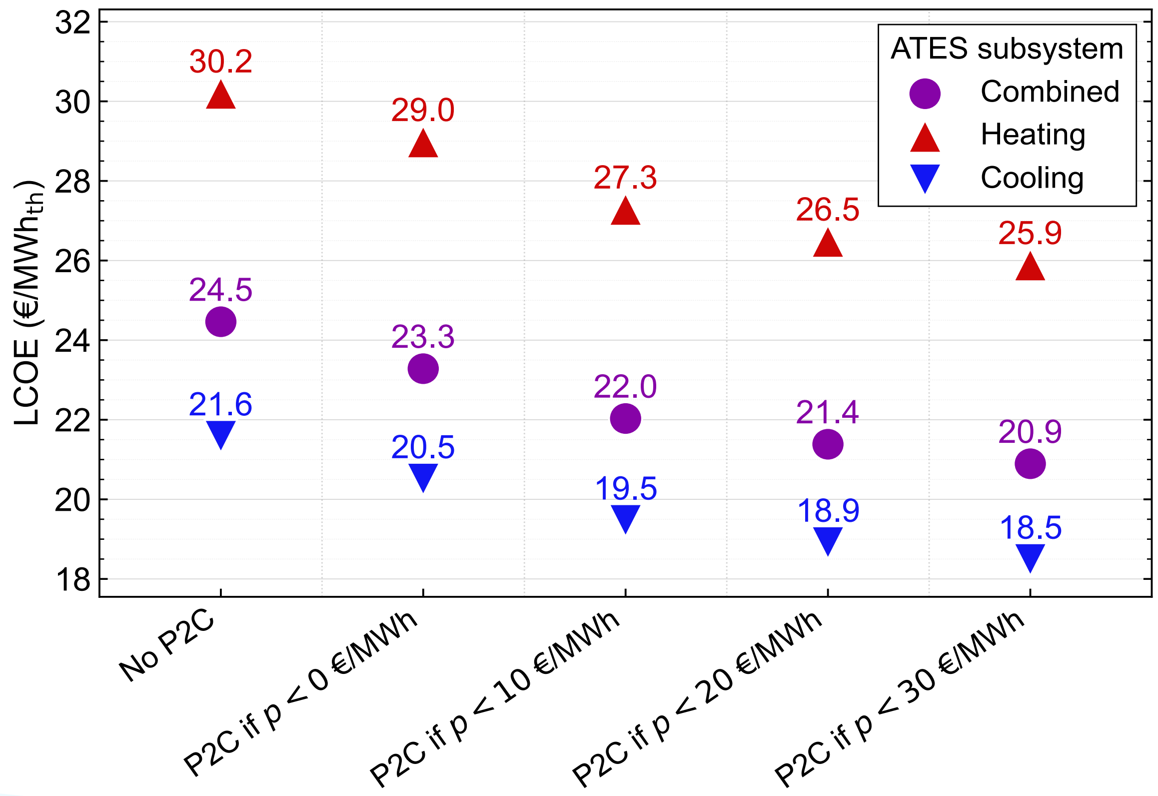



**With P2C**:

- Increased thermal radius of cold well
- Increased cooling of the confining aquitard layers

# Cost of Heating and Cooling with ATES

**Figure 6:** LCOE of P2C scenarios after 5 years




## P2C reduces costs of cooling with ATES

- For considered scenarios: higher price threshold, more savings in cooling costs
- What is the optimum price threshold?
- General electricity price level varies per years
  - → Set price threshold per year

## P2C seems to also affect LCOE of heating

- But: only due to increased extraction/heating supply during hours with low electricity prices
- Assumes that this heating is useful (needs to be evaluated, otherwise additional costs to remove excess heat)

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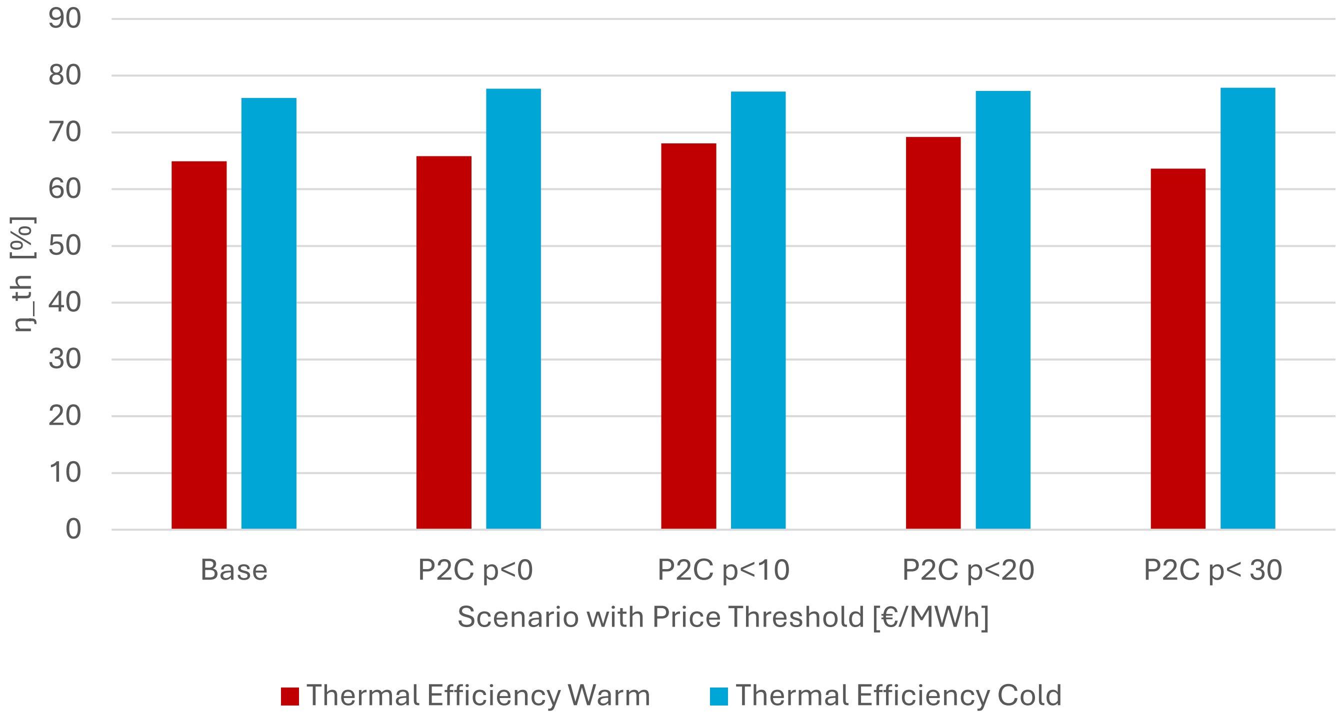
# Thermal Recovery Efficiencies

**Figure 7:** Thermal recovery efficiency of the warm and cold well after 5 years



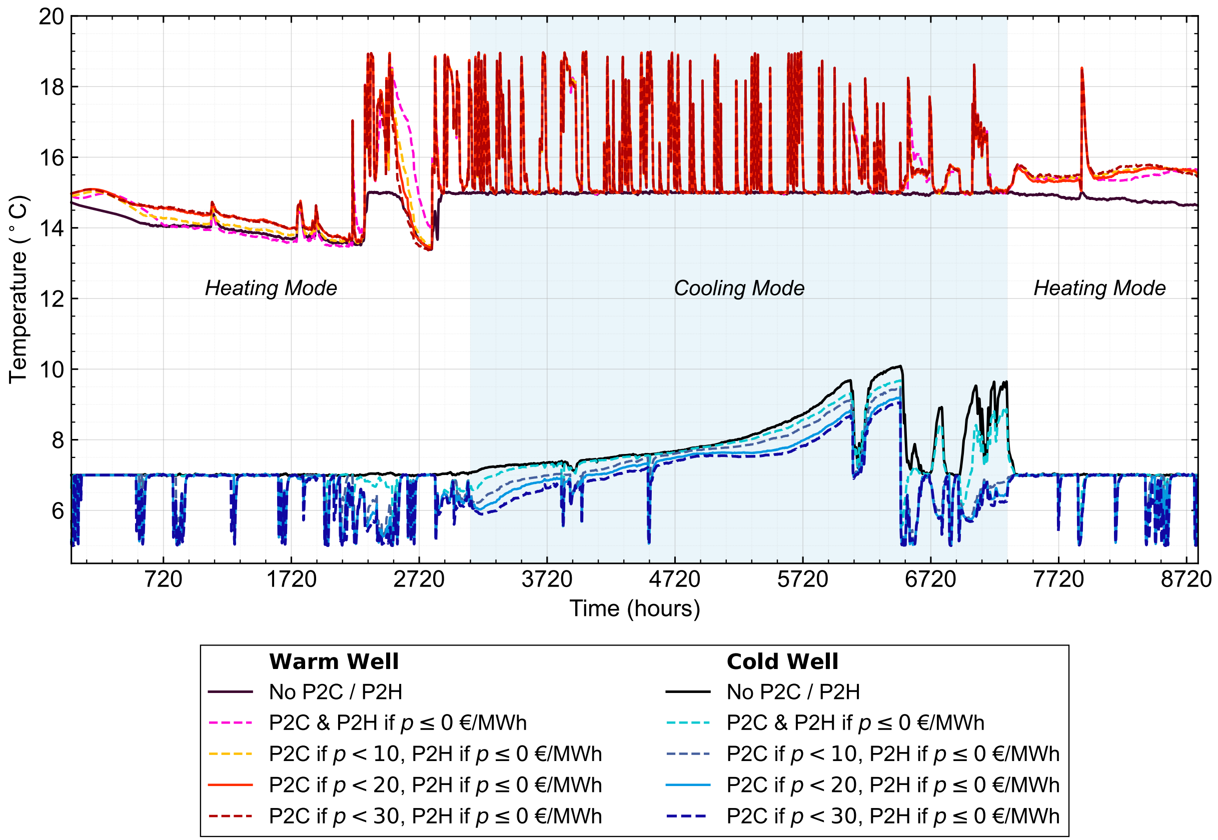

P2C operation has little effect on the thermal recovery efficiency of the ATES

# Combining P2C with P2H

Additional Graphics and Observations

# P2C & P2H: Well Temperature 1/2

**Figure 8:** Temperature at cold and warm well in year 4

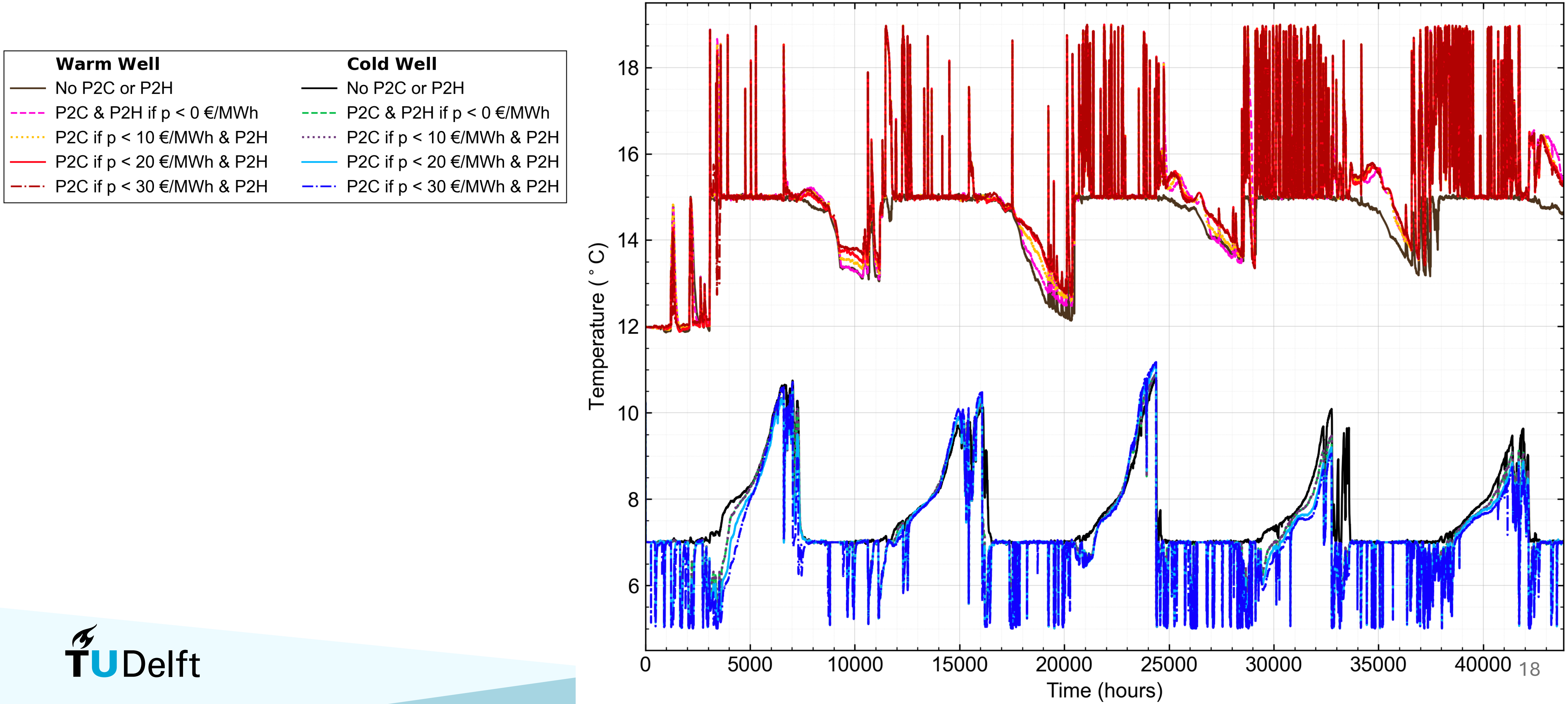



**Effect added P2H:**

- Increased well temperature of the warm well during heating
- Increased injection warm well → increased extraction cold well
- Increases cooling deficit through additional extraction

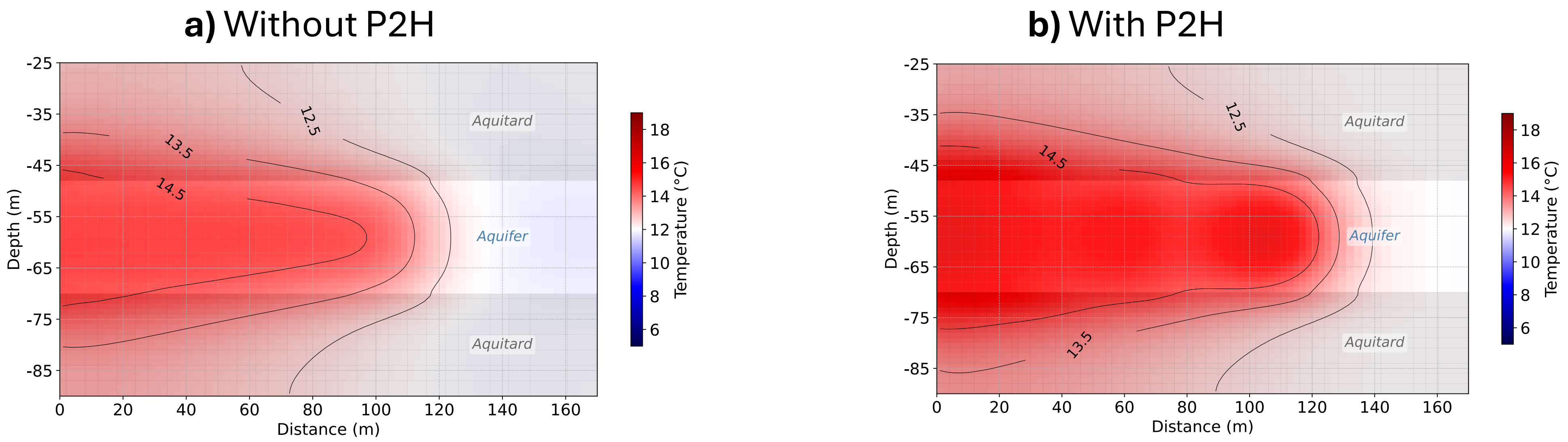
# P2C & P2H Well Temperature 2/2

**Figure 9:** Extraction temperatures over 5 years



# P2C & P2H Operation

**Figure 10:** Warm well cross section November year 5

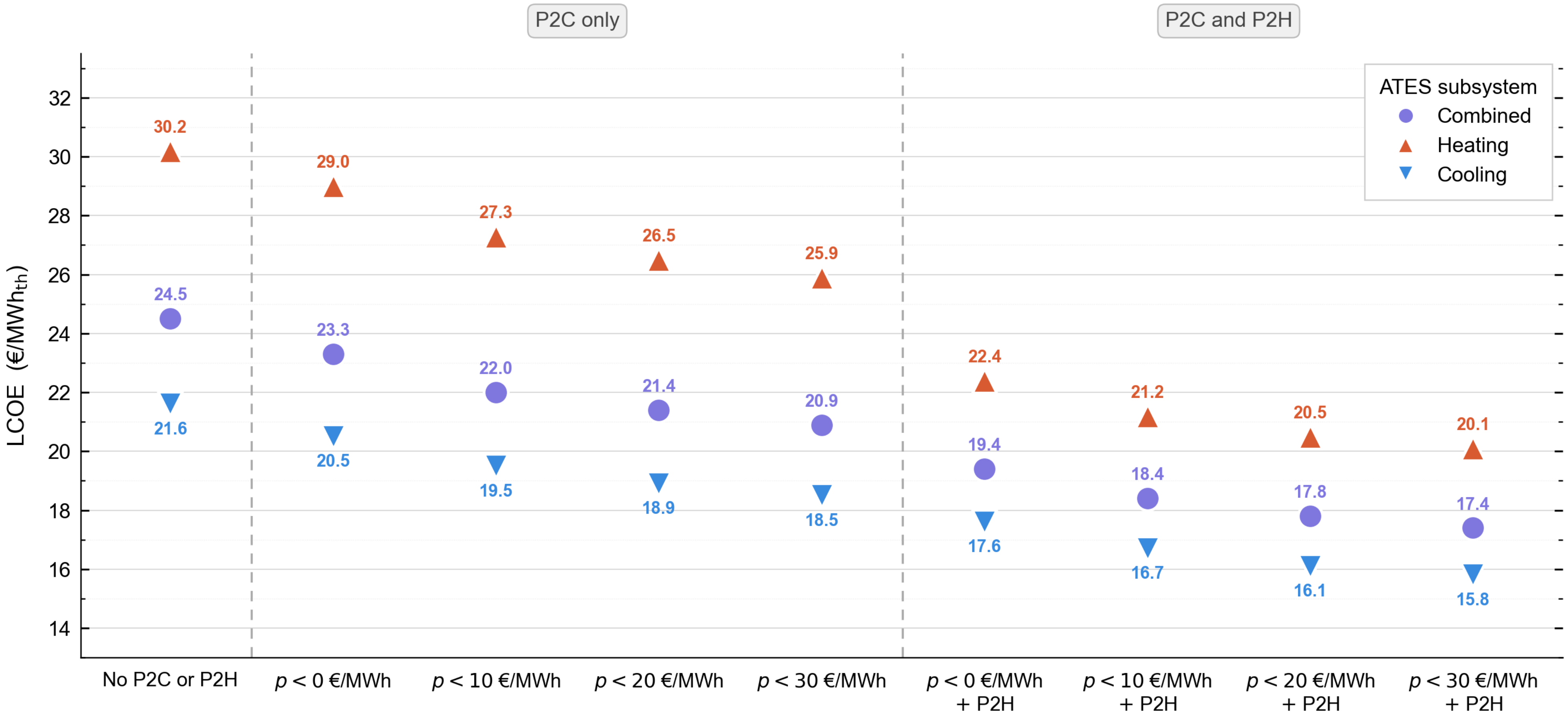



**With P2H:**

- Increased thermal radius of warm well
- Increased heating of the confining layers

# LCOE Analysis 1/2

**Figure 11:** LCOE after 5 years of operation in different scenarios

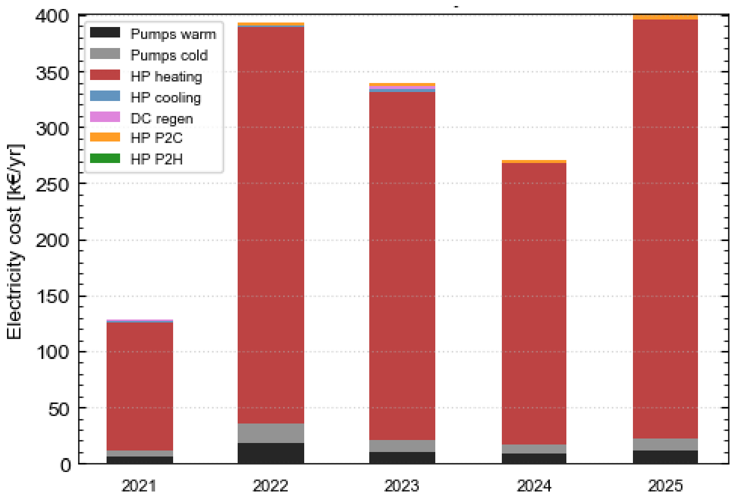


# LCOE Analysis 2/2

- P2H has a higher impact on the cost for heating than P2C has on the cost for cooling

- P2H reduces cooling costs by increasing extraction in hours with low prices (same for P2C and heating)

**Figure 12:** Annual electricity costs P2C (p < 30€/MWh) and P2H scenario




**P2H** if p < 0 €/MWh can **reduce the overall costs of the cooling dominated system.**

- Costs for using heat pump for heating dominate operational costs
- Increased cooling deficit: store additional extracted cooling in buffer tanks on the surface or shifting of cooling demand

# Final Reflection

Reflection on Assumptions and Results

# Key Assumptions & Limitations

- ATES model
  - No groundwater flow
  - No anisotropy within subsurface layers
- **Dynamics between subsurface and surface** components not included
- Scenarios
  - **Additional extraction of heating and cooling** in P2C/P2H scenarios usable on the surface
  - Reliable **predictions** of electricity price and demand
  - Complete **system costs** not calculated (heating & cooling without ATES not included)
  - No rules for lengths of switches

**Address Limitations**

- Additional Scenarios
- Uncertainty Analysis
- Modelling of Surface Components

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# Key Takeaways

**P2C and P2H** operation of ATES in cooling dominated systems is promising to provide **additional flexibility** to the electricity grid while **reducing costs** for heating and cooling.

- P2C reduces cost for cooling with the ATES
- P2H reduces costs for heating, but needs P2C
  (to reduce effect on cold well, while providing more flexibility for the electricity grid)
- Benefits of P2C strongly depend on electricity price and demand uncertainties