Operational Monitoring of Thermal Dynamics in Deep Geothermal Production and Injection Wells with Fiber Optics from the Surface to the Reservoir

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Introduction

To ensure a sustainable use of the deep geothermal resources, a reliable production must be ensured regarding well integrity, microseismicity, and thermal/hydraulic changes in the reservoir. Monitoring of a geothermal well during all life cycles is therefore crucial. However, conventional methods for measuring inside boreholes are usually temporally and spatially limited. Distributed fiber optic sensing allows for permanent monitoring of various physical parameters in high resolution during all times. This work focusses on the use of Distributed Temperature Sensing (DTS) in a deep hydrogeothermal reservoir.

The Upper Jurassic 'Malm' aquifer in the Bavarian Molasse Basin is Germany's most actively used geothermal reservoir. At a geothermal heat plant in Munich that consists of three doublets, a permanent fiber optic monitoring system was installed in 2019 in two wells. A third well is being equipped in 2024. Among others, the temperature data collected is being used for thermal and hydraulic characterization and monitoring of the reservoir and borehole.

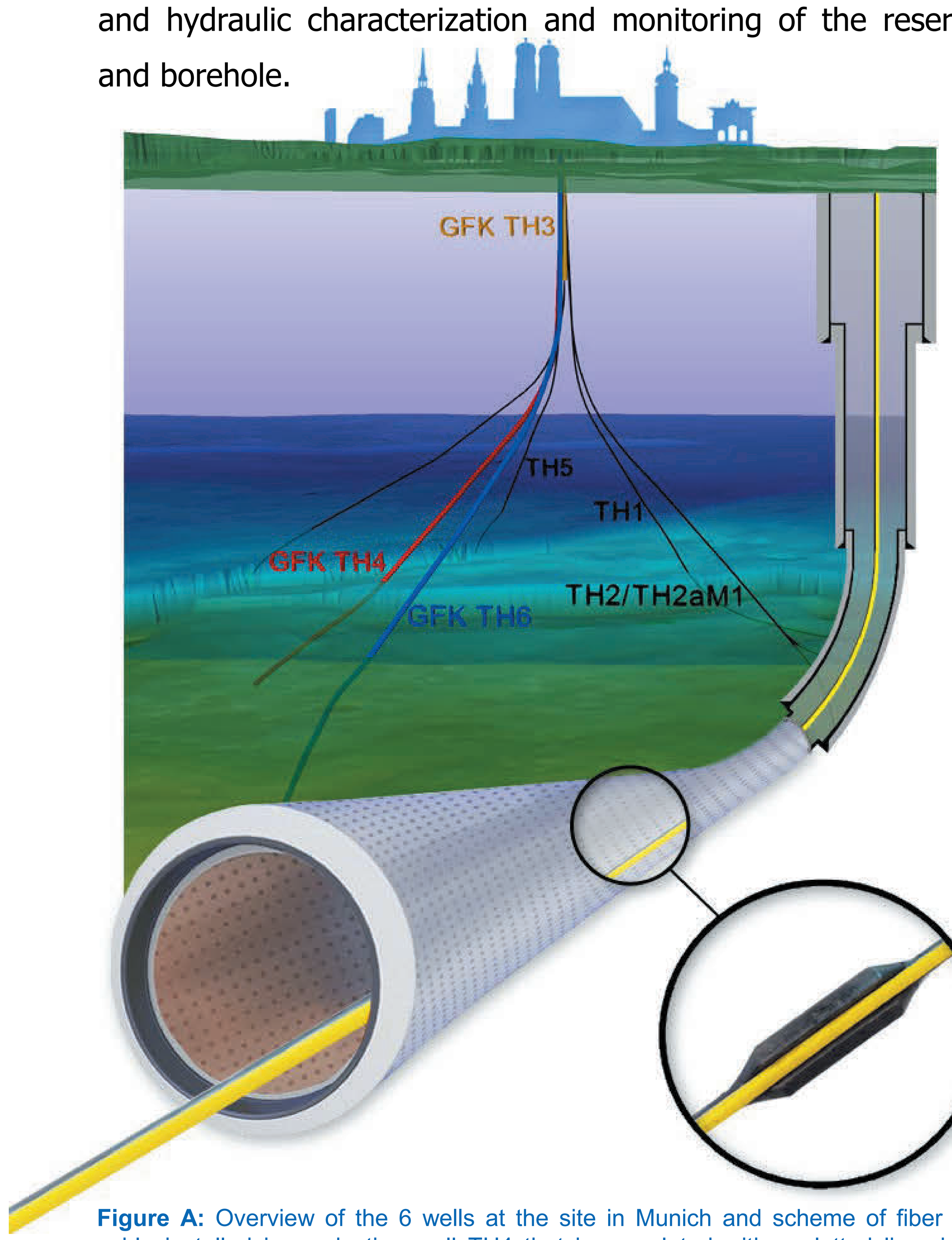


Figure A: Overview of the 6 wells at the site in Munich and scheme of fiber optic cable installed in production well TH4 that is completed with a slotted liner in the reservoir section. The cable (yellow) is attached to suspended sucker rods down to total depth of the borehole.

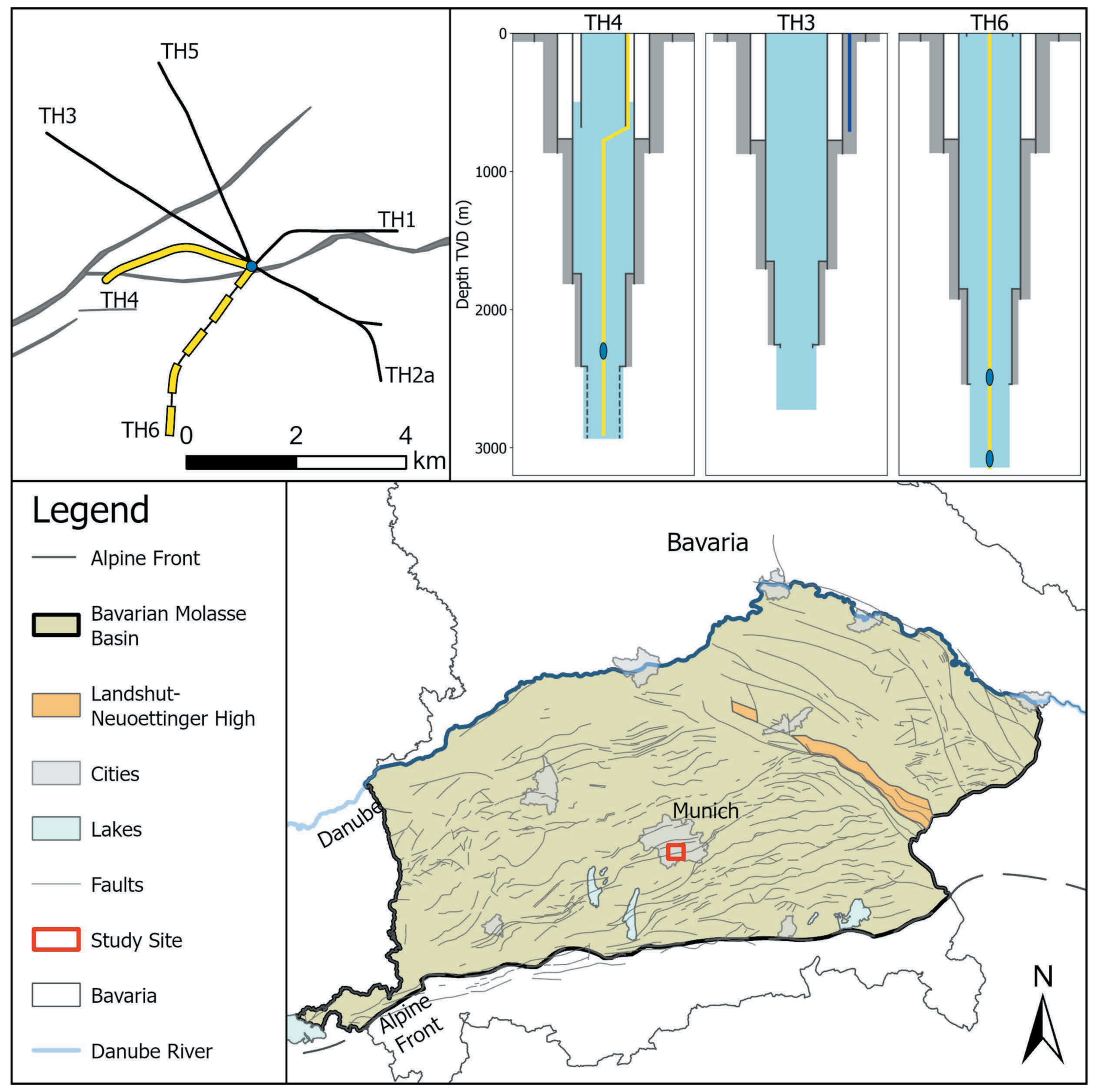


Figure B: Location and setup of the fiber optic monitoring system. A detailed view shows the paths of the six wells and the installed (yellow/blue) and planned (yellow dashed line) fiber optic cables in schematic views of the boreholes. The high deviation of the wells (up to 65°) is not shown in this figure.

Distributed Fiber Optic Sensing

Distributed fiber optic sensing (DFOS) is an optical measuring method that allows to continuously measure physical parameters such as temperature (DTS) and strain/acoustics (DAS) along fibers with high accuracy (DTS: 1 meter, 10 minutes, ± 0.6°C in this case). Distributed Temperature Sensing analyses specific parts of the backscattered light from laser pulses that are sent along the fiber to measure the temperature at each point in the fiber. The depth of each measuring point is calculated by the two-way travel time. Installation of fiber optic monitoring systems in geothermal wells is not yet standard and the installation can be technically challenging. Additionally, fiber optic pressure/temperature gauges are installed at this geothermal site to calibrate temperature readings and monitor the pressure in the reservoir.

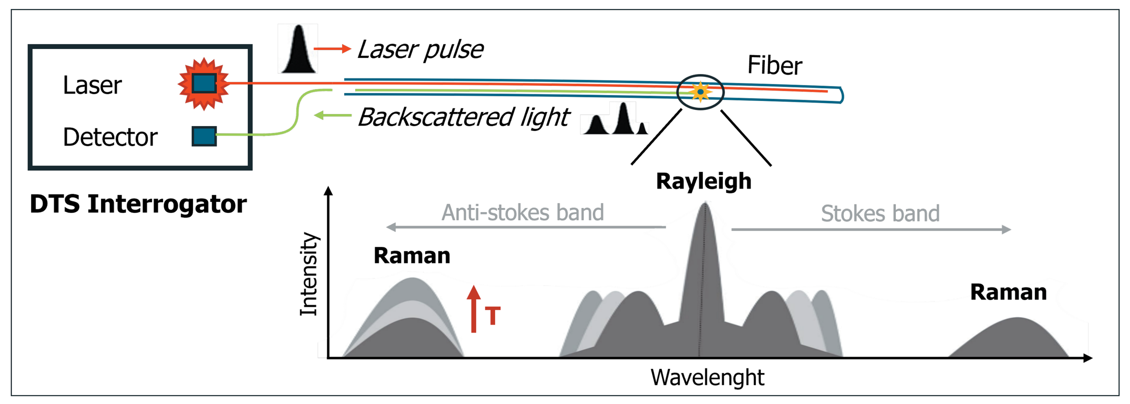
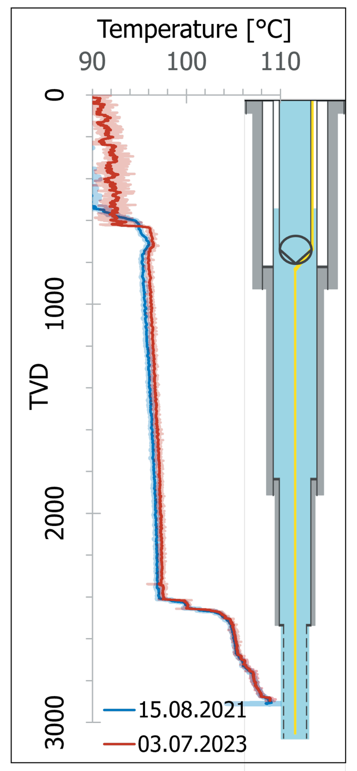


Figure C: Function principle of Distributed Temperature Sensing: An interrogator sends laser pulses along a fiber. In each location, parts of the light are backscattered. The backscattered light consists of different elements that are altered in intensity/wavelength depending on the temperature at the location of scattering. DTS looks at the ratio of Raman Anti-Stokes and Stokes to calculate the distributed temperature. Modified after [1].

DTS Data Interpretation Results

The temperature data collected in the producer TH4 is used as a permanent monitoring system and to address topics in the borehole and reservoir that can not be quantified using conventional data:



- Geothermal gradient assessment
- Flow zone interpretation & observation
- Reservoir pressure
- Interference between wells
- Production temperature tracing and prognosis
- Lithology assessment
- Fluid level detection
- Heat loss quantification (heat conductivity)
- Pump monitoring
- ...

Figure D: DTS profiles of TH4 during different times of maximum production (115 l/s).

Interaction between Wells

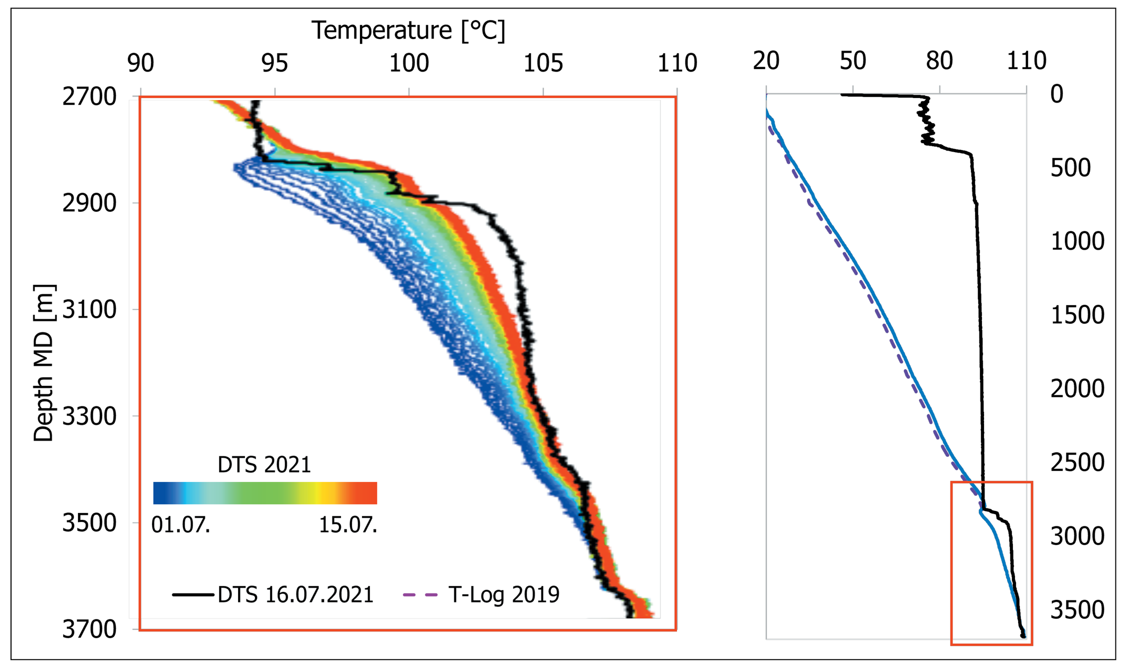


Figure E: DTS profiles of production well TH4 during shut-in 16 month after a cold-water injection and subsequent first commissioning in 2021. On the 02.07.2021 the producer TH1 and the injector TH3 went into production influencing the temperature in the borehole of well TH4. A hydraulic connection is also visible in the pressure data (-1.6 bar in TH4). Th4 went into production on the 16.07.2021.

Fluid Level Detection

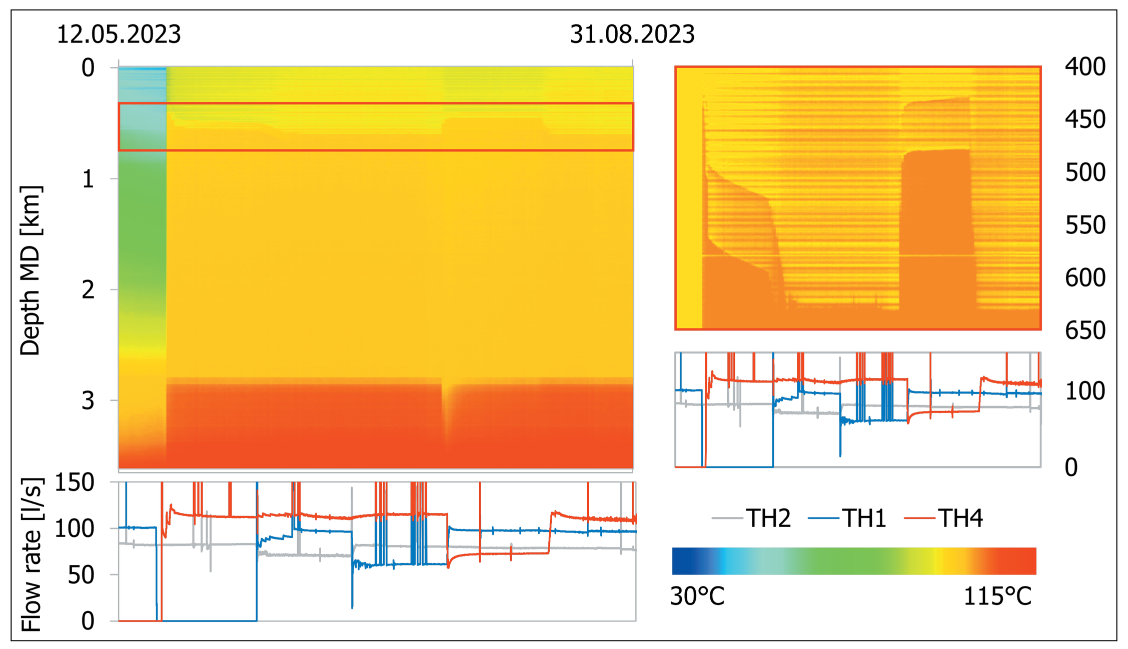


Figure F: Heat plot of DTS data from well TH4 during long-term pumping and injection tests in 2023 and flow rates of the three production wells. The fluid/gas interface is visible in the sharp temperature contrast. A doubling of this interface might indicate an oil phase on top of the thermal water.

Hydraulically Active Zones Monitoring

The Malm aquifer is a heterogenous carbonate aquifer with a complex interplay between fractures, karstification and dolomitization that control permeability. The hydraulically active zones derived from conventional production logging (PLT spinner) could be confirmed and quantified more precisely by DTS data through injection profiling [2] and especially inverse modelling of production profiles [3] in 2021 and repeatedly during the following production phase.

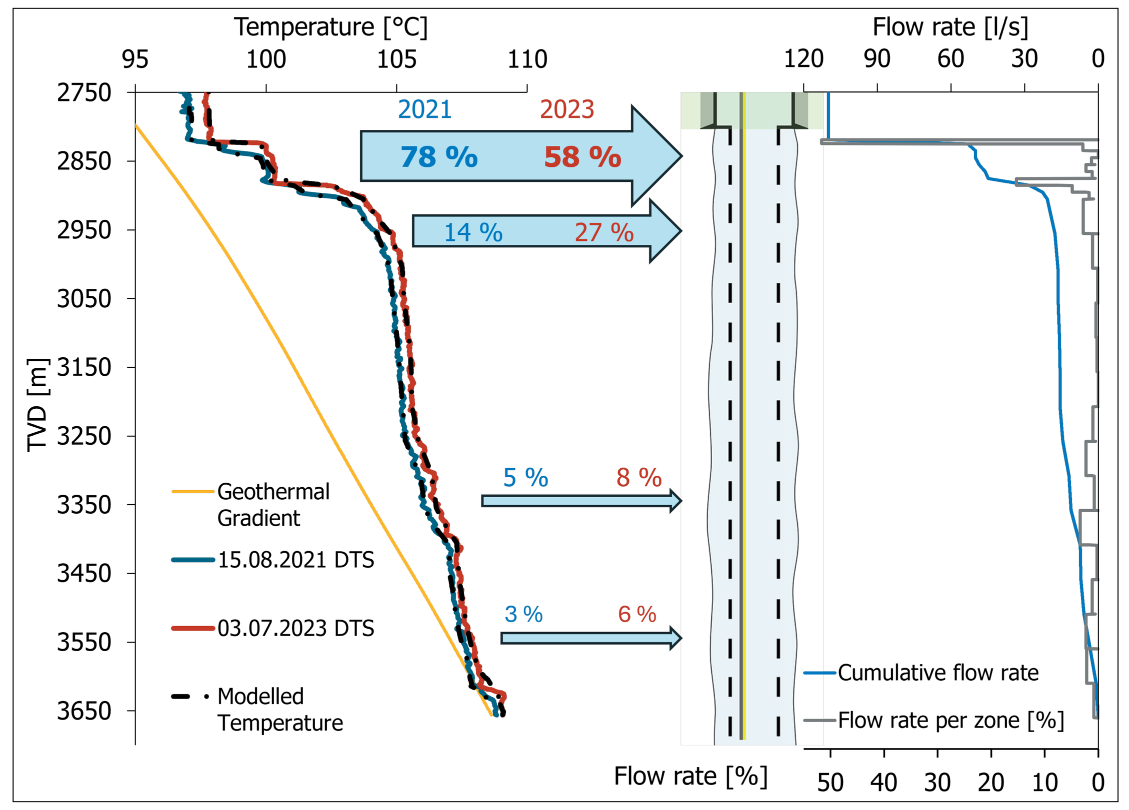


Figure G: The inversely modelled hydraulically active zones from DTS profiles for 2 different times in the reservoir of TH4. The 2 uppermost flow zones can be linked to strongly karstified areas. Within 2 years, production temperatures increased by 1°C, which can possibly be explained by shifts in the flow zones.

Conclusion & Outlook

A technically challenging permanent installation of fiber optic cables down to total depth could be implemented that allows for permanent distributed temperature sensing, point pressure measurements and also distributed acoustic sensing. With DTS analysis, the reservoir knowledge could be deepened. Especially the temperature distribution and the hydraulic/thermal behavior in the reservoir will help in targeting for future projects in the Malm reservoir. In spring 2024 a FOC will be installed in an injector at the site down to total depth to monitor a geothermal doublet for the first time. Here, relevant topics will also include hydraulically active zone interpretation, interaction analysis of the multi-well site and injectivity monitoring.

References

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2. Schölderle, F., Lipus, M., Pfrang, D., Reinsch, T., Haberer, S., Einsiedl, F., Zosseder, K. (2021). Monitoring cold water injections for reservoir characterization using a permanent fiber optic installation in a geothermal production well in the Southern German Molasse Basin. Geothermal Energy, 9(1)

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GFK Monitor
GFZ Helmholtz-Zentrum Potsdam
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SWM Stadtwerke München
Fraunhofer IEG
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