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TRANSGEO

Proof-of-concept study on reuse of abandoned wells for DBHE development

TRANSGEO Deliverable 1.1.1

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Executive Summary

Deep Borehole Heat Exchangers (DBHEs) are an emerging geothermal technology that extend the concept of shallow borehole heat exchangers to greater depths, enabling more efficient heat extraction from the subsurface. Operating as closed-loop systems, DBHEs circulate a heat carrier fluid within a borehole, extracting geothermal energy via conduction without requiring an aquifer. Compared to shallow systems, DBHEs achieve higher temperatures due to increased depth, making them particularly suitable for heating applications and thermal energy storage.

A key advantage of DBHE technology is its compatibility with existing oil and gas infrastructure. Repurposing abandoned hydrocarbon wells significantly reduces drilling costs, which are otherwise a major barrier to deployment. Field experience from European pilot sites (Germany, Austria, Slovenia) demonstrates that such systems are technically mature, operationally robust, and capable of delivering reliable heat over decades. Even under moderate geothermal conditions, DBHEs can supply low-temperature heat for residential, agricultural, and industrial use, confirming their broad applicability beyond high-gradient geothermal regions.

System performance is primarily governed by geological conditions (geothermal gradient, depth, and rock thermal conductivity) and operational parameters, particularly heat extraction rate and fluid circulation. Higher depths and gradients yield better thermal output, while excessive heat extraction can lead to rapid temperature decline and reduced long-term performance. Optimal system design therefore requires careful matching of heat demand with sustainable extraction rates. Continuous, stable heat demand is critical for economic and technical success.

The preferred technical configuration is a coaxial system with annular inflow, which maximises heat transfer and minimises thermal losses. While design factors such as pipe material, insulation, and working fluid influence efficiency, their impact is secondary compared to system-level optimisation of flow rates and demand management. Water remains the standard working fluid due to its reliability and cost-effectiveness.

Economic viability depends largely on proximity to a stable heat consumer and limited heat transport distances (<3 km). Case studies show that DBHE projects can achieve positive returns under favourable conditions, particularly when supplying continuous heat demand. However, high upfront investment costs and regulatory uncertainties, regarding liability for repurposed wells, remain key challenges.

Feasibility analyses indicate that a typical 2,500 m deep DBHE in Central Europe can deliver 100–300 kW of thermal power and approximately 1,400 MWh annually under sustainable operation. While technically and legally feasible, commercial viability depends on heat prices, subsidies, and optimised system integration. Repurposing existing wells significantly improves project economics and represents a strategic opportunity to convert legacy fossil infrastructure into low-carbon heat supply systems.

The TRANSGEO project (https://www.interreg-central.eu/projects/transgeo/) is co-funded by the European Regional Development Fund through the Interreg Central Europe program. The overall objective of TRANSGEO is to investigate the potential to transform abandoned hydrocarbon wells into new sources of green geothermal energy. To reach this goal, the TRANSGEO team is providing new tools and knowledge to support communities and industries in the energy transition and to break down economic and technical barriers to well reuse.

A. Description of technology

Deep Borehole Heat Exchangers (DBHEs) are based on the well-established technology of shallow Borehole Heat Exchangers (BHEs), which form the foundation of geothermal heat extraction. While shallow BHEs are widely applied and considered state-of-the-art in the new building sector, DBHEs remain a relatively uncommon technology. Both systems operate on the same fundamental principle: a heat carrier fluid circulates in a closed-loop within a single borehole, without the need for an aquifer, transferring heat from the surrounding subsurface by conduction (Lund and Boyd, 2016; Raymond et al., 2015a). The extracted heat is utilised by surface installations according to site-specific demands before the cooled fluid is reinjected into the borehole (Gascuel et al., 2022).

In the literature, DBHEs have been discussed as an alternative to Enhanced Geothermal Systems (Doran et al., 2021; Falcone et al., 2018; Renaud et al., 2019). Unlike shallow BHEs, which typically employ U-tube or double U-tube configurations, DBHEs are usually constructed as coaxial systems (Koltzer et al., 2024). There is no universally accepted depth threshold defining a DBHE, with classifications ranging from depths exceeding 200 m to several thousand metres depending on regional practices (Piipponen et al., 2022). Despite the shared operating principle, shallow and deep systems differ in application: shallow BHEs can provide both heating and cooling, whereas DBHEs are primarily designed for heating and thermal energy storage (Sliwa et al., 2015).

Numerous simulation studies and operational data have demonstrated that heating performance increases significantly with depth, resulting in higher return fluid temperatures in DBHE systems (Holmberg et al., 2016; Lund et al., 2020; Wang et al., 2017; Piipponen et al., 2022). As a consequence, DBHEs require less surface area than shallow closed-loop systems to meet the same heating demand and are particularly suitable for applications with dominant heating loads and limited space availability, such as densely populated areas (Cai et al., 2021; Deng et al., 2019a). However, high drilling costs and concerns related to well integrity remain major barriers to widespread adoption (Kolo et al., 2023). Repurposing existing oil and gas wells that are no longer in use is considered a promising strategy to improve the economic feasibility of DBHE projects.

System performance is strongly influenced by well configuration. The most effective DBHE design is a coaxial system with annular inflow, in which the fluid descends in the outer annulus and ascends through an inner pipe. This configuration provides superior thermal contact with the surrounding rock and reduces heat losses from the ascending fluid, particularly in the cooler upper sections of the borehole. Compared to U-tube systems, it also enables higher flow rates for the same borehole diameter (Holmberg et al., 2016; Kalmar et al., 2020; Law et al., 2014; Wang et al., 2017). Coaxial systems with centred inflow are less efficient for heating purposes (Law et al., 2014; Wang et al., 2017).

Water is commonly used as the working fluid due to its favourable balance between cost and thermal performance, with antifreeze additives applied when necessary. Alternative fluids such as CO_2 are being investigated for improved heat transfer and reduced friction losses, though challenges related to corrosion and high-pressure operation persist (Gascuel et al., 2022). The use of additives to enhance thermal performance is also under evaluation (Alimonti et al., 2018).

Given the wide range of parameters influencing DBHE performance, comprehensive analysis, modelling, and design optimisation are essential before system implementation to ensure efficient and economically viable operation.

B. Lessons learned

The combined experience from the reference site Landau (Germany; D 1.1.6), the TRANSGEO pilot sites Rakičan (Slovenia; D 2.3.6), and Weinviertel (Austria; D 2.3.2) combined with the generic modelling results (D 1.1.6) confirms that deep borehole heat exchangers in repurposed hydrocarbon wells are a technically mature, economically viable, and environmentally sound option for local heat supply. Success depends less on advanced materials or complex designs and more on the quantification of realistic heat demand, favourable thermal conditions, optimal operational control, and supportive regulatory frameworks.

Repurposing existing hydrocarbon wells for DBHE is technically proven and robust, which is demonstrated by the long-term operation of the DBHE installations in Landau, where depleted hydrocarbon wells were successfully repurposed into deep borehole heat exchangers and are reliable over decadal timescales. Continuous operation for more than ten years confirms the mechanical integrity, thermal stability, and operational robustness of coaxial DBHE systems when properly designed and installed. The pilot studies in Weinviertel and Rakičan further confirm that this concept is transferable to other geological settings, provided that minimum thermal conditions are met. Even under moderate geothermal gradients and reservoir temperatures, DBHE systems can deliver useful low-temperature heat for space heating, agricultural, or commercial applications. Technical feasibility is not limited to exceptional geothermal anomalies such as the Upper Rhine Graben. Instead, DBHE systems represent a broadly applicable solution for utilising existing deep wells across sedimentary basins in Europe.

Geothermal gradient, depth and thermal conductivity are the dominant geological success factors across all investigated sites and confirmed by generic modelling; the geothermal gradient and effective usable well depth are the most influential geological parameters controlling outlet temperature and long-term sustainability. Lessons learned include that high geothermal gradients (as observed in Landau) enable outlet temperatures above 30 °C over decades, allowing direct heat use and significantly improving project economics. Under average gradients (~30 K/km), outlet temperatures decline rapidly for comparable heat extraction rates, often necessitating heat pump integration. In repurposing projects, cementation depth and selection of the active heat exchange interval play a critical role in maximising thermal performance. These findings underline that thermal conditions must be assessed early and conservatively, as they define the feasible heat demand and determine whether “free heating” or heat-pump-supported systems are realistic.

The heat demand management is the key lever for sustainable operation, as generic modelling clearly shows. The heat extraction rate is the single most influential operational parameter affecting outlet temperature and long-term system performance. Overextraction leads to rapid temperature decline and may render direct-use applications unviable. Conservative heat demand significantly improves outlet temperatures and long-term stability, even under modest thermal conditions. There is a direct trade-off between short-term heat output and long-term sustainability, which must be explicitly managed. This leads to the conclusion that DBHE systems must be designed starting from realistic, continuous heat demand profiles, rather than from maximum technically achievable output. Matching the system to a stable, year-round consumer is more important than maximising installed capacity.

Both site data and sensitivity analysis demonstrate that **there is an optimal circulation rate for each DBHE configuration**. Deviating from this optimum—either higher or lower—can reduce outlet temperature due to thermal short-circuiting between downward and upward flow paths. Lower flow rates increase bottom-hole temperature but also increase thermal losses along the upward path. Higher flow rates reduce residence time and heat uptake despite lower internal heat exchange losses. Flow rate optimisation is therefore site- and design-specific and cannot be generalised across projects. This highlights the importance of numerical modelling and system calibration, particularly when adapting legacy wells with fixed geometries.

The pipe material and diameter have secondary but non-negligible effects. The sensitivity analysis shows the thermal conductivity for the inner and outer pipe should be low and high, respectively. High thermal conductivity of the outer pipe enables the system to extract heat from the near wellbore region, while the low thermal conductivity of the inner pipe prevents thermal losses of the ascending fluid to the descending fluid, an effect that is called thermal short-circuiting (TSC). TSC is further favoured by great depths and low flow rates. Gascuel et al. (2022) also showed that the effect of the change in thermal conductivity of the inlet pipe is more prominent at low values (e.g., 1-5 W/m/K) but negligible for higher values (e.g., 10 W/m/K). The thermal properties of the inlet pipe depend on the material that is used, which for example can be high density polyethylene (HDPE), vacuum insulated tubing (VIT), insulated coil tubing; glass fibre reinforced plastic – in German: “Glasfaserverstärkter Kunststoff” (GFK).

As the modelling results show, **the choice of working fluid has little impact on thermal performance** on outlet temperature under typical DBHE operating conditions. Antifreeze additives slightly reduce thermal performance but may be necessary for operational safety. Advanced fluids (e.g. nanofluids) show negligible benefits at the system scale considered. Simplicity and reliability favour the use of standard water-based fluids, unless site-specific constraints dictate otherwise. This supports the conclusion that system-level optimisation should prioritise heat demand, flow control, and insulation, rather than alternative working fluids.

The economic viability depends primarily on local heat demand and proximity, which the TRANSGEO pilot studies in Weinviertel and Rakičan demonstrate (D2.3.2 and D2.3.6). The economic feasibility is strongly dependent on the existence of a nearby, continuous heat consumer. Lessons learned include that short transport distances (typically a few hundred metres) are critical for economic viability, systems supplying agricultural, industrial, or municipal users and operating costs are consistently low, with CAPEX and heat price being the dominant economic drivers. All evaluated scenarios in Rakičan yield positive Net Present Value (NPV) and attractive Internal Rate of Return (IRR), confirming that DBHE projects can be economically robust even at modest temperature levels, provided that demand conditions are favourable.

The regulatory and liability frameworks are the main non-technical barrier. While technical, environmental, and economic feasibility is demonstrated, the studies clearly show that regulatory uncertainty is currently the main obstacle to wider DBHE deployment. Existing mining and hydrocarbon legislation does not clearly address long-term liability transfer for repurposed wells in some of the TRANSGEO partner countries (e.g. Austria, Germany). Land-use planning restrictions often conflict with small-scale geothermal installations at legacy well sites. These issues can outweigh technical risks and delay or prevent otherwise viable projects. The conclusion is that policy and regulatory clarification is essential to unlock the full potential of reusing boreholes as DBHE systems.

DBHE systems offer a low-impact and low-risk contribution to decarbonisation. Across all sites, DBHE systems demonstrate a minimal environmental impact, high operational availability, very low emissions and noise. The overarching lesson is that DBHE technology represents a low-risk, incremental geothermal solution, well-suited for rural, semi-urban and urban areas and for the productive reuse of existing subsurface infrastructure.

C. Requirements to reuse hydrocarbon wells as Deep Borehole Heat Exchangers

From the technical aspects, a review of the literature and sensitivity analysis study revealed that the screening criteria for potential geothermal resources in a hydrocarbon environment, which could be developed using DBHE technology, depends on four main groups of parameters: initial well properties, geological conditions, well design parameters, and operating conditions. Some of these factors are fixed, while others can be optimised during design or operation. Sensitivity analyses help distinguish critical parameters from those with minor influence.

Initial well properties are fixed characteristics of existing wells. Well location is crucial, as excessive distance to heat consumers leads to high heat losses and uneconomical operation. The distance between the DBHE and the consumer should generally not exceed 3 km due to the high cost of heating networks (Koltzer et al., 2024). Casing size at depth is another decisive factor; wells with a deep 7” subsurface casing are considered most suitable for repurposing.

Geological conditions cannot be altered and therefore strongly constrain DBHE performance. A high geothermal gradient and high rock thermal conductivity are desirable. Although not analysed in detail in the TRANSGEO sensitivity analysis (D1.1.6), the presence of thick, shallow aquifers and strong groundwater flow should be assessed, as groundwater movement may significantly influence heat transfer and fluid temperature behaviour.

Well design parameters can be partially optimised before commissioning. DBHEs typically use a coaxial configuration with annular inflow, which offers better thermal contact with the surrounding rock and lower pressure losses than U-tube systems. Water is generally the preferred working fluid due to its superior thermal conductivity and volumetric heat capacity compared to alternatives such as diathermic oil. Pipe design is also critical: the outer pipe should have high thermal conductivity to enhance heat exchange, while the inner pipe should be well insulated to prevent thermal short-circuiting. Insulation options include HDPE (thermoplastic) and vacuum-insulated tubing (VIT), with VIT offering better performance at a higher cost. High thermal conductivity cement and good cement-to-formation contact are essential, though many older wells use bentonite cement with relatively poor thermal properties.

Operating conditions have a major influence on system performance and longevity. Higher flow rates increase overall heat extraction but reduce production temperature, while lower flow rates yield higher outlet temperatures but lower thermal power output. System design must align with the requirements of the connected heat consumer. Consumer temperatures should not fall below 60 °C to ensure economic base-load operation. Continuous operation is recommended to maximise economic performance, with at least 8,000 operating hours per year.

Overall, successful reuse of hydrocarbon wells as DBHEs requires favourable fixed conditions, careful design choices, and optimised operational strategies to ensure both technical efficiency and economic viability.

Next page - Table 1: Parameters to reuse hydrocarbon wells in sedimentary basins as deep borehole heat exchangers based on literature review and sensitivity analysis.

	Impact on other parameters	Min-Max Value	Opt. Value	Literature references	Min-Max Value	Opt. Value	Variability of parameter
		from literature			based on sensitivity analysis		
Initial well properties							
Well location	Geothermal gradient Temperature Distance to energy consumer	--	--	--	--		fixed
Distance to energy consumer (pipeline, km)	--	0-3	0	Koltzer et al. (2024)	--		fixed
Depth	Geothermal gradient Outlet temperature	With the global mean gradient: 30 K/km, a minimum depth of a well (usable depth interval for DBHE) is required: 1000 m (30 °C)					fixed/ variable
Casing diameter at DBHE base (inch)	--	6 5/8	>7	Projects: Prenzlau (GER), Sucha Beskidzka (R-1, PL) Koltzer et al. (2024)	--		fixed
Casing-Formation contact	Heat transfer	No exact numbers available		Kohl et al. (2000): Weissbad: 1 cm thick loose contact zone extending over 1/3 of the total borehole has an influence	--		fixed
Casing material	--	Thermal conductivity of carbon steel = 54 W/m/K					fixed
Geological conditions and reservoir properties							

Geothermal Gradient (K/km) Heat Flow	Outlet Temperature	The higher the better global mean gradient: 30	Heat Flow Viewer and Database https://ihfc-iugg.org/viewer/	30 - 80 (Landau)	fixed
Well design parameters for DBHE					
Tube configuration	co-axial (annular or centred inflow)				variable
Working fluid (W/m/K)	Amount of heat extraction	water additives	Alimonti et al. (2018)	no impact 0.51 - 0.8	variable
Outlet pipe diameter (m)	--	The variation of the outlet pipe diameter shows no big effect on the outlet temperature	Doran et al. (2021)	neglectable 0.09 - 0.14	variable
Outlet pipe conductivity (W/m/K)					variable
HDPE (high-density polyethene)	Costs Amount of heat extraction	0.4	Gascuel et al. (2022)	The output temperature can be elevated by ca. 1 °C with a VIT	
VIT (vacuum insulated tubing)		0.03 - 0.037			
Insulated coil tubing		0,022			
Grout (thermal conductivity; W/m/K)	Amount of heat extraction Costs	0.7 (bentonite; used for O&G) | 2.02 - 2.7	Dijkshoorn et al. (2013); Gascuel et al. (2022); Pascual-Munoz et al. (2018); Sapinska-Sliwa et al. (2015)	--	variable
Operational properties					
Flow rate (l/s)	--	3-10	Gascuel et al. (2022)	2.67 - 6.27	variable

Outlet temperature (°C)	Amount of heat extraction	--	60	Koltzer et al. (2024)	29 - 41	variable
Duration of operation (h/yr)	--	8000	--	Koltzer et al. (2024)	8760 (43 800 h in 5 yrs)	variable

D. Workflow to reuse hydrocarbon wells as Deep Borehole Heat Exchangers

The workflow of DBHE is presented in the following cases, which reflect the choice of repurposing hydrocarbon wells as closed-loop systems.

Option 1 (TRANSGEO pilot site Rakičan, Slovenia): Planned workflow

1. Preparation of the 30 x 30 m work site, Construction of a 30 m access road to the well
2. Mobilisation of the workover rig, Installation of the workover rig and preparation for intervention on the well
3. Arrangement of the wellhead before work begins (hermeticity control, replacement of valves and sealing elements)
4. Installation of well cleaning equipment (preparation of well cleaning fluid, installation of a chisel and well cleaning tools)
5. Logging (multi-finger caliper, CBL-cement-bound log, acoustic log)
6. Installation of production equipment to establish a DBHE (installation of insulated production pipes, hermeticity testing)
7. Assembly of the wellhead
8. Installation of a heat exchanger
9. Construction of pipeline connections to consumers (1000 m)
10. Installation of pumps to establish the circulation of the heat transfer medium (e.g. water)
11. Valves, pressure gauges and thermometers for monitoring
12. Installation of electrical equipment and control system
13. Construction of connecting power cable (approx. 500 m)
14. Wiring of the surface heat production system
15. Installation of equipment for monitoring and management of the system

Option 2 (TRANSGEO pilot site Weinviertel, Austria):

Well Summary (As-Built Basis)

- Total depth: 1480 m (backfilled sand from bottom to 1418 m, cement from 1418 m to 1412 m)
- 13-3/8 inch conductor casing: surface to 8 m
- 9-5/8 inch surface casing: surface to 299 m
- 6-5/8 inch casing: surface to TD
- Perforations: 1405 m to 1410 m
- Gravel pack: 1365 m to 1412 m
- Original production tubing: 2-7/8 inch set at 1109 m
- Permanent bridge plug: set at 1361.5 m
- New geothermal tubing: 2-3/8 inch with centralisers
- Well fluid: water
- Wellhead and tree: 7-1/16 inch x 3-1/8 inch, 21 MPa

1. Mobilisation and Wellsite Preparation (1.0 days)

- Transport workover rig and auxiliary equipment to the location
- Rig up over the existing wellhead
- Inspect the cellar, conductor and wellhead integrity
- Install workover well control stack
- Pressure test surface equipment

2. Well Kill, Secure and Initial Checks (0.5 days)

- Confirm that the well is static and water-filled
- Verify absence of sustained casing or tubing pressure
- Pressure test tubing and annulus
- Prepare well for tubing recovery

3. Removal of Existing Production Tubing (1.5 days)

- Remove christmas tree and production wellhead components
- Install workover BOP stack
- Release the tubing hanger
- Pull 2-7/8 inch production tubing in stands
- Lay down tubing for inspection and disposal

4. Formation Isolation and Gravel Pack Sealing (2.0 days)

- Run the work string to the top of the gravel pack
- Perform cement squeeze across the gravel pack interval from 1365 m to 1412 m to seal the formation and perforations
- Displace and clean up
- Wait on cement
- Verify squeeze success by tagging and pressure testing

5. Installation of Permanent Bridge Plug (0.5 days)

- Run a permanent bridge plug on the work string
- Set plug at 1361.5 m above sealed gravel pack interval
- Apply the setting procedure per manufacturer's specification
- Pressure test from above to confirm isolation integrity

6. Wellbore Preparation for Geothermal Completion (0.5 days)

- Clean out the above bridge plug
- Confirm the internal casing condition
- Drift 6-5/8 inch casing to ensure full bore for new tubing
- Confirm water-filled wellbore

7. Installation of New Geothermal Tubing (1.5 days)

- Run 113 joints of 2-3/8 inch tubing with centralisers
- Land tubing at planned depth with a wireline re-entry guide at 1020 m
- Land tubing in tubing hanger
- Pressure test tubing
- Configuration:
    - Tubing used as a production leg
    - Annulus used as an injection leg

8. Wellhead Re Completion and Surface Configuration (0.5 days)

- Install 7-1/16 inch x 3-1/8 inch christmas tree rated to 21 MPa
- Configure the wellhead for annulus injection and tubing production
- Install pressure monitoring on tubing and annulus
- Fill and balance the system with water

9. Commissioning and Integrity Testing (0.5 days)

- Perform surface pressure testing of tubing and annulus wellhead components
- Pressure test the water-filled well as a closed-loop system to verify overall integrity and absence of formation losses
- Circulate water down the annulus and up the tubing, monitoring pressures and flow stability

10. Demobilisation and Handover (0.5 days)

- Rig down workover equipment
- Demobilise rig and service units
- Restore site
- Update well records and final well schematic
- Handover to the geothermal operator

E. Feasibility analysis

Hypothetical Case: Reuse of a 2,500 m Dry Well as a Deep Borehole Heat Exchanger in Central Europe

With a geological and thermal framework of a well with a total usable depth of 2,500 m, a geothermal gradient of 3°C/100 m and surface temperature of 10°C°the bottom-hole temperature is 87°C. So, the stabilised formation temperature can be 80-85°C. A realistic long-term surface outlet temperature ranges from 55–65°C.

The **thermal output** for a 2,500 m vertical DBHE with the smallest borehole diameter of 7", a rock thermal conductivity of 2.5 W/mK (average sedimentary rock), a coaxial insulated tubing and a flow rate optimised to avoid thermal short-circuiting should be for a long-term sustainable operation between 100 – 300 kW_{th}. A realistic annual heat production is based on the assumption of 8,000 equivalent full-load hours with 200 kW_{th} average output. Because DBHE systems do not operate at full power year-round due to seasonal heat demand, thermal drawdown and maintenance downtime result in a realistic annual heat production of maximal 1400 MWh/year.

The **hypothetical customer** is an existing greenhouse with a workshop and a living building with an annual heat demand of 300 MWh. The former heat source has been an oil heating with a yearly demand of 30 000 litres of oil (100-130 ct/litre), which costs 30,000 - 39,000 €/year.

The investment costs for a DBHE reuse (**CAPEX**) are dependent on the well condition (age), the tubing type (e.g. steel vs plastic), and are between 250,000 and 1 000,000€.

Operational costs (**OPEX**) are derived from TRANSGEO Deliverable D 2.3.2 and D 2.3.6, which are between 25,000 – 30,000 € and include, amongst others, maintenance and costs for the heat pump(s).

The method is **technically feasible** because there is no permeable reservoir and formation fluid required, no stimulation, no induced seismicity, and there is a mature insulated tubing technology. The **legal feasibility of a** closed-loop DBHE has strong regulatory advantages against open systems, because no water extraction permit and no reinjection permit are needed. Before installation, an operational plan has to be submitted and standard construction permits.

Therefore, a single 2,500 m DBHE well is technically feasible and legally straightforward, but commercially viable only under high heat prices, subsidies and optimised system design. However, reuse significantly lowers financial barriers and can make carefully selected projects viable, especially where abandonment liabilities would otherwise occur.

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TRANSGEO Deliverable D 1.1.6: Engineering workflows for retrofitting abandoned wells

TRANSGEO Deliverable D 2.3.2: Feasibility study for the pilot region Weinviertel (Vienna Basin)

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