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Project Implementation And Initial Data Collection

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A Research And Energy Production Geothermal Project On The TU Delft Campus: Project Implementation And Initial Data Collection

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ABSTRACT

A geothermal well doublet, designed with two primary aims; one of research and the second of commercial thermal energy supply, is currently being installed on the campus of Delft University of Technology, with the wells being drilled in the second half of 2023. The project includes a comprehensive research program, involving the installation of a wide range of instruments alongside an extensive logging and coring program and monitoring network. The doublet has been cored, with continuous samples from the heterogenous reservoir being complimented with more distributed side-wall cores, alongside a large suite of open-hole well logs in the reservoir section of both wells. Such investigation is rarely undertaken in geothermal projects. A fiber optic cable will monitor the production well, and will be installed all-the-way down to the reservoir section when the well completion is installed, at approximately 2300m depth. The reservoir is the fluvial Lower Cretaceous Delft Sandstone that is used as a geothermal reservoir in a series of existing and planned doublets in the West Netherlands Basin. A local seismic monitoring network has been installed in the surrounding area with the aim of monitoring very low-magnitude natural or induced seismicity. A vertical observation well with electromagnetic sensors will be drilled in a few years' time between the injector and producer to monitor cold-front propagation. The total project is targeted to supply around 25 MW of thermal energy at peak conditions, next to this project a thermal energy storage system is planned to provide a seasonal buffer. The project is a key national research infrastructure and is being incorporated into the European infrastructure EPOS (European Plate Observing System, https://www.epos-eu.org/), such that accessibility and data availability will be as wide as possible. All observations will be included in a digital-twin framework that will allow better decisions to be made in future geothermal projects. This paper presents the implementation and initial data collection from the project, including an initial evaluation of the logging and coring campaigns.

1. INTRODUCTION

Nearly half of Netherlands' natural gas consumption is used for heating. Direct-use geothermal heating is one of the key available low-carbon energy solutions and is projected to cover around 30% of the demand which would result in around 700 direct-use doublets being installed in the Netherlands (Platform Geothermie et al., 2018). In the EU, it is projected that 25% of heating energy can come from geothermal energy, with 10% of the total demand coming from underground thermal energy storage (Ciucci, 2023). In the Netherlands, the vast majority of the existing (~20) projects supply thermal energy to the greenhouse farming sector, which has been a substantial success story, with further penetration in this sector projected in the coming years. However, urban heating supply (where the majority of the heating demand exists) has yet to be supplied in a major way.

At present the geothermal sector in the Netherlands is dynamic with >20 exploitation licences being granted annually; however, the current rate of drilling is between 1 and 2 doublets per year (NLOG, 2023). There are a multitude of interconnected reasons why this is the case, which range from key issues related to the behaviour of the subsurface, to surface plant and energy distribution facilities, and commercial arrangements. For example, induced seismicity is a major social-technical issue, as the Netherlands has extremely low natural seismicity and has suffered from increased seismicity induced due to gas extraction (Muntendam-Bos et al., 2022), and it is clear, as can be seen later in this paper, that to achieve the industry ambitions, geothermal doublets must be drilled close to each other in heterogeneous reservoirs, which can introduce interference (e.g. Wang et al., 2023). In addition, to decarbonise the heating sector, substantial advances need to be made in commercial (financial and contractual) arrangements, and in the integration of heating system components, including supply, distribution, storage and heat pumps.

In response to several of these challenges, and a desire to fully decarbonize the TU Delft campus by 2030 (van den Dobbelsteen and van Gameren, 2022), the Geothermie Delft (https://geothermiedelft.nl/en/) project was established with the dual aim to develop new scientific insights, methods and knowledge and to deliver thermal energy to the TU Delft campus and a portion of the city (Vardon et al., 2020). The project consists of a ~2.5 km deep geothermal doublet, with production and injection from the Delft sandstone, an early Cretaceous sedimentary fluvial deposit, in the West Netherlands Basin (Willems et al., 2020). The project will be operated by a commercial entity (a consortium of Aardyn, EBN, TU Delft and Shell Geothermal), with the first energy production planned in 2025. The doublet will be connected to a heating grid, an aquifer thermal energy storage system, and a heat pump to form a comprehensive urban heating system. In the second part of 2023, the doublet was drilled and a wealth of information collected. This paper gives an overview of the project, the scientific programme and the data collected during the drilling of the doublet.

2. PROJECT DESCRIPTION

The Geothermie Delft project, illustrated in Figure 1, consists of a doublet targeting the early Cretaceous Delft sandstone formation, which is located at approximately 2 km deep beneath the campus of Delft. The target reservoir location is situated within a syncline bounded to the south-west by a seismically inactive fault at approximately 1km distance and to the north-east by another seismically inactive fault at approximately 4km distance from the surface location (Figure 2). Both wells are deviated such that they move away from the closer fault and target a deeper (hotter) portion of the reservoir. To the east and north-east of the reservoir, respectively, are two other geothermal projects which serve to provide heat mainly to greenhouses, highlighting the proximity and potential of interaction of geothermal projects. The two wells have been drilled vertically for some eight hundred metres, where they deviate from vertical and from each other, so that water can be pumped between them over a horizontal distance of around 1.3km at reservoir depth. Hot water will be produced at around 80°C initially at a rate of up to 350m^3 per hour and after thermal energy is extracted will be re-injected at a temperature as low as 20°C. This leads to a maximum thermal energy extraction rate of ~25MWth.

The heat-supply aims of the project to supply an existing second-generation heating network on the TU Delft campus and a newly constructed heating network supplying existing buildings in a part of the city of Delft, the Netherlands. The TU Delft campus heating network currently operates at a ~110-130°C supply temperature, which will be modified to operate at a reduced temperature, i.e. ~80°C or less for the majority of the year/weather conditions, and elevated to ~90°C via a heat pump when the outside air temperature drops below -10°C via a heat pump, i.e. turning it into a third generation heating network. This heating network will also be expanded from four tracks to five to supply further existing buildings associated with the campus. The newly constructed heating network (called Open Warmtenet Delft https://www.delft.nl/warmtenet) will supply a portion of high-intensity housing in the city built in the 1960s and 1970s. A novel high-temperature aquifer thermal energy storage (HT-ATES) system is planned to be installed to bridge the seasonal fluctuation in heating demand (Bloemendal et al., 2020), and an above ground buffer tank is planned to provide a daily buffer. Additional peak capacity, when needed, will be provided by the existing gas-fired boilers which currently supply the heating requirements of the TU Delft campus. Due to the combined capacity of the geothermal doublet, the HT-ATES, heat pump and short-term buffer it is anticipated that ~95% of the thermal energy can be provided.

During the second half of 2023, both wells of the doublet have been installed, alongside a substantial scientific data and sample collection programme. To install a functional injector well, a side-track was required from ~830m to final depth at ~2.5km due to wellbore instability, and a second side-track at ~2.2km depth (see Figure 2), which slightly reduced the doublet spacing. The research questions that are targeted to be answered relate to field-scale geothermal operations, e.g. How reliable is the long-term energy production? How do materials perform in the long-term? and How can geothermal projects be best monitored?

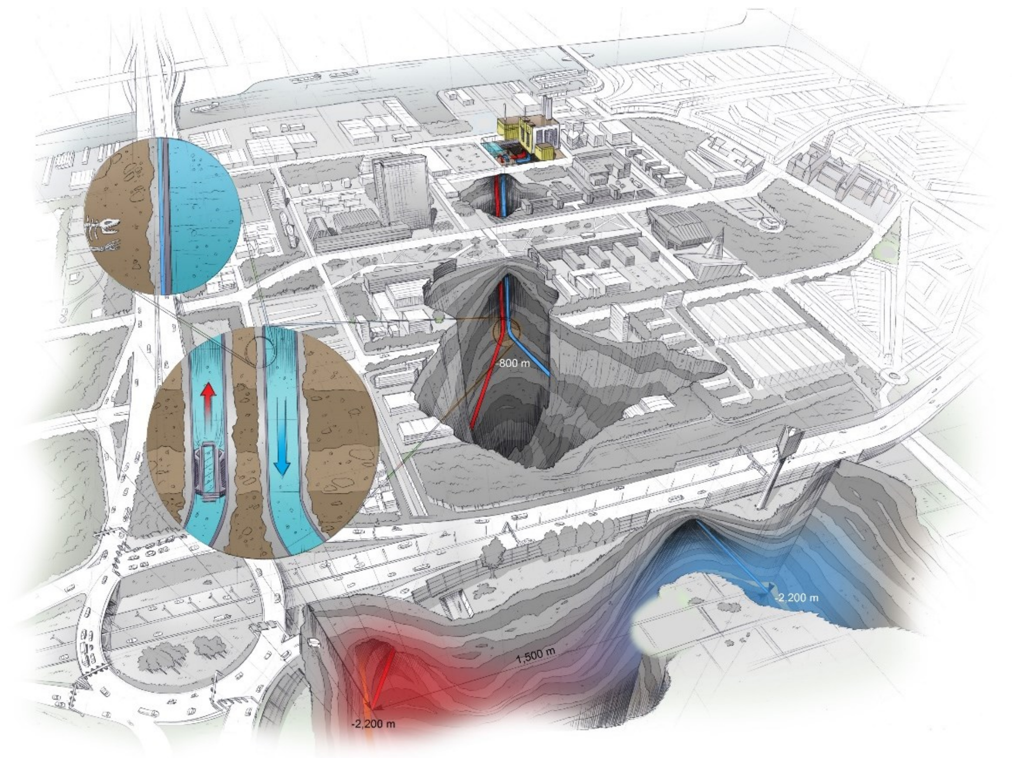

Figure 1: Illustration of the Geothermie Delft geothermal doublet, demonstrating the deviated wells and the TU Delft campus (illustration credit: Total shot productions).

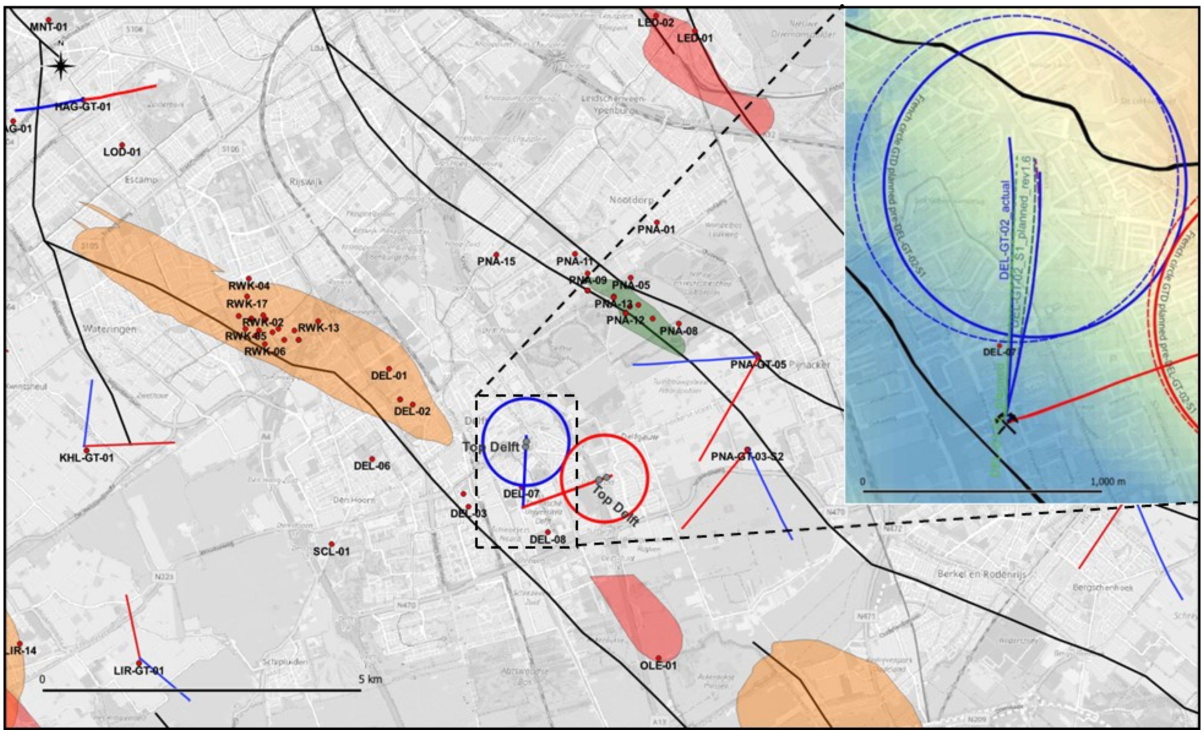

Figure 2: Map indicating the project location (wells and approximate influence area indicated by the red and blue lines and circles near the center of the figure), the surface surrounding the project, the main subsurface faults, offset wells and oil and gas fields. Inset: details of the initial injector wellbore on the left and the side-tracks on the right of the initial bore. (credit: Annelies Bender and Walter Eikelenboom, Aardyn)

3. SCIENTIFIC PROGRAM

One of the key project aims is to install measurement instruments and collect samples and data in order to address the scientific questions listed above. For more information on the wider scope, this website has up-to-date information: https://tudelft.nl/geothermalwell. For the initial part of the program, solid sampling, wireline logging, fiber optic installation and installation of a local seismic monitoring system were undertaken. Drilling and well parameters were made available by the operator to the research team. In the following research program, an HT-ATES system will be installed, a deep observation borehole is planned directly through the cold plume, extending significantly below the reservoir, tracers will be utilized and a bypass system installed so that experiments can be undertaken live on the produced geothermal brine.

Rock samples were taken using a variety of methods, selected due to speed, cost, being intact and having a comprehensive set of samples, with a summary of the collected samples presented in Table 1. Cuttings were sampled throughout the drilling at a resolution of between 3 m and 10 m depending on the relevance to the scientific questions and the drilling speed, with a total of over 2000 samples taken. Cores were split across the two wells, with a focus on the cap-rock and the reservoir. 4” cores were taken in the producer (DEL-GT-01), in the cap-rock and the upper reservoir capturing a sample of the alternating shale / sandstone reservoir section typical of the fluvial origin of the reservoir. The coring operation proved challenging, due to the inclined well-bore, and highly heterogenous formation which resulted in core-jamming during the operations, restricting the length of core recovery for each coring run. A total of ~86 m were recovered, with 70 m in a continuous sequence. In the injector (DEL-GT-02-S2), a total of 81 side-wall cores were collected, which allowed sampling throughout the reservoir and targeting of key features within the reservoir, as this was done after wireline logging. Prior to any physical or destructive testing on the cores, the cores have been preserved in as intact a manner as possible. For this purpose, the cores were stabilized within their barrels by injecting foam, and sealing the cores with a wax and a vacuum pack comprising aluminum and plastic layers to reduce water and oxygen leaving or entering the cores. Shale cores were additionally stored in a fridge to reduce drying. Core plugs will be taken from the ends of select cores, to allow initial investigation, after which the cores can be again re-sealed. Electronic cores (via CT scanning) have been made of all the cores and further detailed scanning may take place before deciding which tests can be done on each core.

A comprehensive wireline logging campaign was undertaken in each well in the reservoir section. This included the following logs: Gamma Ray, Spectral Gamma Ray, Caliper, Bulk Density, Neutron Porosity, Micro-Resistivity Image, Dipole Sonic (including full wave form), Ultra-Sonic Borehole image and Nuclear Magnetic Resonance. In addition, the sonic logs were also run within cased hole to provide information on the cementation of those casings. An example of a selection of the data is shown in Figure 3 over a ~100m depth range. The heterogeneity of alternating sand and clay layers, corresponding properties and geological features can be clearly observed. These are expected to lead to a complex heat transfer behavior during project operation, and this will be a focus of ongoing research.

Table 1: Samples collected during doublet installation (depths are in Measured Depth (MD), i.e. length along the well).

Well	Sample Type	Amount	Top Depth (m MD)	Bottom Depth (m MD)	Sampling rate
Producer DEL-GT-01					
	Cuttings	1083	90	2930	
		154	90	840	10 m
		632	845	2510	5 m
		297	2511	2930	3 m
	Core	85.58 m	2511.5	2651	
	Brine	11	Mixed from reservoir		
Injector (motherbore) DEL-GT-02					
	Cuttings	729	90	2638	
		152	90	840	10 m
		461	845	2290	5 m
		116	2293	2638	3 m
Injector (side-track 1) DEL-GT-02-S1					
	Cuttings	132	2000	2560	
		45	2000	2300	5 m
		87	2303	2560	3 m
Injector (side-track 2) DEL-GT-02-S2					
	Cuttings	123	2218	2581	3 m
	Sidewall Core	81	2349.8	2556.1	

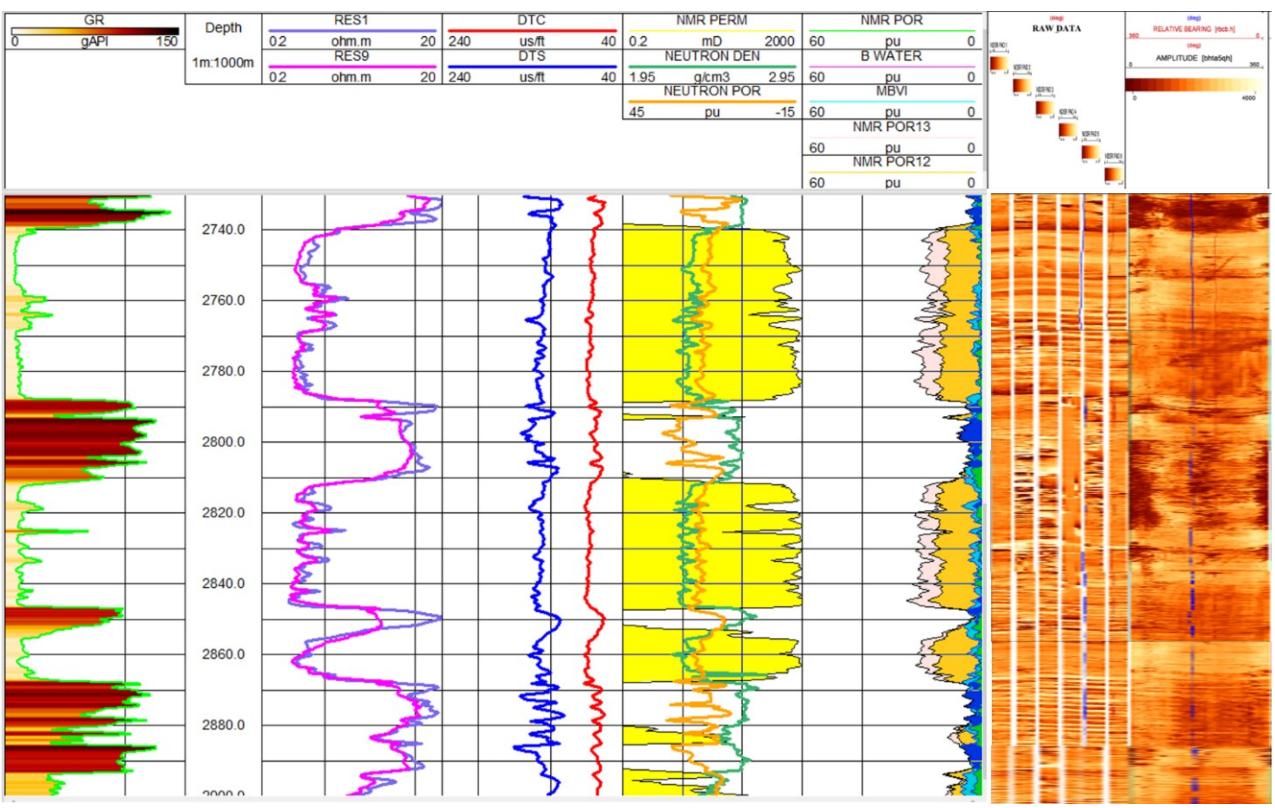

Figure 3: Sample of the wireline logging data for the producer well at the reservoir depth along the well path (meters in measured depth, i.e. the along-well depth). Logs from left to right: GR=Gamma Ray; RES=Resistivity; Sonic, DTC=compressional wave slowness, DTS=shear wave slowness; Neutron density and porosity; NMR=Nuclear Magnetic Resonance; Micro-Resistivity and Ultra-Sonic Imagers.

A fiber optic cable is being produced at present which will be installed inside the production well casing during commissioning. This cable is being designed to have distributed pressure, temperature and acoustic sensing, which will allow dynamic and continuous well testing during operations, and is designed to investigate the short- and long-term influence of the reservoir heterogeneity. In addition, a longer-term plan is to install a monitoring borehole within the cold plume, in order to monitor the temporal and spatial distribution of the injected cold water.

The area where the geothermal project is installed is not naturally seismic (Muntendam-Bos et al., 2022), and does not have previously observed seismic activity. However, there is a significant social focus on seismicity and current models predict the potential of seismicity from cooling (Buijze et al., 2021), despite only a single M0.0 seismic event being measured due to comparable geothermal projects in the Netherlands. Therefore, a local seismic network surrounding the project has been installed, with the layout shown in Figure 4. The system was designed in order to be able to detect and locate any seismic activity related to project activities. The centreal and two most southerly seismic stations were installed to 200m depth. At the top of the figure, the northern seismic monitoring station DAPGEO-02 is seen, which was developed as a significant sub-project (Vardon et al., 2023). Here, a 500m deep seismic monitoring station was installed. A series of geophones and optical fibres were installed to investigate low-magnitude seismicity and to calibrate downhole fibre-optic equipment to be installed in the wells. A coring programme was undertaken in sand formations potentially suitable for (high-temperature) thermal energy storage and deep clays suitable for use as a caprock for thermal energy storage and at representative geological conditions for the disposal of radioactive waste (note: no radioactive waste disposal will take place in this location). In addition, a comprehensive logging suite was taken including Nuclear Magnetic Resonance, density and shear-wave velocity logging, which are rarely taken in the shallow subsurface.

Figure 4: Layout of the local seismic geophone network (orientation such that north is vertical)

To ensure that the data can be combined and assimilated with geological and reservoir modelling techniques, a digital twin is being established. The objective is to integrate all data, models and geological interpretations, with the objective to improve decision making in future geothermal projects (Voskov et al., 2024), especially in locations where multiple projects may interfere with each other or have the opportunity to be operated as a field.

4. SCIENTIFIC DATA AND AVAILABILITY

All data is targeted to be collated and released publicly. The data strategy is illustrated in Figure 5, where raw data will be made available augmented by metadata and industry standard formatting and stored on a data repository with a fixed digital object identifier (DOI), which ensures that the data is unchanged and maintained. The project DOI is: https://doi.org/10.4121/85b3725b-80fa-4b0b-9db2-475bfd8f0265. Data derivatives, i.e. raw data after processing, analysis, modelling or data compiled for article publication will be separately stored, including citation to the raw data, and will have their own DOI. This is designed to ensure traceability and availability of the data. These data will also be included in the EPOS data portal (https://www.epos-eu.org/dataportal) which is designed to catalogue and bring together solid earth science data in Europe and will improve the findability and accessibility of the data.

At present the data collected during the drilling of the doublet is being prepared for upload onto the data repository. The first dataset will be the wireline logs which will be available this DOI: https://doi.org/10.4121/2a7b2a63-dd7b-46bc-a275-97729b3ab348. To allow the researchers involved in designing and executing the data collection to make first use of the data, a two-year embargo on data may be implemented at their request. However, when possible, data will be made public earlier and metadata will always be available, so that available data when under embargo can be personally requested.

The data which were collected during the drilling of the seismic monitoring borehole (DAPGEO-02, see Figure 4), is findable via the overall project DOI, but also available separately: Drilling Report https://doi.org/10.4121/21640148.v3, Initial borehole dataset https://doi.org/10.4121/20299644.v2 and Core CT-scans https://doi.org/10.4121/21528819.v2.

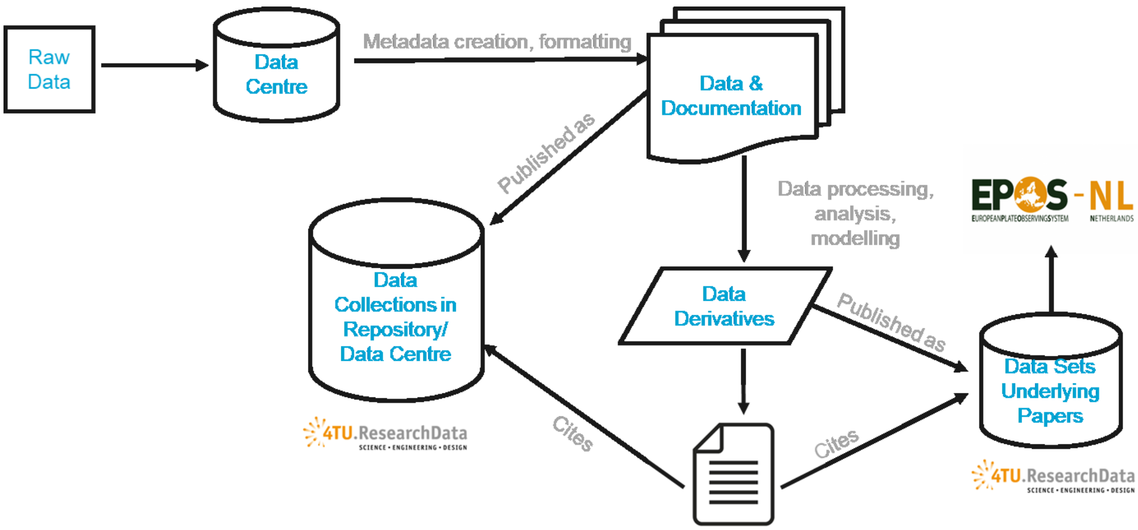

Figure 5: Data curation approach.

5. CONCLUSIONS

A geothermal doublet with a joint scientific and energy production aim has been recently drilled on the TU Delft campus. This project was designed to encompass scientific infrastructure and therefore offers an opportunity for detailed scientific study on a low-enthalpy geothermal project in a heterogeneous sedimentary fluvial reservoir. The doublet will be integrated into a heating network, comprising two heating networks, an aquifer thermal energy storage system, a local buffer and a large heat pump, with the intention of supplying energy with virtually zero associated carbon emissions. An overview is presented of the currently installed equipment and the samples taken, with the data curation approach detailed, with the objective of creating a lasting reference geothermal project.

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DATA AVAILABILITY

We believe in open science. All data collected by the research team will be available when it has been prepared for dissemination. Much is available on the 4TU research repository with a collection DOI of https://doi.org/10.4121/85b3725b-80fa-4b0b-9db2-475bfd8f0265. For a discussion on access to other data, please contact our data manager Liliana Vargas Meleza (geothermal@tudelft.nl). Access to samples may also be possible. As samples may be destroyed by their use, a committee has been set up to assess access requests. Please contact us for further information.

REFERENCES

Bloemendal, M., Vardon, P.J., Medema, A., Snelleman, A., Marif, K., Beernink, S.T.W., van Veldhuizen, F., Pijnenborg, M., Sudintas, G., and van Oort, T.: HT-ATES at the TU Delft campus. TU Delft / ENGIE, Delft. (2020). https://www.warmingup.info/documenten/ window-fase-1---a1---verkenning-hto-tud---feasibilityht_ates_tudelft.pdf

Buijze, L., Fokker, P.A., and Wassing, B.: Quantification of induced seismicity potential of geothermal operations. WarmingUP report. (2021). https://www.warmingup.info/documenten/warmingup4b1_report_r1_quantification_of_induced_seismicity_potential_of_ geothermal_operations.pdf

Ciucci, M.: Innovative Technologies in the Development of Geothermal Energy in Europe. Briefing requested by the ITRE Committee, Policy Department for Economic, Scientific and Quality of Life Policies. European Parliament (2023).

van den Dobbelsteen, A., and van Gameren, D.: Sustainable TU Delft: Vision, Ambition and Action Plan for a Climate University (2022). https://filelist.tudelft.nl/TUDelft/Research%20sites/Sustainability/Sustainable%20TU%20Delft%20-%20Vision%20ambition%20and%20action%20plan%20v5.3_220927.pdf

Muntendam-Bos, A.G., Hoedeman, G., Polychronopoulou, K., Draganov, D., Weemstra, C., van der Zee, W., Bakker, R., and Roest, H.: An Overview of Induced Seismicity in the Netherlands. Netherlands Journal of Geosciences, 101, (2022), e1.

NLOG: Overzicht Geothermie. (2023), https://www.nlog.nl/geothermie-overzicht.

Platform Geothermie, DAGO, Wartenetwerk, and EBN.: Master Plan Geothermal Energy in the Netherlands (2018) https://geothermie.nl/images/bestanden/Masterplan_Aardwarmte_in_Nederland_ENG.pdf.

Willems, C.J.L., Vondrak, A., Mijnlieff, H.F., Donselaar, M.E., and van Kempen, B.M.M.: Geology of the Upper Jurassic to Lower Cretaceous Geothermal Aquifers in the West Netherlands Basin - An Overview. Geologie en Mijnbouw/Netherlands Journal of Geosciences, 99 (2020), e1.

Vardon, P., Abels, H., Barnhoorn, A., Dieudonné, A.C., Drijkoningen G., Beernink, S., Laumann, S., Schmiedel, T., Geris, P., Pauw, P., Neeft, E., van den Berg, J., and Vargas Meleza, L.: Geothermal Project on TU Delft Campus - DAPGEO-02 Drilling Report. Version 3. 4TU.ResearchData. dataset. (2023). https://doi.org/10.4121/21640148.v3

Vardon, P.J., Bruhn, D.F., Steiginga, A., Cox, B., Abels, H., Barnhoorn, A., Drijkoningen, G., Slob, E., and Wapenaar, K.; A Geothermal Well Doublet for Research and Heat Supply of the TU Delft Campus, World Geothermal Congress (2020).

Voskov, D., Abels, H., Barnhoorn, A., Chen, Y., Daniilidis, A., Bruhn, D., Drijkoningen, G., Geiger, S., Laumann, S., Song, G., Vardon, P., Vargas L., Verschuur, E., and Vondrak, A.: A research and production geothermal project on the TU Delft campus: initial modelling and establishment of a digital twin. Proceedings, 49th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2024).

Wang, Y., Voskov, D., Daniilidis, A., Khait, M., Saeid, S., Bruhn, D.: Uncertainty quantification in a heterogeneous fluvial sandstone reservoir using GPU-based Monte Carlo simulation. Geothermics, 114, 102773.