Interreg
EUROPEAN UNION
North-West Europe
DGE-ROLLOUT

REPORT WP Long Term – 4.1
DGE in urban district heating networks

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14.7.2022

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1. Introduction

This report covers a detailed view into the integration of geothermal and thermal storage sources into district heating networks, the future market potential of the implementation of DGE into heating grids, and the best practise strategies and three examples from Mol (Belgium), Bochum (Germany) and Weisweiler (Germany) for flexible and, if feasible, cascaded use of deep geothermal energy, subsurface thermal storage and heat pump implementation applied to district heating. Please note that large parts of sections 1-3 were adopted from the publication "Roadmap Tiefe Geothermie für Deutschland" (*Roadmap Deep Geothermal Energy for Germany*) by Bracke et al. (2022).

2. Overview types of district heating networks

2.1 Low temperature heat networks

Low-temperature heat networks (LT networks) - also cold networks - with temperatures between 15°C and 60°C can heat supply much more efficiently than conventional heating networks, and also make it easier to integrate several renewable energy sources. In most European countries, LT networks have so far been used too little. However, they represent an important option for the housing industry and are an interesting technology for heating of especially new building districts. When LT networks are provided, considerably more economical local and district heating infrastructures can be built than for networks with higher operating temperatures.

Low temperatures of up to 60°C at maximum can be achieved from rather shallow DGE wells of around 1500-2000 m depth. Alternatively, deeper wells producing higher temperatures could be coupled to LT networks in cascaded systems, where higher temperatures are first used for industrial processes or HT networks, while remaining temperature/back flows are than integrated. Since both the geological structure and the planning and execution of projects for the exploitation of such temperatures are feasible in many locations, DGE wells for LT networks are of relatively low risk concerning feasibility and production rates. However, as for all DGE wells planned to be integrated to district heating grids, the wells have to be as close as possible to the network access, which can be challenging in or close to cities or densely built-up areas.

2.2 Low-Ex networks

An extension of the LT networks is the development of low-exergy heating networks, so-called low-ex (LE) networks. These allow consumers to be both consumers and producer for heating and cooling at the same time (prosumer). The networks can supply different users with their demand-based temperature as required, but can also integrate other decentralized heat such as solar thermal energy, geothermal energy, waste heat or process heat. These heating grids are well suited for cascaded systems with very different demands on temperature and the amount of heat.

The exploration and exploitation of geothermal wells producing heat for LE networks are of either relatively low risk if rather shallow with low demand on temperature and flow rate, or of high risk if high temperatures and flow rates are required. However, as heat production rates of such wells can be adjusted to the total input into the grids, also heat input from other sources will be operated and may even buffer a reduced production rate from wells. An over-production of heat could be used for storage for the heating season in winter.

2.3 Conventional heat networks

The vast majority of existing heat networks in the cities are operated at higher temperature levels and a large-scale conversion to LE networks or LT networks is not feasible due to the highly diverse municipal customer structure very unlikely. Conventional local and district heating networks heat with temperatures from 70°C up to 130°C with a heat output of 1 MW to 1 GW. At present, the transformation to the 4th generation of district heating generation is taking place. This involves lowering the supply temperature to below 60 °C, so that low-temperature heat sources, especially renewable energies, can be integrated. The majority of district heating does not have these technical constraints and are supplied with more than and is supplied to over 80 % from fossil fuels. Since a significant reduction of the operating temperatures of these networks due to supply obligations and the heterogeneous customer structures is not feasible in most cities, the challenge is to convert the source side from centralized fossil to many decentralized RES generators and a change in load management.

For the integration of DGE into these conventional, HT (high temperature) heating grids, production wells either need to be deep and produce HT water, or the utilization of HT heat pumps (HP) for raising the temperatures to the required levels are mandatory. Since the required temperatures in the heating grids are mostly depending on the outside temperatures, the temperature lift of HPs might be relatively low in “warm” winters.

Most of these heating grids are utilized in larger cities, which mostly doesn’t allow for DGE production right next to the heat customers. However, using lager input temperatures and pipelines into the cities will allow eat production in the vicinities of cities within a radius of approximately 10-20 km. In any way, the exploration and exploitation of DGE “sweet-spots” close to the heating grids is often of relatively high risk, since the wells need to produce high temperatures at high flow rates (which requires a certain type of geological settings of rocks and structures in the subsurface).

4. Current and future situation of district heating

Today, district heating networks are operated in >90% of the German larger cities (80 towns and cities with more than 100,000 inhabitants) to provide both heat for buildings (approx. 50 %) and industrial process heat. It is expected that by 2030, all major German cities will use district heating and this will expand from 88 TWh/a to 114 TWh/a annual work by 2050. In medium-sized German cities (approx. 620 towns with 20,000-100,000 citizens) an increase from 20 TWh/a to 42 TWh/a is expected. Furthermore, an increase in the share of district network-based heating from 50 % to 80 % by 2050 is expected. A similar development is expected in the approx. 1.390 small towns (<20,000 citizens), where the proportion of the share of municipalities with district heating supply is expected to increase to 60 %.

The share of industrial processes in the district heating demand is approx. 50 TWh/a (44 % of total demand). The demand for replacement of heat sources and grid connection is expected to increase less than for residential heating, since many companies have their own generation plants for process steam, heat or electricity and modernize them individually, Hence, benefits from efficiency improvements in the industrial sector can be implemented faster and easier than in the building sector. However, the generation of process steam from geothermal energy (directly or indirectly via HP) and the injection of industrial waste heat into municipal heating systems should gain in importance in the future if the producers are connected to the infrastructure.

About a quarter of NW Europe's population lives in village structures with mostly no grid-connected heat supply, which is rather organized on a decentralized oil and gas combustion. This is why the politically targeted expansion of "citizen energy," especially in smaller communities or districts, is of great importance. Similar to the models for the operation of wind and solar parks in the electricity sector, the grid-connected supply of heat could be provided by - e.g. cooperatively operated - geothermal energy plants, which could contribute significantly to decarbonization in rural areas and provide independence of supra-regional or international energy imports for large parts of countries.

5. Market potential for implementing DGE into district heating

Municipal, supra-regional, and international energy supply companies are facing great challenges in the transformation and expansion of their energy sources as well as the distribution networks. Due to the small amount of space required in urban areas and their vicinity, geothermal energy can cover a large share on the generation side: By 2030, deep geothermal energy could be able to feed at least 20% of the district heating networks and, together with surface geothermal energy, could cover at least 20-30 % of the municipal heat demand. However, several years are required for integrating geothermal heating plants into the municipal heat supply (currently 5-7 years for one installation) require binding municipal and corporate municipal strategies, site-specific feasibility studies, and securing the resource under mining law. The danger of a blockade by competing applicants is and should be considered in the regulatory process through an appropriate design of the permit fields. In particular, the expansion and networking of geothermal infrastructures across municipal boundaries can increase the annual full load hours from 30% to 70%, and the operating hours of heating plants from a good 2,000 h to 4,000-6,000 h or even more. The buffering effect of the network also increases the utilization of each connected geothermal heating plant (in the sense of the amount of energy produced per production well) and thus its economic efficiency due to decreasing heat production costs. This is also due to the increase of the connection rate in dense urban neighbourhoods and the reduction of network temperatures to 60 to 80 °C.

In addition, the testing, set-up and implementation of seasonal underground heat storage capacities in the networks and the development of business models for sector coupling between heat distribution, heat storage (bidirectional load management) and the electricity side (especially large-scale HP) are essential for the energy industry. Municipal activities for transformation and expansion of heat networks should start at this point. Despite the small area required for a geothermal plant, many regions and municipalities do not face the necessary number of geothermal heating plants that can be built in urban areas. In addition, energy provides, grid operators and municipalities should also examine the connection of geothermal heating plants from the periphery and provide transport routes to the inner cities.

By 2030, the building sector must, in accordance with the Federal Climate Protection Act 2021, reduce its CO_2 emissions by 43% compared to the annual emission levels of 2020. Geothermal energy already has a double-digit market share. It is to be expected that the heat supply for neighbourhoods through the construction of LT grids with geothermal sources will be pushed further. In contrast, the housing industry faces a decarbonization of the heat supply for existing housings, which challenges the necessary investments both in the buildings (efficiency), in building (increasing efficiency standards through building refurbishment) and in the conversion to climate-neutral supply technology. Particularly in the case of existing buildings in the social housing sector, it is necessary to evaluate which of the options will lead to greater cost containment. For example, it may be possible to maintain the distribution systems of the heating systems and change the generation side from fossil to renewable sources with local heating networks. Depending on the available temperature from local heating networks, a wide range of experience in the energy refurbishment of existing buildings proves that the energy refurbishment of suitable building age classes can be carried out cost-effectively and makes sense compared to (partial) demolition and new construction.

6. Strategic outlook for activities fostering the implementation of DGE into heating networks

Operators of existing heating networks are currently challenged by massive changes in concepts of heat source implementation into their grids as well as costly grid expansion, since in many regions heat plants firing fossil fuels (gas, oil, coal) for heat production have to be replaced/have to replace former fuels by climate-neutral, renewable sources. Especially in regions with excellent conditions for DGE projects, with good production rates and sufficiently high temperatures to guarantee economic applicability, are advised to utilize geothermal heat for existing grids in the next years. The collaboration with grid operators as well as the energy providers is a mandatory step for the demonstration and to stimulate more stakeholder interest and involvement. Since most municipal energy providers and grid operators are (currently) not able/willed to risk investment in “green field” DGE projects, publicly funded pilot projects for regional demonstration are required. Besides principle activities in exploration (field campaigns, seismic data acquisition, deep drillings, seismological monitoring, etc), the technical feasibility for heating grid implementation can be challenging. Sweet spots for geothermal production may not match grid distribution and require expensive and extensive grid expansion. Here, the especially short- to mid-term economic viability of DGE integration can be debatable to not feasible from the operator’s point of view.

On the other hand, the expansion of the district heating networks is a declared goal of many regions and countries, especially in regions of increase heat demand, like metropolitan areas and industrial regions. Besides grid expansion, new grids will be installed. In the current situation of relatively high risks in DGE projects, new heating grids are very unlikely being planned and installed based on DGE implementation strategies. First, regions with existing networks will consider and test DGE as one of the potential heat sources (but never the only one). Once the feasibility and economic viability of DGE and its integration into district heating in various settings are demonstrated, the risk of invest will decrease, and "green field" projects will emerge that could even motivate the planning of new heat networks on the long term.

7. Examples

Within the framework of the DGE-Rollout project, several activities are directly linked to regional demonstrations of the implementation of deep geothermal energy into existing district heating grids. All three examples are at very different stages in their development.

7.1 DGE for district heating in Mol (Belgium, Flanders)

VITO started the Balmatt geothermal project in November 2009. With the project, VITO wanted to explore the geothermal potential of the Lower Carboniferous Limestone at a depth of 3000 to 4000 m. After a process of preliminary studies and a 2D seismic exploration, the first drilling was spudded on 15 September 2015. MOL-GT-01 hit hot water at a depth of 3200 to 3400 m in the limestones of the 'Kolenkalk' Group. In the following years two more deep wells were completed: MOL-GT-02 which serves as an injection well, and MOL-GT-03 which was carried out as a second production well, but ultimately turned out to be 'dry'.

In January 2017, VITO started the procedures for the procurement of the construction of the geo-thermal power plant and the above-ground installations. A connecting pipeline between the Balmatt site and the boiler room of the heat network of VITO – SCK•CEN had to be installed and a geothermal power plant had to be built.

At Flemish level, the interest of the Campine region in geothermal district heating and the ambition of the city of Antwerp to valorise residual heat from the industry provoked a discussion on district heating (2016). The debate was strongly influenced by the role of the operators of the local gas distribution networks in the development of district heating and the interests of the municipalities in these companies. The debate on district heating and geothermal also resulted in an amendment of the Flemish Energy Decree stimulating the regulatory framework for district heating and cooling. In addition, the Flemish government added geothermal as one of the technologies that is eligible for financial support under the Flemish support scheme for strategic ecological investments. Deep geothermal was also added as renewable energy source under the call for Green Heat.

Strengthened by the results of the first two wells and the new support schemes, a plan for geothermal district heating network connected to Balmatt were drawn in the municipalities of Mol and Dessel. In June 2016, VITO started the technical preparations of MOL-GT-03. The drilling had a double objective. Firstly, the well was designed to explore if the Devonian strata below the LCLG have geo-thermal potential. Secondly, it was considered to be used as a second production well to supply heat to the planned heat network. This plan looked viable with the new financial support schemes. Mid 2017, the decision was taken to drill MOL-GT-03. The well was spudded on 13 December 2017 and target depth was reached on 06 July 2018. The well, however, proved to the dry and the plan to develop the geothermal district heating was suspended.

The heat demand from the network to which the plant is currently connected is approximately 30,000 MWh per year. The network is operated with a supply temperature of 70 – 65°C in summer and 95 – 105°C in winter. The return temperature is around 65 – 70°C in winter and 60°C in summer. Based on the tests performed, the injection temperature appears to be between 57.5 and 71°C, depending on the demand of the heat network.

7.2 DGE for district heating in Weisweiler (Germany, NRW)

Currently RWE's lignite-fired power plant "Weisweiler" 15 km east of the city of Aachen produces approx. 2 GW electricity and 160 MWh heat for urban district heating. A major supply line towards Aachen feeds 85 MW heat as well as additional feeders supply the city of Juelich and villages as well as commercial areas in the vicinity for building heating and some industrial process heat. The power plant's operation will phase out and be shut down in 2029, and heat supply has to be substituted. DGE is planned being one of the heat-producing renewable energy sources for this district heating grid. The STAWAG (Stadtwerke Aachen AG, main energy provider Aachen) and other regional energy suppliers plan to expand the mostly old-fashioned, conventional heating grid, which needs an input temperature in Weisweiler of about 130°C, while most of the new grids and new parts of the existing grid are planned to operate at lower temperatures. A change of the whole heating network towards a LT grid on the short term is unlikely.

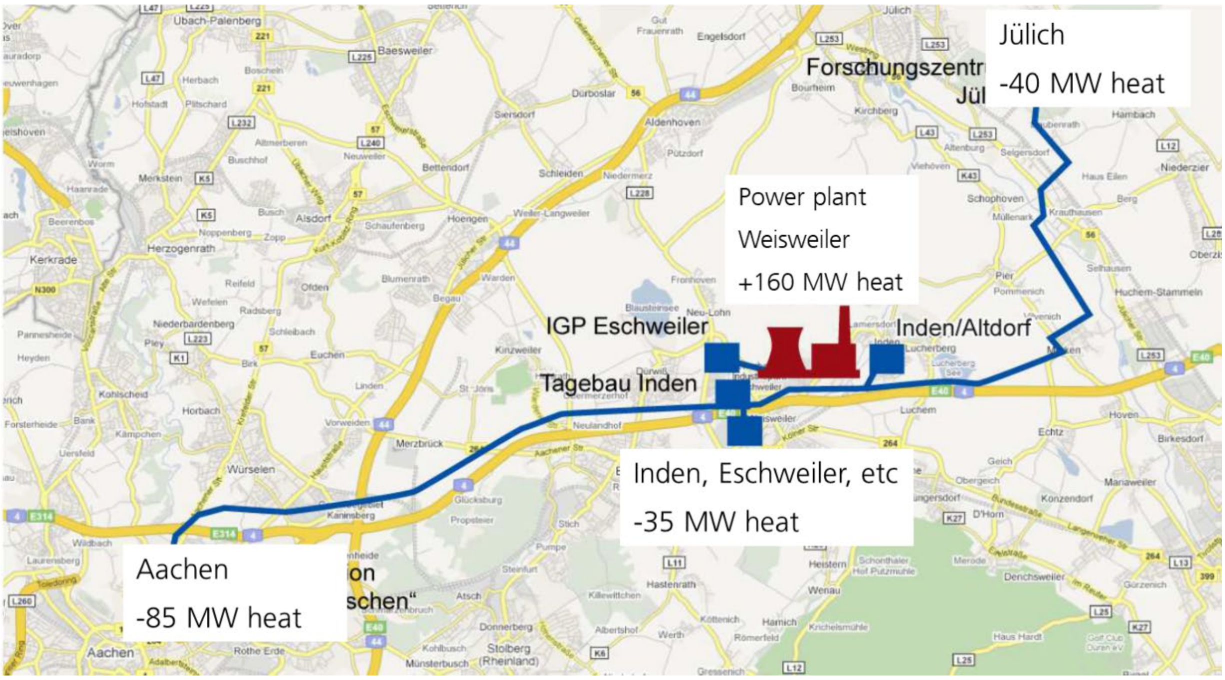

Figure 1: Current heat production at the power plant Weisweiler and its implementation into the district heating grid, which supplies cities and villages in its vicinity (Source: RWE Power AG).

The preparation of regional DGE projects already started and it was stated that production wells in the area of the power plant may provide 10-25 MWh heat from carbonate reservoirs in 2-4 km depth at temperatures of 100-130°C. DGE wells towards the west and east may show rather lower production rates because of lower reservoir temperatures. Here, the implementation of HT HPs could provide the required temperatures for grid integration. In anyway, several production doublets are needed to substitute a fair amount of the heat of the regional network. Based on the results of the first DGE production and grid implementation demonstration in Weisweiler by Fraunhofer IEG in cooperation with RWE and STAWAG, follow-up projects are anticipated.

The integration of DGE into district heating in the Weisweiler-Aachen region will demonstrate the utilization of DGE for implementation into existing and clearly arranged grid structures. In comparison to the implementation into complex inner-city networks, DGE will feed into a main line with subordinated and ideally cascaded urban heating grids. The existing structure outside of the cities generally allows for an array of multiple DGE plants along the main line without any conflict to existing buildings and infrastructures. Furthermore, the high temperatures expected at the Weisweiler production side may also stimulate nearby location of industries with high demand for high process temperatures and heat quantities.

7.3 Combined DGE and subsurface heat storage for district heating in Bochum (Germany, NRW)

In the area of Bochum south, where the Fraunhofer IEG offices and laboratory buildings are located, geothermal heat sources can substantially contribute to meet the heat demand of the neighborhood. The current heat demand of the buildings situated near the TRUDI site, expressed as kWh/y for each 100 m^2 of area, is showed in Fig.2. It can be observed that in the district of Querenburg, situated in the southern area of Bochum, most of the heat demand is required by the Ruhr University Bochum (RUB), depicted in the south-west of the map.

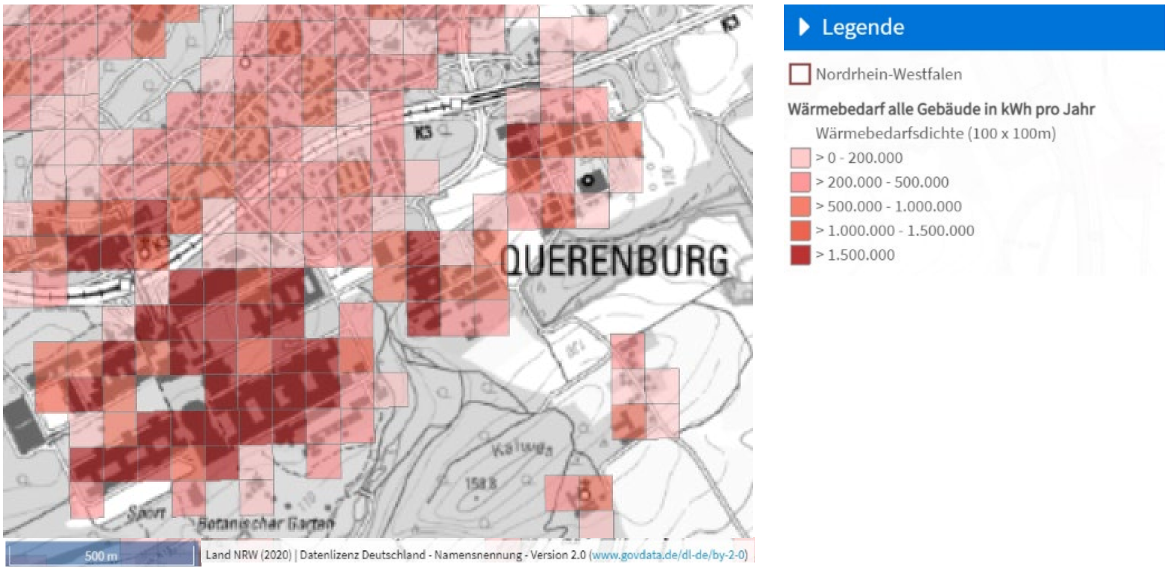

Figure 2. Heat demand near TRUDI site. Source: Energieatlas NRW

From 2018, the district heating network of the Unique Wärme GmbH & Co. KG, supplies heat and electricity to the RUB campus with around 5600 employees and 43000 students, in addition to 4800 rented flats, 760 homes and 115 other customers of the surrounding Querenburg neighborhood. It is made of three gas fired boilers and two combined heat and power (CHP) units. The plant can generate a total thermal output of about 9 MW and 7,5 MW of electricity. In addition, the existing buildings with offices and laboratories of Fraunhofer IEG have an annual heat demand of 165 MWh that is supplied by locally employed geothermal HPs (140 kW) and the shallow geothermal system “Geostar”, which are decoupled from the district heating.

In this context, in the DGE-Rollout project a newly designed 500 kW HT HP prototype is installed at the Fraunhofer IEG location of Bochum and connected to the existing district heating grid, which requires supply seasonally varying temperatures of 80-120°C. The HP is sourced by flooded mine galleries that are employed as seasonal thermal heat storage and are heated up during the summer season by means of concentrated solar power (CSP) trough parabolic collectors. Developed during the DGE-Rollout project, as part of the HP system installation, are the hydraulic connections to the district heating that allow to inject up to 2 MW of thermal power, giving the possibility of some additional heat supply from geothermal sources.

At the location it is also planned to drill a DGE well with a depth of up to 1500 m that will allow to produce heat from hydrothermal waters at a constant temperature between 40°C and 60°C. Current heat production from this well is expected to be 5 MW. In its final configuration, the demonstrator of combined DGE and solar thermal heat sources feeding a large-scale subsurface heat storage and implemented into district heating via HT HP may produce up to 50.000 MWh per year.

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