PWG1: Technology

Technical Fact Sheet

Ad Hoc WG6

MEDIUM DEPTH GEOTHERMAL FOR DISTRICT H&C

Coordinator: Giorgia Pinna (OGS, Italy)

Collaborators: Nina Rman (Geological Survey of Slovenia, Slovenia)
Vit Hladik (Czech Geological Service, Czech Republic)
Ignasi Herms (ICGC, Spain)
Phil J. Vardon (TU Delft, The Netherlands)
Jannis Epting (Unibas, Switzerland)
Maciej Miecznik (MIN-PAN, Poland)
Staša Borovic (HGI-CGS, Croatia)
Emilio L. Pueyo (IGME, Spain)
Luca Guglielmetti (Unige, Switzerland)

Table of contents

1 GLOSSARY AND ABBREVIATIONS

BHE: *Borehole Heat Exchangers*. Circulating of fluid within pipes that allow the exchange of heat in the subsoil.

CHP: *Combined Heat and Power*. Production of energy with a high energy efficiency due to the combination of both heat and power.

DHC: *District Heating Cooling*. Network systems for delivering heating, hot water and cooling services from a central point of generation to the end users.

DHW-SHW: *Domestic Hot Water - Sanitary Hot Water*

GSHP-GHP: *Ground Source Heat Pump or Geothermal Heat Pump*. A central heating and/or cooling system that transfers heat to or from the ground and uses a heat pump between the ground heat exchanger and building heat exchanger.

HC: H*ydrocarbon* is an organic compound consisting entirely of hydrogen and carbon.

GWh/yr: *Gigawatt hours per year*.

HC: *Hydrocarbon*.

LiBr: *Lithium Bromide*.

MDG: *Medium Depth Geothermal*.

MWth: *Megawatt Thermal*.

RES: *Renewable Energy Sources*.

TJ/yr: *Terajoule per year*.

TOE/yr: *Tonnes Oil Equivalent per year*.

WG: *Working Group*.

2 TECHNOLOGICAL OVERVIEW

There are several geothermal classifications based on direct use and electricity generation (Fig.1), enthalpy and depth of the geothermal resource (Fig.2), energy efficiency and multiple technology used for DH generation (Fig.3).

The Medium geothermal Ad Hoc WG is between shallow and deep one because there isn't a rigid boundary. Within the COST Action CA18219 (Geothermal-DHC), the following range of temperature and depth 30°-90°/100°C and 400-2000/3000 m, respectively, was assumed as limits of medium depth geothermal system, considering the direct use of the geothermal resource and a normal geothermal gradient (2-3°C/100 m), closely linked to the geology of the site. Therefore, heat pumps, heat exchanger and hydrocarbon technologies are used and described.

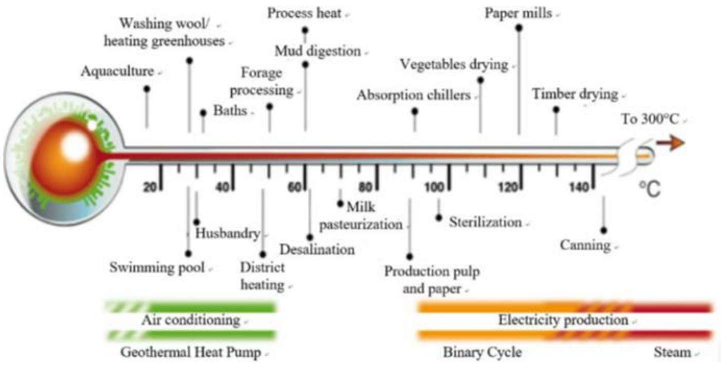

Figure 1: Use of geothermal heat for different resource temperatures (Modified Lindal diagram, Di Bella G. et al., 2018)

The Medium geothermal exploration is similar to HC exploration consisting in several surveys (geological, hydrogeological, geochemical and geophysical) necessary to identify the location of potential geothermal reservoirs and to plan conventional geothermal energy plants. The results of these surveys provide information on the heat resource, permeable reservoir, supply of water, reliable recharge mechanism and characteristics of the overlying layers of the reservoir (cap rock). Sometimes it is possible to utilize already existing information from research wells or oil and gas wells that are now depleted, saving time and drilling costs that increase with depth. However, some potential areas for MDG may not have any kind of oil exploration data (i.e. seismic sections and wells) because they were ruled out from the HC point of view; shallow basins, mountainous regions, basement rocks. Evaluation of MDG in these regions is an important challenge that must be tackled with cost-effective geophysical methods (gravimetric and magnetic surveying) in combination with serial balanced cross sections, robust petrophysics, etc.

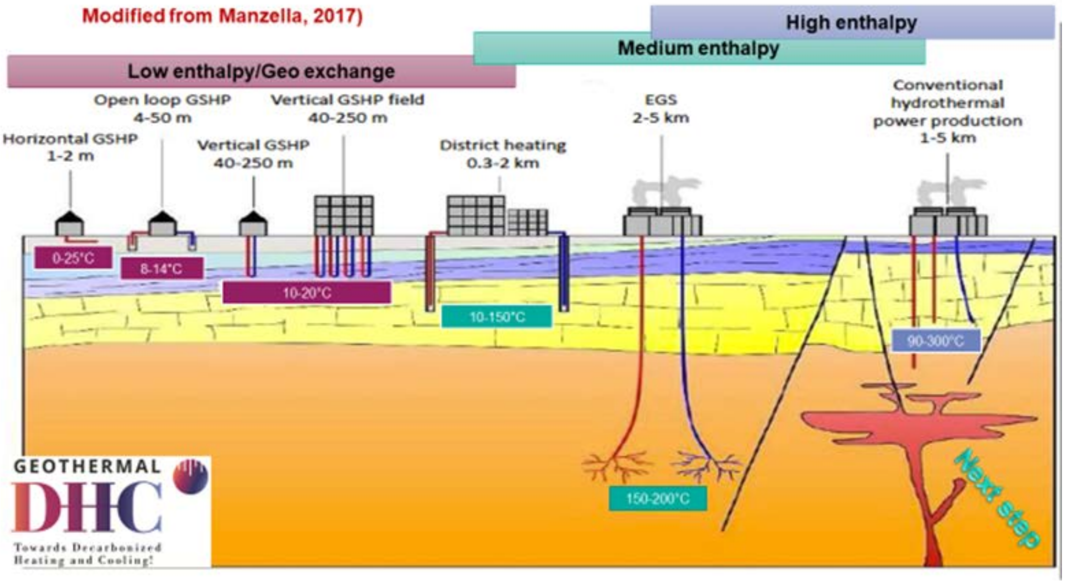

Figure 2: Geothermal classification based on enthalpy and depth range

In general, a conventional medium geothermal plant is characterized from:

1. A production facility
   - Deep wells and downhole and circulation pumps
2. A mechanical system
   - Heat exchangers
   - Substations
   - Transmission pipelines and distribution networks
   - Cooling systems (refrigeration)
3. Peaking or back-up plants
4. Disposal system
   - Re-injection deep wells
   - Injection pump
   - Storage pond or river

A well is drilled into a geothermal reservoir to provide a steady stream of hot water. A downhole circulating pump is used in a well to lift the fluid to the surface. Unless the well is artesian, downhole circulating pumps are needed, especially in large-scale direct-use systems. The generated heat needs to be distributed to heat users; this is achieved via a district heating network. DHC systems can be designed as "open" or "closed" distribution networks. The characteristics of open and closed systems are quite different. For example, closed systems generally employ insulated piping for both the supply and return piping, whereas, open systems may use insulation only on the supply piping. A careful engineering design is necessary for the transmission pipelines that carry fluids from the wellhead to the site of the application, subjected to thermal expansion, being heated rapidly from ambient to geothermal fluid temperatures Furthermore, the cost of transmission pipelines and the distribution networks is significant when the geothermal resource is located at great distance from the geothermal plant.

Heat exchangers are commonly used to transfer the heat from geothermal water to a secondary fluid. The heating of buildings is achieved by passing this heated secondary fluid through heat convectors (or emitters) located in each building. Geothermal resources can be also used to provide space cooling or refrigeration to buildings, commonly by absorption chillers, using heat as the driving force to produce cold water (geothermal inlet fluids between 80～150℃, depending of the absorbers agents used: LiBr/water or water/ammonia and the single or double effect selection) but also adsorption chillers which can work with much lower inlet temperatures (between 55°～90°/200℃, depending of the adsorption agent used: single-stage silica gel–water or zeolite/water).

A peaking system may be necessary to meet maximum load. This can be done by increasing the water temperature, by means preferably of other renewable energy as heat source (i.e. biomass, solar thermal energy) or using non-renewable sources by conventional boilers (e.g. natural gas), coupled with storage tanks. When the geothermal water temperature is limited (below 50°C), large heat pumps are used to increase the temperature of the DHC working fluid. Fluid disposal is normally done reinjecting the fluid to the ground through one or several injection wells.

In conclusion, a production facility is used to bring up and warm the water, and a mechanical system delivers the heat energy directly for its intended use. Afterwards the cooled water is re-injected into the geothermal reservoir. For DHC grids, the production/injection schemes are normally based on single or multi-doublets (production and re-injection wells) or triplets (1 production and 2 re-injection wells) although the configurations are normally adapted based on the local industrial experience and the reservoir characteristics. Along the life-time of the DHC plants, it is important to monitor its performance by controlling several parameters like: the reservoir temperature and pressure, the well head temperature and pressure, the production and injection well rates, the water and gas geochemistry of the geothermal fluids (which sometimes contain considerable concentrations of minerals and gases which can cause scaling and corrosion in wells and surface installations). Furthermore, 3D numerical heat-transport modelling allows to investigate (1) groundwater protection issues; (2) thermal energy potential assessment; as well as (3) forecast functioning of the "doublet" system and regeneration of the geothermal reservoir over a long period of time.

The heat production and demand are usually not equal during a day or a year. Geothermal systems can usually produce almost constantly whereas the demand is weakly varying daily and strongly varying seasonally. Buffers (e.g. tanks) are usually required in heating networks to account for the daily variation, but are too small to account for the seasonal variation. It is possible to reduce or stop the production from geothermal wells to cover this mismatch in supply a demand and consider heat storage for larger capacity.

3 STATE OF THE ART REGARDING THE USE IN HEATING AND COOLING GRIDS

The geothermal energy can be used directly for heating and cooling purposes or be harnessed to generate clean electricity. Here, the Medium Depth ad hoc WG mainly considers the direct uses of geothermal resources. The underground hot water can be used for space heating and cooling and domestic hot water production through DHC grids, heating of pools and spas, greenhouses and aquaculture facilities, agricultural drying, snow melting and cooling, pasteurize milk and food processing, industrial process heat, GSHPs and for many other geothermal heat applications (Lindal B., 1973), based on the resource temperature (Fig.1).

DHC, also referred as district energy or heat networks, delivers heating, hot water and cooling services through a network of insulated pipes from a central point of generation to end users. The fluid for direct use applications is usually transported in the liquid phase. Numerous types of pipe materials (metallic and non-metallic) are available for geothermal heating systems with great variation in cost and durability. Other factors including pipe size, installation method, head loss and pumping requirements, temperature, insulation, pipe expansion and service taps should be evaluated during a DHC design.

Medium or high temperature resources are needed for electricity generation. The medium temperature fields are also used for electricity generation or for combined heat and power (CHP), thanks to the development of binary cycle technology, in which geothermal fluid is used via heat exchangers to heat a process fluid (with a lower boiling point) in a closed loop.

New trends are cascaded direct uses, trigeneration systems (DH + DC + power generation), hybrid systems with RES (geothermal, solar energy, biomass, ambient heat and excess heat/cold) as shown in Figure 3. A primary motivation for building these systems was security of supply by improving the energy efficiency, using coal, biomass and waste as energy sources, in preference to oil. The integration of different energy sources means to be not dependent upon a single source of supply.

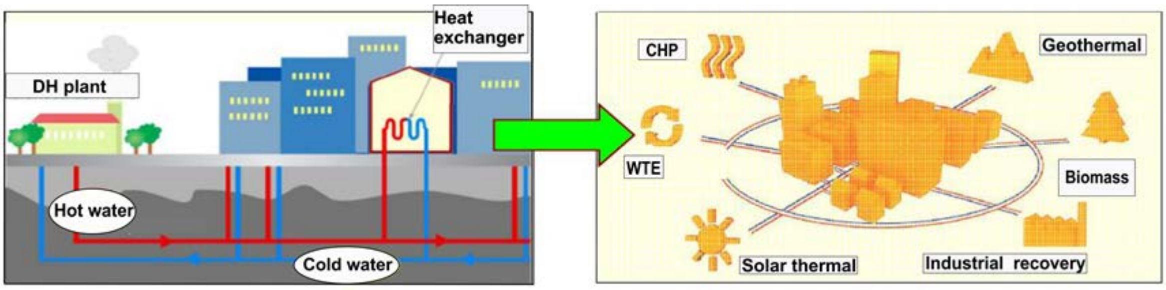

Figure 3: Geothermal DH plant, traditional on the left and hybrid on the right (Ferraresi F., 2010)

4 SELECTED CASE STUDIES

Many case studies have been collected and only few are presented below. The case studies were provided by some partners of the COST Action 18219 or extracted from the Geothermal District Heating database [(http://geodh.eu/database/)](http://geodh.eu/database/) The selection of these case studies is based on projects already implemented and connected to the district heating network, projects under new development and is mainly based on the direct use of the geothermal source.

The most representative case studies presented here, show the different uses of geothermal resources: heating only, heating and sanitary water, in combination with heat from industrial process, heat pumps, conventional gas boiler and other renewable sources (RES). Furthermore, the trend in geothermal is focused on enhancing the cascade direct use, exploiting the residual heat in multiple systems with decreasing thermal demand, as well as the utilization of old wells, drilled for oil exploration, not economically exploitable or sterile.

1. Location: Ferrara municipality (Emilia Romagna region - Italy)
Project Description (since 1983, extension under development): Ferrara, city of the Renaissance in the UNESCO World Heritage List, discovered the geothermal source in 1956, as a result of oil and gas exploration by AGIP, drilling Casaglia 1 well to 3379 m without finding hydrocarbons but evidenced the presence of 100ºC salt (65 g/l) water starting at about 1100 m in fractured Mesozoic

carbonates within a large structural high. In 1981, it was completed for geothermal production under a joint venture with the national utility Enel Green Power and a new well (Casaglia 2, 1,960 m deep) was drilled and tested up to 400 m^3/h of fluid on pump. In 1983 Ferrara Municipality started to build the downstream heating plant and DH network and the first geothermal heat delivery took place in 1990 by using Casaglia 2 as production (at the rate of 200 m^3/h on pump) and Casaglia 1 as reinjection wells. In 1995, a second production well (Casaglia 3, few meters from Casaglia 2) was drilled to 2000 m, doubling the field's flow rate. The surface equipment works in a closed circuit at 18 bar pressure. The geothermal resource is 105 – 85°C and operating temperature of DH is 90– 60°C. DH supplies about 320 buildings for the heat and about 85 buildings for sanitary hot water The heat plant is composed of the geo-system terminal, peak-load and back-up methane gas boilers, hot and cold water regulating storage tanks, a 150 ton/day solid waste incinerator and an inter-connecting pump station (Fig. 4). A co-generation unit was added in 1999 (Carella R., 1999). A 30-km grid of double pre-insulated steel pipes covered an extensive area along the central axis of Ferrara town, starting from its northwest outskirts for a total of 2.7 million m^3 of heated space. Geothermal energy provides 5.000 TOE/yr of the energy, corresponding to almost 60% of the total, as compared to about 20% each originating from the incinerator and the gas boilers. At the end of 2019 Italian Hera Group took over the geothermal power plant and the DH grid, operating in more efficient conditions. The new planned and integrated DH or hybrid system involves the southeast suburbs, reaching 25.000 housing units and 160 kilometers, saving 54 thousand tons of CO_2 per year and 38 tons of dust. Furthermore, the use of a part of heat for productive sectors such as viticulture or fish farming.

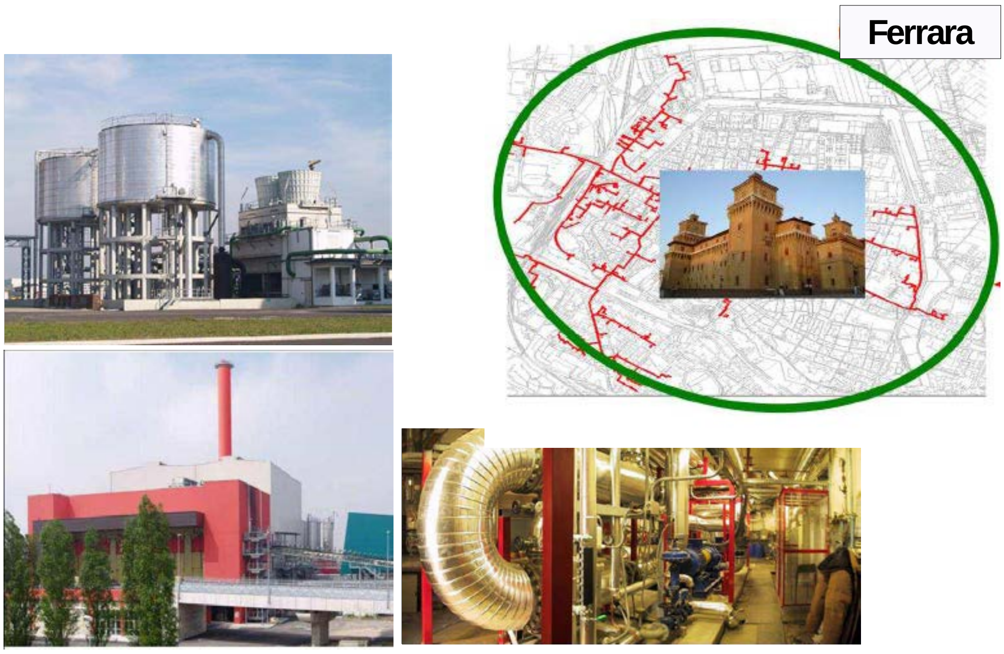

Figure 4: Geothermal plant (up left), waste incinerator (down left), Ferrara DH (up right), methane boilers for integration and back-up (down right). (Ferraresi F., 2010)

2. <u>Location</u>: Lendava (Pomurje region, Slovenia)

<u>Project Description</u> (since 1994): Lendava municipality in the NE of Slovenia, covers 123 km^2. A geothermal doublet provides district heating to the town since 2006. The production well Le-2g was drilled in 1994 at 1.5 km and reinjection well Le-3g in 2007 at 1.2 km. Water comes mainly from the Upper Pannonian sandy Mura Formation. The temperature of the geothermal reservoir is about 80 °C and the operating temperature of DH is 66–40°C. If the available heat in the primary circuit plate heat exchanger is not sufficient, the high-temperature heat pump and gas boilers

provide additional heat in the secondary circuit. Cooled water is injected back into the aquifer at a rate below 25 l/s and at wellhead pressure of approximately 4 bars. The DH length is 3.2 km providing space heating to several public buildings (school, kindergarten, etc.) and blocks of flats (total 50.000 m^2). Lendava geothermal DH plant "sensu stricto", under the Petrol d.d./Petrol Geo d.o.o. authority, is the only one in Slovenia as showed in Figure 5 (number 6). Furthermore, snow melting of the sidewalks (S in Fig. 5) is another direct use of geothermal heat from the already utilized thermal water and the company has improved some old oil wells into geothermal ones to be used for greenhouses. (Rajver D. et al., 2019). The two wells tap the same aquifer as the spa Terme Lendava in Figure 5 (number 5, blue arrow), fed by the water of three wells Le-1g, Pt-20 and Pt-74 (T_{out}= 61°-55 °C) and used in cascades: for space heating, sanitary water heating, bathing, and balneology in pools.

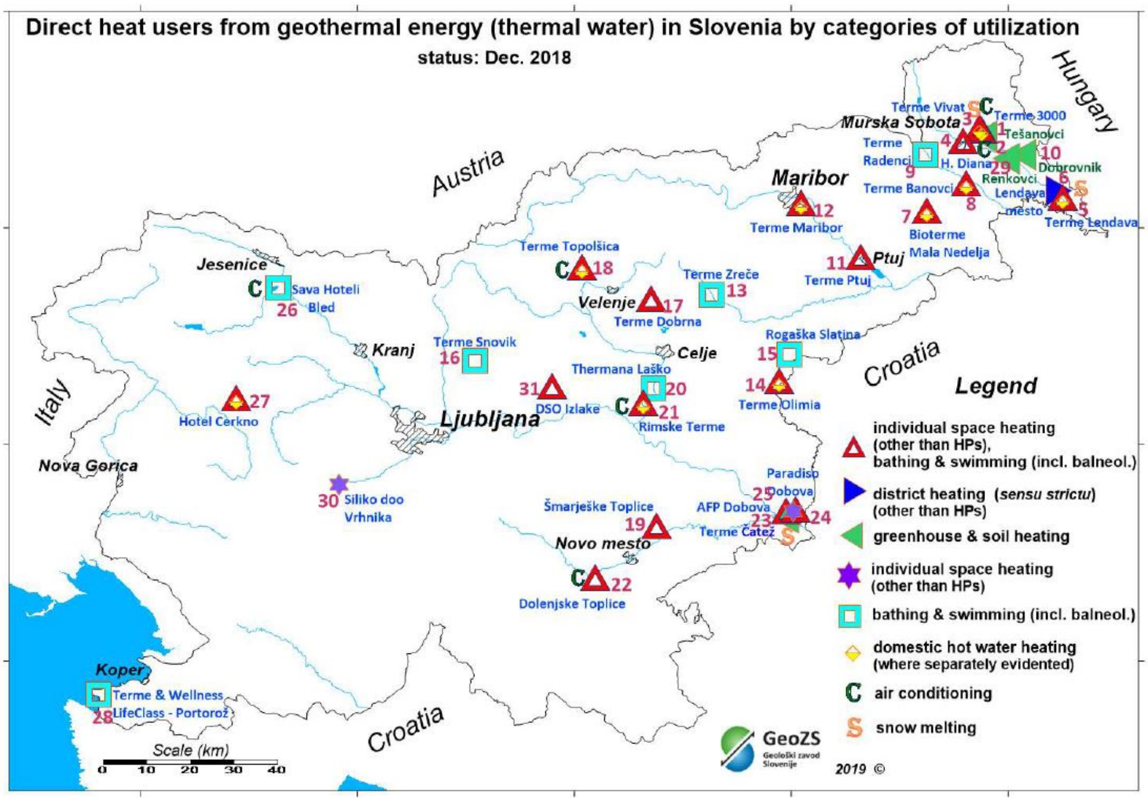

Figure 5: **Direct heat use of geothermal energy in Slovenia** (Rajver D. et al., 2019).

3. *Location:* ***Podhale geothermal system (Southern Poland)***

   Project Description (1967, extension under development): The Podhale geothermal system covers an area of approximately 530 km2 (on the territory of Poland only) and consists of 9 production, 2 reinjection and some currently inactive wells. The term of Podhale geothermal system is used to refer to the sub-flysch aquifers of the Podhale Trough (S-Poland), characterized by Middle Eocene and Mesozoic (mainly Triassic) pore-fissured carbonate formations, covered by the overburden flysch, thick up to 3 km. The wellhead temperature of exploited waters reaches 90°C, while the reservoir temperatures may reach 94–100°C at a depth of 3–3.5 km. Geothermal exploitation is concentrated in 7 mining areas, of which the Podhale 2 mining area is characterized by highest capacities. The total extraction of thermal waters from the Podhale geothermal system in 2019 was nearly 6.5 million m3, of which almost 5 million m3 in the Podhale 2 mining area alone. The main city in this region is Zakopane (tourist city) located at the foothills of the Tatra Range of the Carpathian Mountains with approximately 27,000 residents. Since 1993 the Polish heating company PEC Geotermia Podhalańska S.A. holds a licence to operate the Podhale 2 mining area. The installed thermal capacity of DH operated by PEC Geotermia Podhalańska S.A. is 81.5 MW, of which 40.7 MW is from the geothermal plant and the remaining 40.8 MW from peak boilers powered with natural gas (Ślimak C., 2016). The DH length is 115 km and operating temperature is 85/55°C. In 2019, 1689 customers were connected to it. In the same year, the ordered thermal power was 73.5 MW and the sale of heat by PEC Geothermal Podhalańska S.A. amounted to approximately 478 TJ (http://geotermia.pl/historia/). In recent years, the share of geothermal energy accounted for over 90% of the heat sold. In addition to DH, e geothermal heat is supplied to 7 big geothermal aqua parks located in the Podhale region. These aqua parks were constructed in the years 2006-2016 (Fig. 6). Geothermal heat is also used for drying wood, heating greenhouses and in the past - for fish farming and soil heating (horticulture). Further development of the Podhale geothermal system is planned, including the drilling of new production and reinjection wells, as well as the expansion of the DH network to other cities and surrounding communes.

Figure 6: **Direct use of geothermal energy in the Podhale region.** (Source of the photo on the right: cowkrakowie.pl).

4. *Location*: ***Trias Westland (Naaldwijk – the Netherlands)***
Project Description (since 2019): The Trias Westland project currently has one geothermal doublet in operation (in 2019 started supplying heat) and another one in construction (http://www.triaswestland.nl/). Both exploit heat from the Delft sandstone reservoir, around ~2.3 km deep. Currently 26 horticulture companies (greenhouses) receive heat (Fig. 9), and it will be expanded to 56 and over 300 homes with the second doublet. The heat network is currently 13.5 km in length and being substantially expanded as a result of the second doublet. The reservoir and extracted fluid is around 85°C, with a return temperature of around 30°C. During this project a trial drilling was undertaken to a depth of 4.1 km to investigate the potential of deeper (hotter ~140°C) reservoirs in this location.

Figure 9: a Dutch greenhouse (https://www.hortidaily.com/article/9140485/)

5. *Location*: ***Děčín municipality (Czech Republic)***
   Project Description: Děčín, to the North near the German border (Fig. 7), is a city with 55.000 inhabitants and a DH system based on geothermal energy by using groundwater with a temperature of 30°C in Bohemian Cretaceous Basin to the depth of 1 km (Myslil V. et al., 2005). The water is directly used for a swimming pool but for heating purposes, two 3.28 MWth heat pumps are used to increase the temperature to 72°C. The system is supported by two cogeneration gas engines and two gas boilers to cover the peak thermal output requirements. The DH system supplies 4687 households and several public buildings.

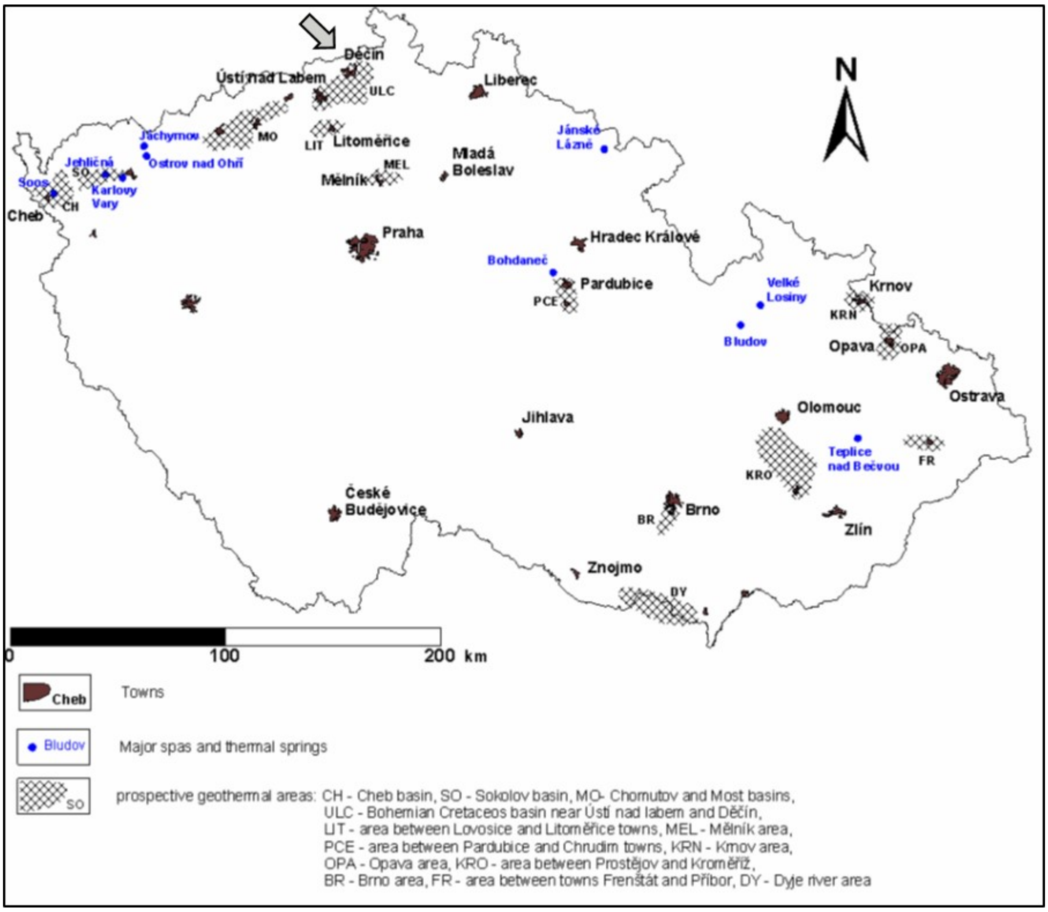

Figure 7: Map of major spa, thermal springs, and prospective areas of Czech Republic. (Myslil V. et al., 2005)

6. <u>Location</u>: ***Riehen town (Canton of Basel-Stadt - Switzerland)***
<u>*Project Description (since 1994 and under development)*</u>*:* The Riehen geothermal plant (Fig. 8) started to provide heating for 200 buildings. It consists of a doublet system with a production well (1547 m) and an injection one (1247 m). The aquifer is located in the Middle Triassic Muschelkalk formation in the area of a fault zone at the Southern End of the Upper Rhine Graben (Link K. et al., 2019). Thermal water at 65°C and a rate of 23 l/s is first conveyed through heat exchangers and then cooled to about 30°C by means of three heat pumps, to then be infiltrated back into the reservoir. The DH length is 38 km and extended to Stetten (Lörrach) in Germany, representing one of the first transboundary direct use facility worldwide. Currently, the geothermal plant supplies around 4.8 GWh/y. Although the productivity of the Riehen system is indisputable, the functioning of the doublet system was questioned by a dye tracer test with no recovery in the production well. After a feasibility study in 2018 showing the chances of operating a second geothermal plant, there are plans underway to expand use of the geothermal reservoir at Riehen by installing a second doublet system.

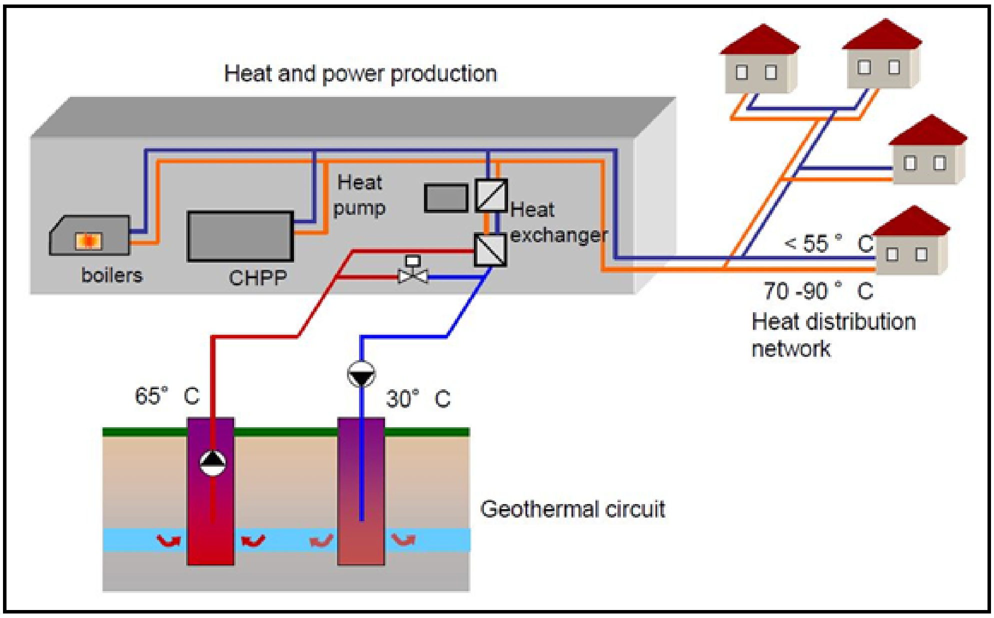

Figure 8: Riehen's geothermal plant (Erdwarme Riehen - Geothermal Communities)

7. *Location: TU Delft (Delft – the Netherlands)*
Project Description (under development): The Delft Geothermal project or DAP well (Vardon et al., 2020) will supply heat to the university campus and surrounding area via a five-track DH network. The project will exploit heat from the Delft sandstone in a reservoir approximately 2.2 km depth, which will produce heat at approximately 75°C at a flow rate of > 300 m^3/hr. Initially, it is proposed to be able to deliver 8 MWth, increasing to 15 MWth by having a cascading temperature DH network. A unique aspect of the project is the level of monitoring and baseline data collected. In Figure 10 a detailed installation description is showed (**https://www.tudelft.nl/en/delft-outlook/articles/campus-switching-to-geothermal-energy/**). In particular, several hundred meters of core material will be collected, fibre optic monitoring systems will be installed in each well (collecting temperature, strain, pressure and acoustic measurements), geophysical monitoring stations (seismometers) will be installed in shallow wells surrounding the project, and geo-fluid sampling and analysis will be undertaken.

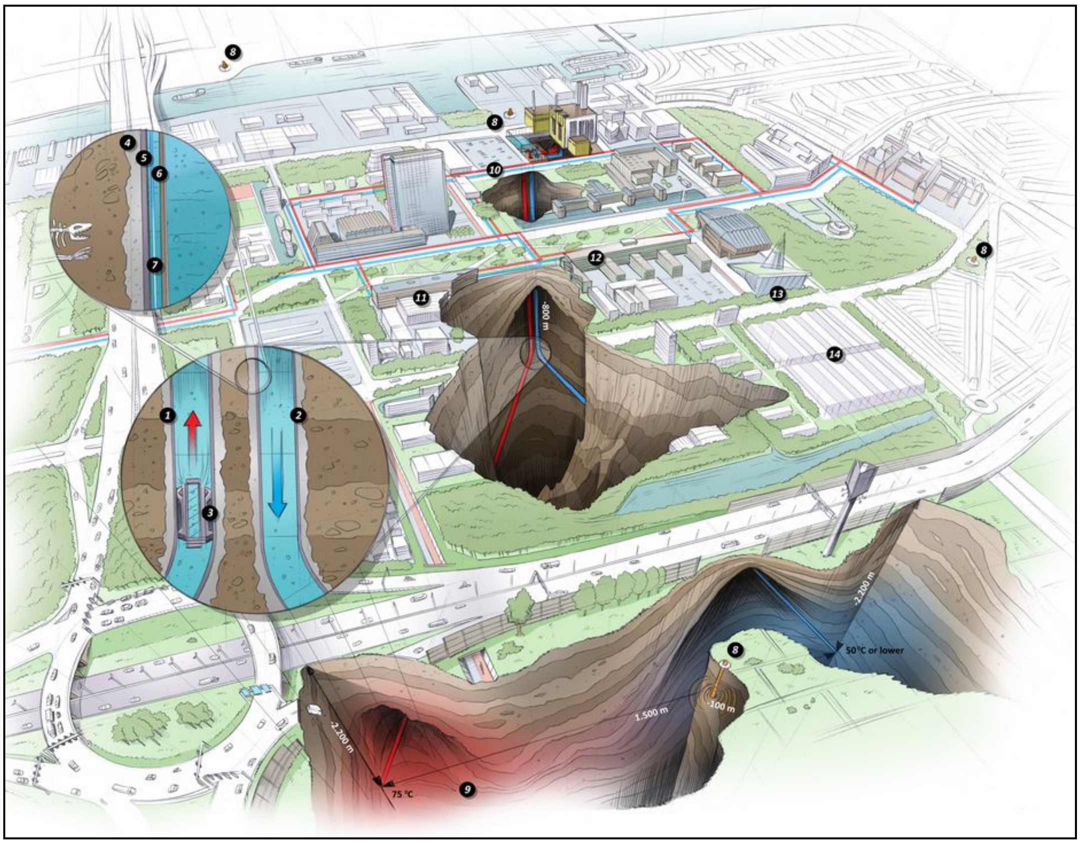

Figure 10: Delft Campus Project: (1) intake pipe, (2) discharge pipe, (3) pump (4), (5), (6) multi-layered pipes with a cement outer wall, a steel pipe and an epoxy inner lining (7) fibre-optic cable, (8) Seismometers (9) groundwater flow through the reservoir (10) heat exchanger (11, 12) adaptation of older buildings)

5 OUTLOOK UNTIL 2050

The main targets for 2050 are: 1) the integration of geothermal heating and cooling into the existing and future energy systems in combination with other RES to increment their penetration, enlarge the use of renewable energy sources contributing to phasing out of fossil fuels for energy supply. 2) an accurate characterization of the subsurface to quantify the geothermal energy potential, reduce the uncertainty and mitigate the risk associated to prospection, exploration, and production phases, ensuring a long term and sustainable use of the geothermal technologies. 3) the reduction of production costs of geothermal energy 4) the reduction of exploration costs and the unit cost of drilling by 50% in 2050 compared to 2015 by developing fully robotized/automatized drilling solutions enhancing speed and safety too 5) the development of new generation medium depth (up to 500 m) BHE for an efficient use of geothermal systems to reduce material (i.e. new plastic pipes) and installation or operating costs (https://www.rhc-platform.org/publications/).

SWOT analysis:

The following SWOT analysis (Fig. 11) helps to build a strategic planning to identify strengths (S), weaknesses (W), opportunities (O), and threats (T) related to a Medium Depth Geothermal project. It is intended to identify the internal and external factors that are favorable and unfavorable in making MDG systems more popular.

COST Action 18219: Geothermal District Heating&Cooling Permanent Working Group, 1, Technology			SWOT list, version January. 2021 Ad-hoc Working Group: MDG (Medium Depth Geothermal)		
Strength	**Mark**	**Average**	**Opportunities**	**Mark**	**Average**
Wide range of technology combination			Political intentions of EU support on renewables		
Enhanced cost-benefit resulting from cascade system			Appropriate for local energy production and storage, decentralization		
Existing project and technological models, well established technology			Minimal carbon emission, low environmental and accidental risk		
No need fuel during operation (excluding electricity consumption)			Appropriate for hybrid projects with bio, solar and HC technologies		
Low operating cost, continuous operation			Geothermal energy used in emerging CHPM (e.g. lithium) technology		
Independent from weather			Refurbishment of fossil driven DH systems (limited to generation 3+ network)		
Low surface space consumption (in urban area)			Large further capacities (low degree of exploitation of known resources)		
High quality heat (temperature) - Direct use of geothermal heat			Public acceptance is rather high on an EU level		
Suitable for conventional DH systems (from generation 3 on)			Time and cost reduction by utiizing previous exploration or abandoned wells		
Recycling of previous exploration data and technologies, and also utilization of abandoned hydrocarbon wells			Multiple use from a single renewable resource, cascade use and circular economy (production-distribution, consumption, reutilization)		
Combination with balneology			Balneotherapy and recreation building a positive picture of geothermal energy		
Baseload energy supply			Increase in jobs (local production of food and plants, spa, etc.)		
Low OPEX			Touristic aspect (greenhouses, spa) promoting green energy		
Very little CO2 emissions			Local resource, not damaged by natural disasters or terroristic actions		
Always available (at any hour even for 365 days a year)			Pressure on developing district heating systems in cities		
Low degree of flexibility with regard to capacity			New residential, office and commercial buildings with low temperature supply requirements		
Understimation of MDG resources in areas not explored by oil research			Development of MDG exploration based on cost-effective technologies (geophysical potential field)		
Weaknesses	**Mark**	**Average**	**Threats**	**Mark**	**Average**
Geological risks in the early phase of the exploration			Solar and wind boom covers all markets		
Geologically conditioned possibility of applications (Dependancy on reservoirs)			The technology qualified "partly renewable"		
Low energy density comparing to other energy resources			Environmental regulations makes operations difficult or preclude it (time consuming licensing procedures)		
Need for research and technology development, in terms of efficiency and cost reductions			Low public awareness and public trust, well-known only in a few countries		
Drilling costs cannot be reduced significantly			No standard European business models, few private investors		
Short transport distance of heat due to losses and investment costs			Other renewables show better financial competiveness		
Dependency on subsidies			Upcoming political interest in green gas energy supply as well as in the electrification of the heating market		
Two much time from project to development			Vanishing public acceptance after non-successful pilot projects		
High initial investment costs (APEX)			Lack of promotion even in areas with great potential		
Risk of seismicity			Risk mitigation schemes / Risk insurance funds available only in a few countries		
Lack of cooperation among geologists and engineers provides under-over designed systems			Lack of funding opportunities following drilling first research well		
Decline of initial capacity with time (due to pressure or temperature drawdown or filter clogging) under control by continuous monitoring			Too little targeted educational programs to foster faster development and applications (energy engineers and designers, economists in RES etc.)		
Well casings corrosion or scaling leading to severe technical problems					
Lack of subsurface data implies higher uncertainty and initial investment					

Figure 11: SWOT analysis for the medium depth geothermal energy

<u>Trend of direct utilization of geothermal energy worldwide from 1995 to 2020</u>:

The direct utilization of geothermal energy worldwide, based on data presented at WGC 2020 (World Geothermal Congress) and compared with WGC 1995-2020) is shown in Figure 12 (Lund J.W. et al., 2020). It is evident the increasing trend of geothermal direct-use in terms of installed thermal capacity (MWt) and thermal energy used (TJ/yr). The distribution of thermal energy by category is approximately 58% for GHP, 18% for bathing & swimming, 16% for space heating (of which 91% is for DH), 3.5% for greenhouse heating, 1.6% for industrial applications, 1.3% for acquaculture pond and raceway heating, 0.4% for agricultural drying, 0.2% for snow melting and cooling, and 0.2% for other applications (Fig.13). Geothermal, a domestic source of sustainable and renewable energy, can replace other forms of energy use, especially fossil fuels and can be combined to other RES leading to a reduction in dependence on imported fuels, elimination of pollutants such as carbon particles and greenhouse gases. As oil and gas supplies dwindle and increase in price, geothermal energy becomes an even more economically viable alternative source of energy. Even though the initial cost of developing a geothermal resource is high (exploring, drilling wells, constructing pipelines and plants), the long-term cost is low. Under the European Green Deal, the European Commission promotes the deployment of renewables and energy efficiency to achieve a secure and sustainable energy future (climate neutrality by 2050).

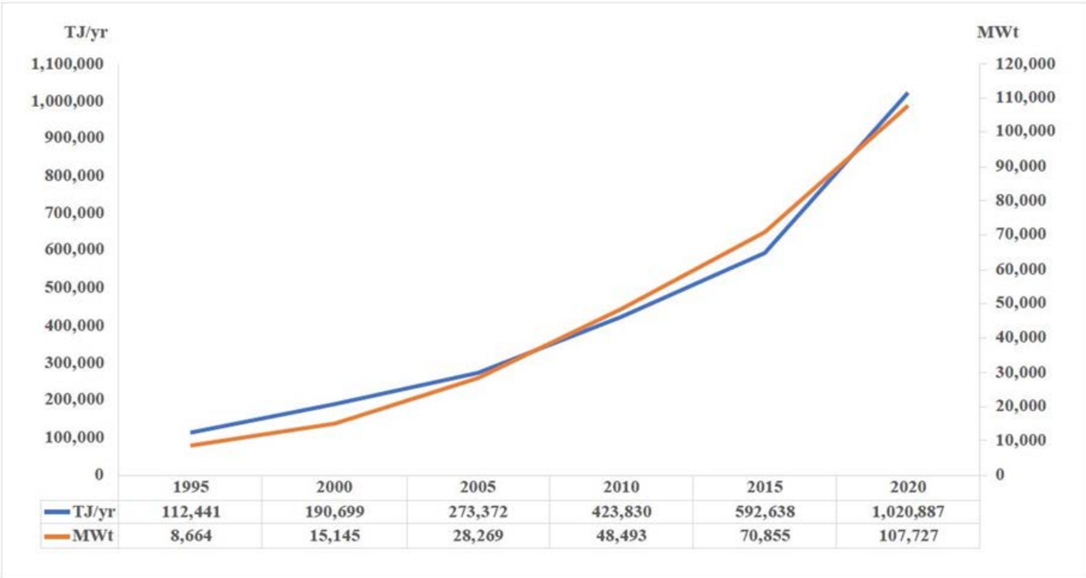

Figure 12: The installed direct use geothermal capacity and annual utilization from 1995-2020

(Lund J.W. et al., 2020)

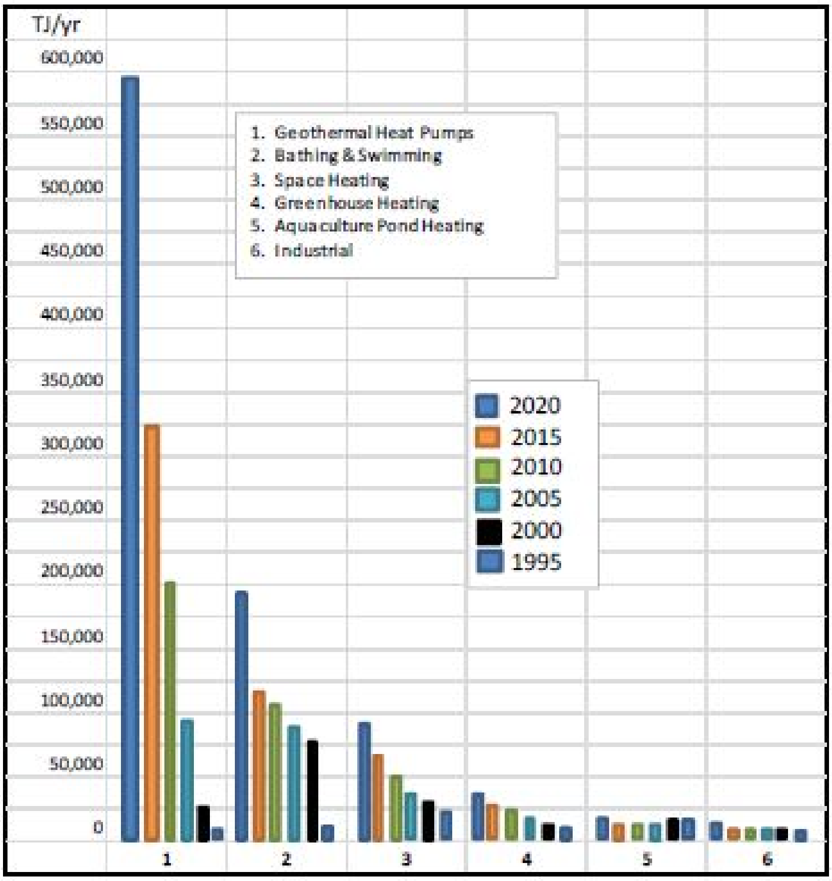

Figure 13: Comparison of worldwide direct-use of geothermal energy in TJ/yr from 1995, 2000, 2005, 2010, 2015 and 2020. (Lund J.W. et al., 2020).

6 REFERENCES

Vardon, P.J., Bruhn, D.F., Steiginga, A., Cox, B., Abels, H., Barnhoorn, A., Drijkoningen, G., Slob, E., Wapenaar, K., (2020 – online) A Geothermal Well Doublet for Research and Heat Supply of the TU Delft Campus, World Geothermal Congress. https://arxiv.org/abs/2003.11826

RHC, 2020. Strategic research innovation agenda for geothermal technologies. https://www.rhc-platform.org/publications/

Rajver D., Lapanje A., Rman N, Prestor J., 2019. Geothermal Energy Use, Country Update for Slovenia. European Geothermal Congress Den Haag, The Netherlands, 11-14 June 2019

Link K., Siddiqi G., Lupi N., 2019. Geothermal Energy Use, Country Update for Switzerland Den Haag, The Netherlands, 11-14 June 2019. Geothermal energy.

Lund J.W. and Toth A.N, 2020. Direct utilization of geothermal energy 2020 worldwide review. WGC 2020, Reykjavik, Iceland, 26/4-2/5/2020.

Di Bella G., Sapienza A., Vasta S., Lombardo G., 2018. Design of a geothermal plant to heat a waterpark swimming pool: Case study of tramutola (Basilicata, Italy). European Journal of Electrical Engineering – n° 5-6/2018, 539-557

Ślimak C., 2016 – PEC Geotermia Podhalańska – stan obecny, perspektywy rozwoju. Instal 2: 6–8 *(in Polish)*

ERDWÄRME RIEHEN - Geothermal Communities, 2015. Riehen: The path to profitable geothermal district heating. MGC (online)

Ferraresi F., 2010. Sistemi di teleriscaldamento geotermici per aree urbane: l'esperienza e le prospettive di sviluppo della rete di Ferrara. Geotherm Expo 2010, Session 4 *(in Italian)*

Myslil V., Stibitz M., Frydrych V., 2005. Geothermal Energy Potential of Czech Republic. Proceedings World Geothermal Congress 2005. Antalya, Turkey.

Carella R., 1999. Italian geothermal district heating systems. GHC Bulletin, December 1999.

Lindal B, 1973. Industrial and other application of geothermal energy. In: Armstead HCH, Geothermal Energy, UNESCO, Paris, pp.135-148.

http://geodh.eu/database/
http://geotermia.pl/historia/

http://www.triaswestland.nl/ *(in Dutch)*

https://www.hortidaily.com/article/9140485/netherlands-trias-westland-starts-with-second-geothermal-heat-source/

https://www.tudelft.nl/en/delft-outlook/articles/campus-switching-to-geothermal-energy/

7 APPENDIX A

Further medium depth case studies

Many case studies were collected, provided by some partners of the COST Action 18219 or extracted from the Geothermal District Heating database (http://geodh.eu/database/). The case studies are based on all direct use of the geothermal source, on projects already implemented and connected to the district heating network or projects under new development. Unfortunately, only seven case studies, the most representative, were selected and inserted in the MDG technological fact sheet while the remaining ones are listed below:

1. Location: ***Grado municipality (Italy)***
   Project Description (2002-2015): The Grado Geothermal Pilot Project aimed to demonstrate the feasibility and sustainability of a geothermal doublet on the Grado Island, with one production and one re-injection well. (Della Vedova et al., 2015). By December 2014, one km of district heating distribution network was and six public buildings were connected. The 1st phase, completed in 2008, confirmed the existence of a geothermal reservoir within the buried Mesozoic carbonate platform. After seismic and gravity surveys two wells (Grado 1 and Grado 2) were drilled down to 1110 m and 1200 m respectively into Paleeogene-Mesozoic carbonate. The Grado reservoir is a confined fractured aquifer hosting anoxic fossil seawaters with temperatures up to 49 °C in Grado 2 (7 °C higher than Grado 1). Two km DH connected to public building and possible development. (Heating)

2. Location: ***Vicenza municipality (Veneto region - Italy)***
   Project Description: Vicenza, 100 000 people, has a large geothermal water reservoir at 68°C around 2 km depth. The well was already existing (drilled in 1983) and the geothermal exploitation began in mid-2013. Heat pumps are implemented to obtain optimum useful heat energy. The operating temperature of DH network in delivery pipes is 85 –65 °C and connected to 211 inhabitants The geothermal heat provided 5,38% (2,4GWh) of the total heat production in 2013. Other heat inputs are: 27,05% (12,1 GWh) cogeneration and 67,57% (30,2 GWh) boiler. This DH reduces energy consumption by up to 60%, i.e. 3885 MWh/year. (Heating)

3. Location: ***Murska Sobota (Pomurje region, Slovenia)***
   Project Description (1987-2015): Murska Sobota covers 64 km^2 in Pomurje region, located in the north-eastern Slovenia. Since mid-1980's, use of geothermal energy was focused on deeper geological formations bearing (Upper Pannonian sandy geothermal acquifer). In the year 2008, 61 buildings were connected to a high temperature DHC powered by thermal water from a deep well Sob-1/87 (870 m deep, $T_{outflow}$ = 49 °C, $Q_{average}$ = 5 l/s). Due to the decreased capacity of the well in the last decades and issues with the need for reinjection, this high temperature DHC has been shut down. Since 2015 an increased use of shallow open-loop systems. by geothermal (water –water) heat pump systems is observed.

4. Location: ***ES511 San Cugat del Valles (near Barcelona, Catalonia) hydrothermal project under development***
   Project Description: known as Can Tintoré anomaly, is a highly fractured granitic fault zone of the eastern border of the Vallès Graben at Sant Cugat, near Barcelona city (Catalonia) that was discovered between the 50's and 60s inside the fluorite underground granite mine called 'Berta' due to unexpected thermal inflows. In 1973 and then in 1983 and 1984 some shallow wells (the deepest up to 400 m) - were drilled in the fault from outside the perimeter of the mine and some long-term well tests were carried out (50 days pumping), and it was reached a resource of up to

80 l/s and temperature of 58 ° C. The wells are still there available but unused. The ICGC some years ago performed a geophysical logging campaign of the main well and since 2020 it is monitored. Few attempts in the past have tried to study the possibility of taking advantage of it. The preliminary phase of study and modeling are analyzing the possibility to take advantage of the resource in a hypothetical DH for the Rubi municipality (close to the anomaly) interested in recent years in DH systems, both for a neighborhood, and for a nearby industrial zone.

5. *Location*: ***Topusko (Sisak-Moslavina region - Croatia)***
   Project Description (1977-1990): In Topusko, three natural thermal springs existed, with an estimated total yield of about 25 l/s, and temperatures ranging from 49 to 55 °C, making it the second warmest natural thermal water springs in Croatia. The geothermal aquifer is Triassic dolomite. From 1977 to 1985 seven exploratory boreholes were drilled, one deep exploration well and four abstraction wells (tapping carbonate complex at 120-190 m depth). Deeper boreholes were not needed because they all have artesian outflow at these depths. Most of the abstraction wells, after the devastation of the area during the war (1990-1995), are not in operation. The thermal water is used for space heating of the hotel, health and rehabilitation centre although the potential is significantly higher. It was thought that Topusko springs were heated by a magmatic body but the most likely hypothesis is that the aquifer receives recharge west from the thrust front of the Petrova gora Mountain, where Triassic dolomites crop out. To protect the recharge area from destruction, it is planned by the Croatian Science Foundation to investigate a wider basin area through the HyTheC project in the period of 2020-2025.

6. *Location*: ***North Madrid town (Spain)***
   Project Description: At the North area of Madrid town, a geothermal reservoir in the tertiary, clastic, consolidated sandstone sediments, a thick multilayer sequence of about 200-800 m with temperatures ranging from 70 to 90º C at depths around 1500 to 2200 m has been evidenced as an important low enthalpy geothermal reservoir. An oil exploration well (Pradillo) and two geothermal wells (Tres Cantos and San Sebastián de los Reyes) drilled at the beginning of the 80's, and other geothermal well (GeoMadrid) drilled in1990 confirms the data. Several attempts tried to develop the exploitation of the geothermal resources al the 80's in Tres Cantos and San Sebastian de los Reyes villages in the 90's and at the end of last decade in GeoMadrid (Canto Blanco) (IGME, 1982 a&b; Lanaja, 1987; Hidalgo et al, 2009) In North Madrid area is planned for heating and cooling in a H&C district, in which are included public buildings and houses. No current exploitation but it will be exploited in the medium term.

7. *Location*: ***Villalonquéjar (Burgos province - Spain)***
   Project Description: At the industrial park of Villalonquéjar (located at the west of the town of Burgos), an important geothermal reservoir located in sedimentary Cretaceous materials with temperatures of around 70ºC at depths of 1800-2500 m was confirmed by a geothermal well drilled in 1981. Though the sands of the lower Cretaceous were the objective of the geothermal well, the carbonates of the upper Cretaceous can be also considered as a good geothermal reservoir. A few attempts to continue with the project took place during the 80's and 90's and the first decade of this century (IGME, 1980-1982; Cuchí et al., 2000). The planned application is heating and industrial uses in the industries located at the industrial park. No current exploitation but it will be exploited in the medium term.

8. *Location*: ***Ústí nad Labem Zoo (Czech Republic)***

Project Description: the heating system at the Ústí nad Labem zoo is in operation since 2005. It utilises thermal water (32 degrees C) from a 515 m deep well, combined with heat pumps and a backup electric boiler. The system covers 30 buildings in an area of 6 ha.

9. *Location: **Green Well B V West Land (Netherlands)***
   Project Description (2007-2012): The DH length is 1.5 km and provides heating to 10 horticulture companies. The geothermal resource provided groundwater with 86°C for production and 35°C warm water for re-injection; operating temperature of the DH is 86°C. (Heating)

10. *Location: **ECW Netwerk (Middenmeer – the Netherlands)***
    Project Description: The ECW Network provides heat for a group of ten horticulture companies, supplying geothermal energy since 2014 (). There are 3 geothermal doublets all drilled to around 2.2 km deep and producing water at around 92°C, and have a return temperature of around 34°C. A heat grid supplies the water to the horticulture companies for heating greenhouses (~100 hectares). A high temperature (85°C) heat storage pilot 10-15 GWh is in the implementation phase. (Heating)

11. *Location: **Orly Airport (Paris - France)***
    Project Description: Coulommiers choose to largely develop geothermal DH in order to ensure a stable and competitive energy price to citizens, to use local resource and reach a good level of comfort. Two wells were realized in the Dogger aquifer, at 1.8 km depth. The geothermal resource is 74°C – 40°C and operating temperature of DH is maximum 105°C. The district heating supplies around 3000 housings and its length is 35 km. (Heating and District Heating Water)

12. *Location: **Alfortville (Ille de France Region - France)***
    Project Description (1985): The DH heats 5400 housings and its length is 5.8 km. Wells were realized in the same Dogger aquifer at 1.8 km depth. The geothermal resource is 74 – 40 to 50°C and operating temperature of DH is maximum 95°C. (Heating and District Heating Water)

13. *Location: **Le Plessis-Robinson (Ille de France Region - France)***
    Project Description: The Plessis Robinson's DH is mainly powered thanks to geothermal energy. Two wells were realized at 1 km depth where the geothermal resource is 39°C -14,5°C and operating temperature of DH is 85°C. This geothermal district heating supplies around 3500 housing, i.e. about 217'000 m2. The DH grid is around 10 km in total. (Heating and District Heating Water)

14. *Location: **Oradea (Romania)***
    Project Description: The geothermal heat plant was designed to supply the secondary fluid (treated water) with a temperature of 102°C, which can provide 80% of the heat demand for space heating at the design value of -15°C outer temperature, and 100% for house hot water. The peak load for space heating is supplied by two natural gas fired boilers, which increase the supply temperature of the secondary fluid from 102°C to 110°C. The geothermal resource is 104°C and operating temperature of DH is 90°C. (Heating and District Heating Water)

15. *Location: **Galanta Municipality (Slovakia)***
    Project Description (2009-2011): Galanta has 15'147 inhabitants. The geothermal district heating supplies 1300 apartments and a hospital. The sedimentary geothermal reservoir occurs in the central depression of the Danube Basin. The Galantaterm was one of the first geothermal

companies in Slovakia to utilise geothermal water for DH and production of DHW. The geothermal resource is 77-78°C and operating temperature of DH is 90/70°C (hospital), 77/52°C (houses) and 55°C for water (thermal spa). Heat output of the geothermal water suffices to cover heat demand of the system up to outdoor temperature 0°C. In case of lower outdoor temperatures, gas boilers started automatically. Four gas boilers with pressure burners with total heat output of 10,6 MWt are installed and used as a peak and backup heat source. (Heating and District Heating Water)

16. *Location:* ***SK - Sereď (Slovakia)***
Project Description (2009-2011): Sereď has 16'000 inhabitants and the geothermal district heating supplies 3760 apartments, i.e. 10,8 MWth. It saves 600'000 m3 of gas each year. The geothermal resource is 66°C and operating temperature of DH is 65/45°C. It is supported by natural gas boilers. (Heating and District Heating Water)

17. *Location:* ***Šaľa (Slovakia)***
Project Description (2009-2011): Šaľa has 23'440 inhabitants. Its location within geothermal active area enables utilization of geothermal energy for space heating purposes supplying 87% of inhabitants. Two district heating systems cover approx. 20 km. The geothermal resource is 70°C and operating temperature of DH is 100/50°C. Geothermal energy is used for pre-heating (70°C production temperature) and it is supported by natural gas boiler.

18. *Location*: ***Hódmező-vásárhely (Hungary)***
Project Description: Geothermal energy utilization in Hodmezo-vasarhely has decades of tradition. The first thermal well was drilled for balneology purpose in 1954. Since 1967 were installed 8 production and 2 injection wells. In 1993 the local government decided to develop an integrated geothermal DH system that supplies around 2'800 flats and 130 institutional consumers providing heating and hot water. The geothermal resource is 90-105ºC of the produced, 30-50ºC of the injected water and operating temperature of DH is 80-87ºC in the heating system 40-42ºC of the household warm water. DH length is at least 10 km. (Heating and District Heating Water)

19. *Location*: ***Mórahalom municipalty (Hungary)***
Project Description: The city has 6'100 inhabitants. A geothermal cascade system was developed to reduce dependency on natural gas by using a renewable heat source. This system consists of two drilled wells, a 1.26 km-deep outflow well and a 0.9 km re-injection well. The sedimentary geothermal reservoir occurs in the Pannonian Basin (Nádor A. et al., 2016). Within the project a new district heating system of 2.85 km was established to supply public buildings. The GHG emission is now reduced by 80%. The geothermal resource is 70ºC (one well) and 40ºC (two wells). The operating temperature of DH is 69-40ºC and 39-25ºC.

20. *Location*: ***Bóly town (Hungary)***
Project Description (2006-2008): Bóly is a small agricultural town with 4000 inhabitants. A DH project started in 2006 and 1500 m production well was drilled. The sedimentary geothermal reservoir occurs in the Pannonian Basin. The geothermal resource is 84°C and 28-34ºC re-injection temperature. The operating temperature of DH is 80-34ºC. DH length is 7 km. (Heating and District Heating Water)

21. *Location*: ***Amager (Copenhagen-Denmark)***

<u>Project Description (1999-2005):</u> The district heating in Copenhagen supplies around 6000 housings and its length is 2000 km. Two 2.6 km deep geothermal wells were drilled to the Bunter Sandstone Formation. The geothermal resource is 74°C and an electrical submersible pump (ESP) with a power of 700 kW pumps up to 230 m^3 per hour from the reservoir. The water is cooled in heat exchangers to approximately 17°C before being pumped back into the reservoir through a 400 kW injection pump (A. Mahler et al, 2013). The operating temperature of DH is 89/80°C - 52/48°C. The geothermal plant produces 14 MW heat (27 MW including absorption heat pump driving by biomass and incineration). (Heating and electricity generation)

22. *<u>Location</u>*: ***Thisted (Denmark)***
<u>Project Description (1980-2001):</u> The first geothermal plant in Denmark based on deep wells, established in 1984, in Thisted and later expanded to produce up to 7 MW heat from 200 m^3/h of 44°C, 15 % saline geothermal water with production from and re-injection in Gassum sandstone at 1.25 km depth. (A. Mahler et al, 2013). The operating temperature of DH, using heat pumps driven by straw boiler, is 76/70 °C - 40/44°C. The DH length is 219 km.

23. *<u>Location</u>*: ***Sonderborg (Denmark)***
<u>Project Description (2007-2013):</u> The new geothermal plant produces up to 12 MW heat from 350 m^3/h of 48°C, 15 % saline geothermal water from Gassum sandstone at 1.2 km depth. The heat is transferred to district heating networks using absorption heat pumps with LiBr on all three geothermal plants. The driving heat comes from biomass boilers with or without associated power production (A. Mahler et al, 2013). The operating temperature of DH, using heat pumps driven by straw boiler, is 83/80°C - 42/46°C. The DH length is 309 km.

References

Rajver D., Lapanje A., Rman N, Prestor J., 2019. Geothermal Energy Use, Country Update for Slovenia. European Geothermal Congress Den Haag, The Netherlands, 11-14 June 2019

Della Vedova B, Cimolino A., Castelli E., Brancatelli G., 2015. Geothermal Heating and Cooling in the FVG Region: The Grado District Heating and the Pontebba Ice Rink Plants. Conference: Geothermal Energy Status and future in the Peri-Adriatic Area, Veli Lošinj, Croatia

Nádor A., Kujbus A., Tóth A., 2016. Geothermal Energy Use, Country Update for Hungary. European Geothermal Congress 19-24 Sept 2016, Strasbourg, France

Mahler A., Røgen B., Ditlefsen C., Henrik Nielsen L., Vangkilde-Pedersen T., 2013. Geothermal Energy Use, Country Update for Denmark. European Geothermal Congress 2013, Pisa, Italy, 3-7 June 2013.

Myslil V., Stibitz M., Frydrych V., 2005. Geothermal Energy Potential of Czech Republic. Proceedings World Geothermal Congress 2005. Antalya, Turkey.

Cuchí-Oterino, J. A., Rodríguez-Caro, J. B., & de la Noceda-Márquez, C. G. (2000). Overview of hydrogeothermics in Spain. Environmental Geology, 39(5), 482-487

Carella R., 1999. Italian geothermal district heating systems. GHC Bulletin, December 1999.

Lanaja J. M., 1987. Contribución de la exploración petrolífera al conocimiento de la geología de España. Instituto geologico y minero de España (*in Spanish*).

http://geodh.eu/database/