Deployment of 5 th Generation District Heating and Cooling grids (5GDHC) in France: two case studies in Orleans and Strasbourg metropolises

Charles Maragna, Virginie Hamm, Camille Maurel

Deployment of 5th Generation District Heating and Cooling grids (5GDHC) in France: two case studies in Orleans and Strasbourg metropolises

Charles Maragna[1], Virginie Hamm[1], Camille Maurel[1]

[1]BRGM - 3, avenue C. Guillemin 45060 Orléans cedex 2 – France

c.maragna@brgm.fr

Keywords: 5GDHC, shallow geothermal, waste heat, Orleans metropolis, Strasbourg Eurometropolis.

ABSTRACT

BRGM is carrying out two opportunity studies on the Metropolises of Orléans and Strasbourg for the implementation of 5th Generation District Heating and Cooling (5GDHC) grids. In Orléans, one considers supplying the extension of an economic activity zone with the 5GDHC powered by a combination of waste heat and shallow geothermal energy. A detailed energy model is being built in TRNSYS, and preliminary results related to the consumer stations are reported in this paper. In Strasbourg, the 5GDHC will supply new residential and tertiary buildings as well as a shopping centre by using the Rhine alluvial aquifer as the main energy source.

1. INTRODUCTION

The Interreg North Western Europe D2Grids project (2018-2023) aims at developing 5GDHC grids, involving several demo sites in Europe (Netherlands, Germany, France, United Kingdom).

A 5GDHC grid exchanges thermal energy between buildings with different needs (Buffa et al., 2019; Interreg NWE D2Grids, n.d.). The grid carries a fluid at low temperature (typically 10-40 °C) to stations that can upgrade the temperature, if needed, to the required level through Heat Pump (HP). Distributed thermal storages can buffer the fluctuation in supply and demand, avoiding oversizing the installation. The 5GDHC architecture allows maximizing the share of low-grade renewables (e.g. shallow geothermal, surficial water bodies, etc.) and waste energy.

The D2Grids project assesses the opportunities to roll out the 5GDHC concept throughout North-western Europe. In a first step, BRGM carried out a regional analysis in three dense urban areas in France, namely Orléans Metropolis, Greater-Paris Metropolis and Strasbourg Eurometropolis respectively located in Centre Val-de-Loire, Grand-Est and Ile-de-France regions.

These regional analyses investigated the existing heating regimes, the existing District Heating Networks (DHN), the available energy sources with a focus on the shallow geothermal potential on each metropolis. For each region, a SWOT (Strength Weakness Opportunity Threat) analysis was built to assess the possibility to implement 5GDHC networks. In a second step, according to the results from the regional analysis and first positive contacts with energy planners and local authority, prefeasibility studies are being carried out in Orléans and Strasbourg metropolises to define local action plans.

Orléans metropolis and Strasbourg Eurometropolis mainly use natural gas to provide heating systems. Some high temperature DHN provide heat through the combustion of biomass and wastes. Nevertheless, the objectives fixed in their respective climate and energy plans intend to decrease the overall energy consumption and to increase the share of renewable energy sources in their heating mix. Both metropolises have a proven high shallow geothermal potential, especially for open loop systems, in the Beauce limestones in Orleans Metropolis and in the Rhine alluvial aquifer in Strasbourg Eurometropolis. This potential represents a good opportunity and a relevant energy source for 5GDHC. In accordance to the new environmental regulation of buildings in France (RE2020), 5GDHC represents a key concept to low carbon renewable heating and cooling systems for the residential and tertiary sectors.

2. ORLEANS METROPOLIS CASE STUDY

The first case study is located in the South of Orléans Metropolis. It is a 45 ha extension of the business park “Parc de la Saussaye” towards the East (cf. Figure 1). The type, volume and thermal needs of the buildings have not been investigated yet, only the surfaces of the plots are available.

The hypothesized 5GDHC grid could valorise the shallow geothermal aquifer of the “Beauce limestones”. The aquifer productive layers are typically in the depth range 30 to 50 m, ant its transmissivity is very high (between 3.10^{-3} m²/s and 3.10^{-1} m²/s). Besides, right in the middle of the existing business park, a factory freezes and processes large amounts of food. As a result, large amount of heat is emitted to the atmosphere at about 35 °C through cooling towers. Due to secrecy reasons, detailed figures cannot be disclosed at this stage. Warming up the 5GDHC grid would be a way to valorise this so-far wasted heat.

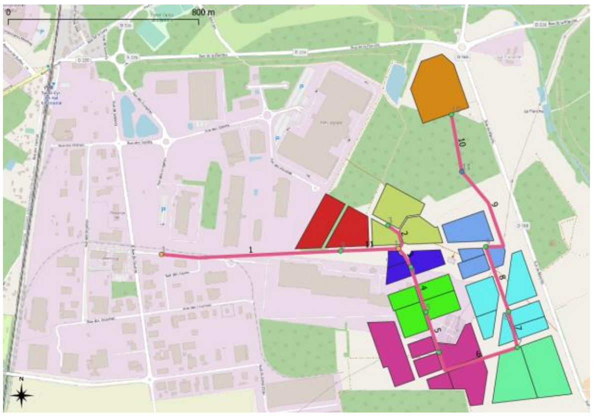

Figure 1: Orléans: Map of the area, including the areas to be urbanized (coloured polygons), the hypothetical 5GDHC layout, stations and geothermal wells.

Here we focus on bi-pipe, bidirectional 5GDHC grids. Such grids have a cold line and a warm line. Stations retrieve fluid from the relevant line, e.g. for heating applications the water is retrieved from the warm line and sent back 4-6 °C colder to the cold line. There is no “departure” and “return” lines as in conventional, high temperature DHC: the flow in each line connecting adjacent stations is bidirectional. If the cooling and heating needs do not compensate each over, flow-rate can be sent to “production” stations (geothermal, waste heat …) which temper the fluid temperature, avoiding the temperature to drift beyond acceptable thresholds.

2.1. Questions being addressed

We aim at estimating the cost and CO2 content of the thermal energy produced and delivered by the 5GDHC grid. More specifically, we want to address the following questions:

- What is the “optimal” share of shallow geothermal energy vs. waste heat?
- Is it worth insulating the line connecting the industrial site to the new cluster of buildings? Can we expect the warm line to deliver temperature in the range 30-35 °C, which may enable direct heating if low-temperature emitters are deployed?
- If so, to which extent is it acceptable to increase the 5GDHN grid temperature without impeding the cooling efficiency?
- Indeed, the thermal consumption of the future buildings is barely known. To which extent is a design flexible? For instance, if more thermal energy is required, how can we restrain the flow rates increases and subsequent pump consumptions?
- Is it worth extending the lines towards the existing business park, and residential zones located in the village of Saint-Cyr-en-Val (not shown in Figure 1)?

2.2 Simulation process

To answer these questions, we use several simulation tools:

- **QGIS3** to map, edit, visualize geospatial data (QGIS Association, 2022),
- **MATLAB** to prepare simulations, post-process results, perform sensitivity analysis, etc. (Mathworks, n.d.),
- **TRNSYS**, a flexible graphically based software environment to simulate the thermal and energetic transient behavior of the above-ground system components (University of Wisconsin--Madison. Solar Energy Laboratory, 1975),
- **ComPASS**, an open platform for hydrothermal modeling,
- **Python** to edit ComPASS files (Van Rossum and Drake, 2009).

The combination of these tools enable investigating the spatial, thermal, and underground aspects of 5GDHC grid development.

2.3. Preliminary results: Thermal behavior of the consumer station

Here we give a short overview of a “consumer” station developed in TRNSYS. Such station can provide heating, cooling and Domestic Hot Water (DHW) to a building. We investigate how design and operational parameters affect the shares of non-renewables (electricity for the Heat Pump and backups) in the thermal energy delivered to a hypothesized building. We first define a “baseline scenario” and we perform one-at-a-time sensitivity analysis. The cold line and warm line temperatures are fixed to constant values.

The thermal loads considered in this study originates from the thermal model of a well-insulated hotel located in Turin, Italy modelled in the framework of the GRETA project (GRETA project, 2017). Overall heating and cooling requirements reaches 249.8 MWh.y^{-1} (139.2 kW) and 68.1 MWh.y^{-1} (84.4 kW) respectively. Orleans and Turin climate are indeed similar, with Heating Degrees Days (HDD) and Cooling Degrees Days (CDD) differences being in the range 10-20 %. The average DHW need was estimated following the methodology developed in (ADEME and COSTIC, 2016). It is estimated to be 125 L.day^{-1} at 40 °C per “standard housing”, i.e. 2-bedrooms apartment of 65 m^2, with hourly, weekly and monthly corrections. Here we assume that the building is equivalent to 80 “standard housings”, the average DHW flow rate is $\langle \dot{m}_{DHW} \rangle$ = 125×80/24 = 416.7 kg.h^{-1}. The energy required to warm up the tap water to the delivery temperature 40 °C is 118.2 MWh.y^{-1}. DHW need reaches about a half (47 %) of the heating need, and is far from being negligible.

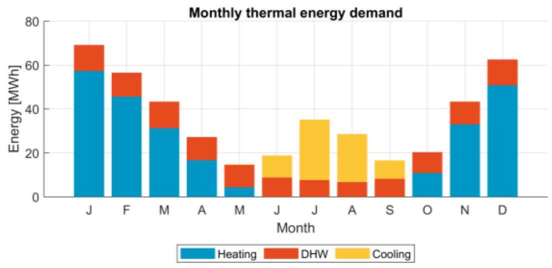

Figure 2: Monthly thermal energy demand

The main components of the station are a Heat Pump (HP), two heat exchangers, one for direct (passive) cooling and one for direct (passive) heating, and three tanks to store the heating, the cooling and the DHW before it is distributed to the building (cf. Figure 3). Thermal energy is produced according to eight modes of operation:

- **Mode 1:** HP produces heating: The warm line feds the HP evaporator and the HP condenser warms up the heating tank. It is triggered before the heating tank temperature falls below the heating set point.
- **Mode 2:** HP produces cooling: The cold line feds the HP condenser, while the HP evaporator cools down the heating tank. It is triggered before the heating tank temperature exceeds the cooling set point.
- **Mode 3:** HP produces DHW.
- **Mode 4:** Simultaneous production of heating and cooling by the HP: the HP evaporator cools down the cooling tank while the heating tank gets warmed up by the condenser.
- **Mode 5:** HP produces DHW and cooling simultaneously. Similar to mode 4.
- **Mode 6:** Direct cooling: The cold line cools down the cooling tank through a dedicated heat exchanger. HP is bypassed.
- **Mode 7:** Direct heating. Similar to mode 6 with connection to the warm line to feed the heating tank.
- **Mode 8:** Simultaneous direct heating and DHW production.

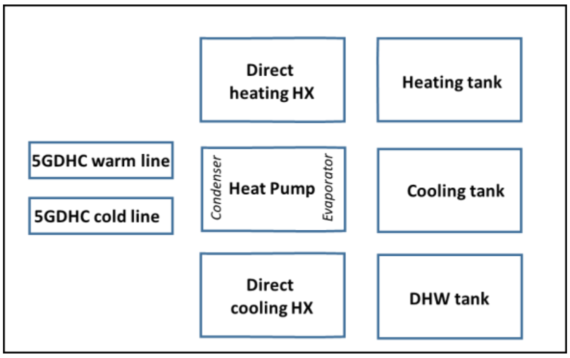

Figure 3: Most elements of the consumer station

A "differential controller" selects the mode of operation by comparing the temperatures of the components, activating actuators (valves and pumps) to transfer the energy between the components.

Fluid is retrieved from the 5GDHC warm line in modes 1, 3, 7 and from the cold line in modes 2 and 6. We assume a constant temperature difference between inlets and outlets of -4 °C (modes 1, 3, 7) and +4 °C (modes 2, 6). For the baseline scenario, we consider $T_{warm\ line}$ = 16 °C and $T_{cold\ line}$ = 12 °C.

The departure temperature from the heating tanks into the heat emitters depends of the outside air temperature as follows:

$$T_{dep,heating} = a - b \times (T_{air,ext} - 16\ [°C]) \qquad \textbf{(1)}$$

We considered low-temperature emitters with a = 31.1 °C and b = 0.56. Note that only low-temperature heat emitters (typically operating in the range 25-35 °C) could take benefit of modes 7 and 8, bypassing the HP and therefore reducing electricity consumption. Cooling is assumed to be provided at $T_{dep,cooling}$ = 15 °C. The difference between departure and return temperatures is 5°C, both for heating and cooling. The HP calorific nominal power is 150 kW. The HP efficiency depends upon the evaporator and condenser inlet temperatures and originates from data provided by manufacturers. Every heat exchanger is sized so that its pinch is +2 °C.

The HP produced DHW at 60 – 65 °C. The French regulation enforces operational constraints for any DHW storage exceeding 400 Litres to avoid the development of legionella (Santé, 2010). Every 24 h, a controller checks if the temperature at the bottom of tank (the coldest place in the tank) reached 65 °C at least once during the last 24 hours. If not, an internal backup heater is turned on to reach this temperature.

Backups downstream the tanks ensure that the set point temperatures (eq. 1 for heating, 40 °C for DHW) are met at any time.

The volumes of the heating, cooling and DHW tanks are respectively $V_{cooling}$ = 5.83 m^3, $V_{heating}$ = 8.00 m^3, V_{DHW} = 0.83 m^3. The DHW tank can store for $t_{DHW} = \frac{V_{DHW}}{\langle \dot{m}_{DHW} \rangle} \times 1000$ [kg.m^{-3}] = 2 h of the average HW consumption.

The station is modelled is TRNSYS v18 and executed with a time step of 5 minutes.

Figure 44 shows the origin of the thermal energy delivered to the buildings on monthly basis. One can notice that:

- The Heat Pump produces the whole heating. No backup is needed. There is no direct heating, since the warm line temperature is much too low (16 °C).
- The Heat Pump produces the whole DHW. No backup is needed. In summer (July and August and too a smaller extent in June and September), most of the DHW is produced simultaneously

with cooling (mode 5). However, the warm line feeds the HP most of the year (88 % of the DHW is produced in mode 3).

- The cold line is cold (12 °C) enough to provide geocooling all along the summer, though a small part (22.0 %) is provided by the HP through mode 5.

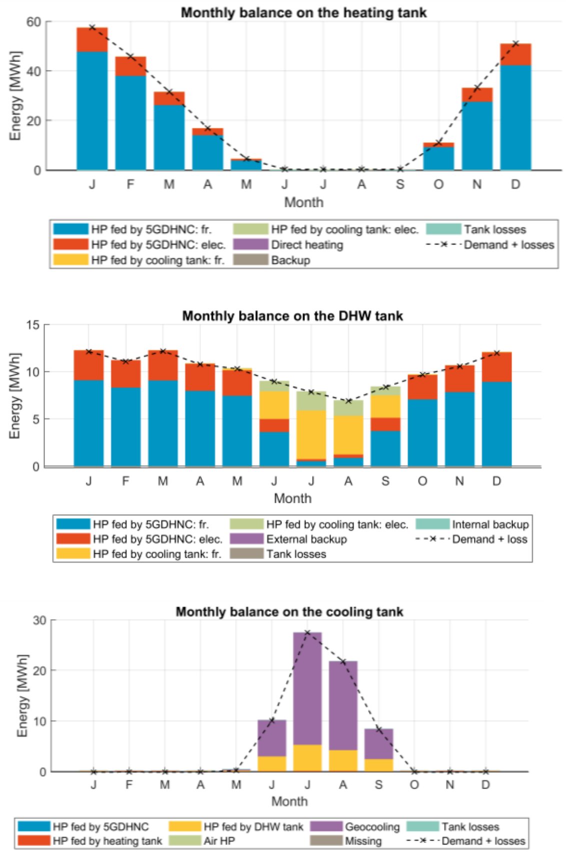

Figure 4: Baseline scenario: Monthly balances on the heating, DHW and cooling tanks, from January to December.

We assess the "efficiency" of the station as the ratio of the electricity (for HP and backups) to the total provided thermal energy (249.8+118.5+68.1 = 300.2 MWh). This efficiency factor is $F = \frac{75.3}{300.2} = 17.2\ \%$, meaning that 100-17.2 = 82.8 % of the thermal energy comes from the 5GDHC grid. Indeed, it would be difficult to define efficiency per use, since electricity can be used simultaneously for two uses through modes 4 and 5.

Next, we focus on the influence of the line temperatures, maintaining ΔT_{line} = 4 K between the warm and the cold line in January, April and August. The share of electricity in the thermal energy F delivered is strongly affected by the line temperature (cf. **Erreur ! Source du renvoi introuvable.**). Both in January and April, F decreases when the grid temperature increases, as expected. Until c.a. 25 °C, this slight decrease is due to an improved efficiency of the Heat Pump for heating and DHW production, the HP being provided with warmer fluid at its evaporator. Beyond 25 °C, the dramatic decrease is due to some heating being provided "for free" by bypassing the HP (modes 7 and 8). This effect is more significant in January than in April, since the relative share of DHW, not affected by direct production, is lower. In August, below 17 °C on the warm line (13 °C on the cold line), most cooling is provided "for free" (mode 6), except the cooling produced simultaneously with DHW which consumes some electricity (mode 5). Beyond 13 °C on the cold line, direct cooling is no more possible, the whole cooling is produced through the HP (modes 2 and 5).

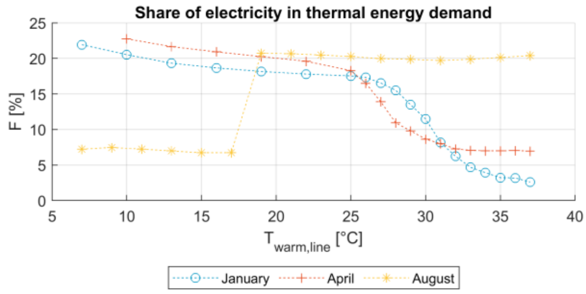

Figure 5: Share of electricity in the thermal energy delivered to the building as a function the line temperature, for January and August.

2.4. Preliminary results: Subsurface modelling

The heat source for the 5GDHC system is the shallow Beauce limestone aquifer. Over the *Parc de la Saussaye*, the Beauce formation is estimated to be 45 m thick and the top of the formation is located at 15 meters below the ground. The stratigraphy series schematic over the Orléans metropolis underground is presented in Figure 6.

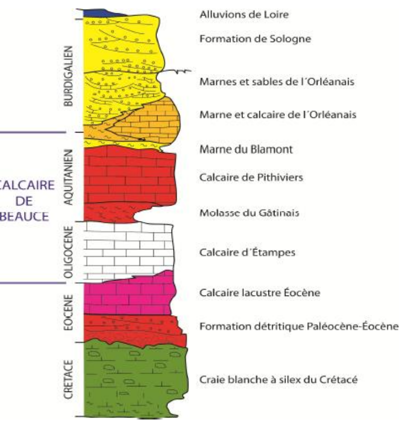

Figure 6: Stratigraphy of the underground over the Orleans metropolis area (BRGM, 2007)

In order to study the feasibility of an open geothermal loop in this area, the first step was to build a model of the aquifer at local scale (9 km x 9 km grid). A configurable hydrodynamic and thermal numerical model of a doublet was built in the ComPass software (Xing et al. 2017) to study the influence of the installations over the thermal plume and the impact on the pressure field. In the vicinity of the site, several drinking water wells are producing important amount of water over the Beauce and Eocene aquifers. They are located on either side of the foreseen implantation site and have thus been included in the numerical modeling to understand the impact and potential interferences between the existing and foreseen installations. The volumes produced are estimated between 7,000 m^3/day over one water well and 500 m^3/day over another one.

The model built is composed of 8 layers, 4 for the Beauce limestones formation, 2 for the marl and sand formations located above the limestones and two for the underlying formations.

The permeability of the limestones (targeted resource) is defined at 3.10^{-11} m². A pressure gradient from the south toward the north has been implemented (estimated according to the piezometric network around 0.045 bars per km). The model grid is composed of prismatic cells from 25 m side near the wells to 300 m side at far field limits. An illustration of the grid and locations of water and geothermal wells is presented in Figure 7. The illustration also presents the initial state of pressure in the model with 0.045% hydraulic gradient along X, from right to left. A simplified geometry was used for the simulation and the reservoir is considered to be homogeneous.

In first simulations, the production well has been placed downstream of the injection well, with an angle from the hydraulic gradient, as the impact of high water flow rates in the water well n°2 (located on the right side of Figure 7) is expected to impact the thermal plume around the injection well.

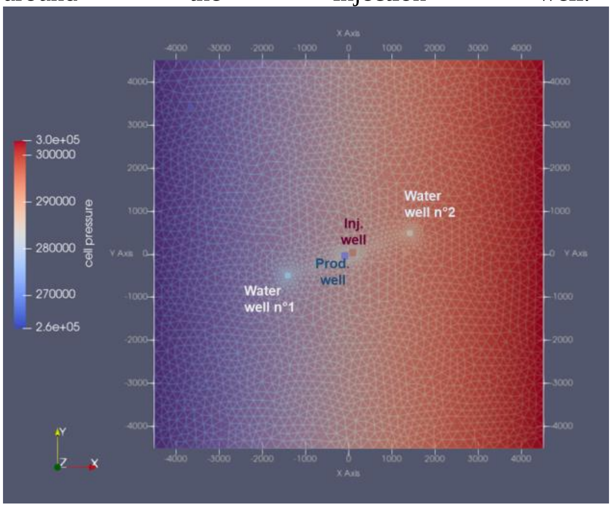

Figure 7: ComPASS grid structure, location of wells and initial pressure condition from a 0.045% hydraulic gradient along x (pressure in Pa).

First simulations of water well production along with the exploitation of a geothermal doublet have been conducted. The chronicle used for production and reinjection flow rates derives from energy model of office building with heating demand not covered by geothermal energy source since priority is given to the waste heat collection. The cooling is however supplied by a geothermal doublet (consumption per year estimated to 721MWh (1.288 MW). The wells are assumed to be operated with a temperature difference from resource temperature of +6°C and the HP efficiency is estimated at 4. The maximum flow rate to be pumped is thus 64 kg/s. The distance between the injection and production wells considered is 200 m and the distance between the two water well is 3,000 meters. The simulations are run over a period of 10 years with launch of geothermal doublet after 2 years.

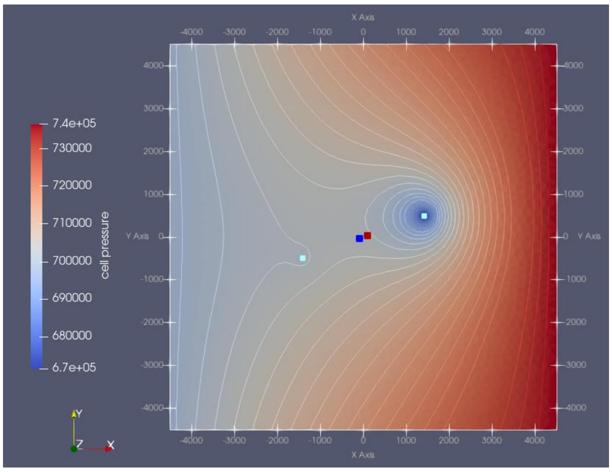

Figure 8: Pressure in the Beauce limestones reservoir after 10 years of simulation

When observing the pressure field after 10 years of simulation, the impact of water wells productions seems to be important near the doublet and tend to impact the fluid flows. Additional runs will be carried out to identify the impact over the cold or hot plume around the geothermal injection well. On-going simulations also plan to study wells placement to identify optimal positioning of geothermal wells to reduce interferences with drinking water infrastructures.

3. STRASBOURG EUROMETROPOLIS CASE STUDY

A second pilot site under study is located in Strasbourg, where the department of Renewable Energies and Heat Networks showed interest in the 5GDHC concept and is currently engaging with operational urban planners to identify whether or not an opportunity to develop projects compliant with 5GDHC technology will present itself in the near future.

Strasbourg Eurometropolis is located in Grand-Est Region along the German border and is composed of 33 municipalities with a population of 487 303 inhabitants on a geographic area of 338 km2 (i.e. 1442 hab/km2 in 2019). 60% of the population of the metropolis is concentrated in Strasbourg and the population of the metropolis represents one quarter of the total population in Alsace. The regional analysis has showed that the heating needs are very high (2,5 TWh/y for residential needs and 1,5 TWh/y for tertiary needs) and only 0,2 TWh/y for cooling demand in the tertiary sector. The tertiary sector seems to be the more adapted to 5GDHC future development, as there is in most cases a need of heating and cooling (even if unbalanced) which is not the case for the residential sector.

In order to define a more specific local action plan, contact has been established with the city of Strasbourg and the persons in charge of the energy development and district heating. After several exchanges, a location under development was proposed in the area of the Baggersee pond (see Figure) to study the possibility for hosting a 5GDHC system. The site will be restructured and is characterized by different usages and needs. Four main types of usages have been identified: residential housings with a surface of 42 000 m2, a shopping center with a surface of 24 000 m2, tertiary needs with a surface of 10 000 m2 and public equipments with a surface of 8000 m2.

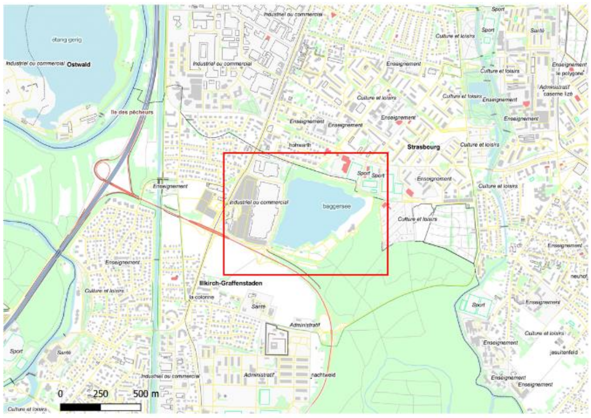

Figure 9: Location of the site for the pre-feasibility study in Strasbourg.

3.1 5GDHC energy modelling system

In progress (will be completed after the congress)

3.2 Subsurface modelling

The heat source for the 5GDHC system is the shallow Rhine alluvial aquifer. The alluvial deposits of the Rhine are the seat of a powerful aquifer (up to 150 m thickness) at the location of the Eurometropolis of Strasbourg. In order to study the feasability of an open geothermal loop in the Baggersee area, the first step was to build a model of the Rhine aquifer at local scale. For this, we used the data from a regional model of the alluvial aquifer that was done during the Interreg IV Upper Rhine LOGAR "Liaison Opérationnelle pour la Gestion de l'aquifère Rhénan" project (2009-2012). The primary objective of this regional model was to simulate the global flow and transport of nitrates in groundwater over several decades and assess the impact of measures to improve water quality. The regional model covers an area of 4289 km^2 with 160 km north-south direction and 90 km east-west direction (Figure 10a). The limits of the Rhine alluvial aquifer are the Vosges at west, the Forêt Noire at east, Karlsruhe at north and Grenzach-Wylen at south. The lithology of the alluvial aquifer is a mixture of fine and coarse sediments. It is composed of two main units: the Neuenburg formation in the upper part and the Bresgau formation in the lower part. These Rhine alluviums lie on the Oligocene marls (Figure 10b).

The regional model is composed of 10 layers, 5 for the Neuenburg formation and 5 for the Bresgau formation. The choice of this 10-layer discretization was made in order to best represent the vertical variability of the permeability induced by the presence of thicker or thinner clayey interlayers within these two formations. The Highest permeability are in the first 20 meters of the Neuenburg formation. The model grid is composed of 100x100 m square cells which represents more than 4 millions meshes. An extraction of the model was done in the area of Strasbourg (Figure 10a and Figure 10c). The vertical discretization was then simplified in the local model as the permeability in the area of Strasbourg were similar for most of the vertical layers. Thus, in the local model, 3 layers are represented: one layer that represents the Breisgau formation and two layers for the Neuenburg formation with higher permeability in the first layer.

The thermo-hydrodynamic model was built by using Marthe code developed at BRGM for 3D modelling of flows and transfers. Once the local geometrical model is built, a second step was to calibrate the average groundwater flow in order to simulate correctly the hydraulic gradient and also the natural temperature of the aquifer. The third step was to include also the existing geothermal loop in the area as the Rhine aquifer is already largely exploited for heating and cooling needs at the location of the Eurometropolis (see Figure 10c).

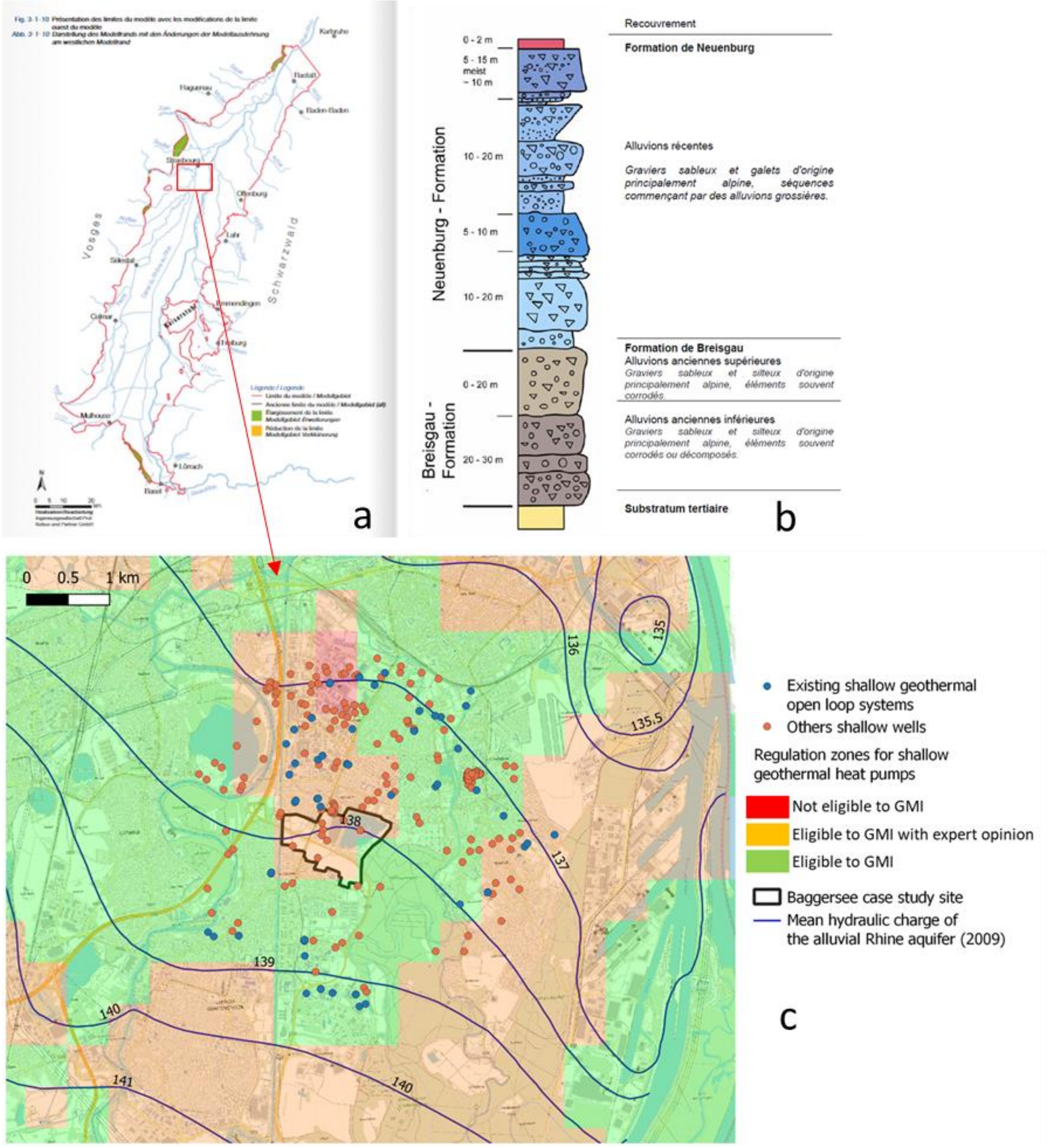

Figure 10: a) Extension of the LOGAR model. b) Schematic log of the Rhine alluvial aquifer. c) Case study extension, regulation zones for open loop systems and local hydraulic gradient.

3.3 Preliminary results

Will be completed after the Congress.

3. CONCLUSIONS

5GDHCN grids are probably a key for the further development of shallow geothermal energy in most European countries. They offer the possibility to valorise local sources of energies and to couple thermal and electric grids.

Numerical tools are being combined to investigate the spatial, thermal, and underground aspects of 5GDHC grid development on two French conurbations. Preliminary results show that the efficiency of a station is strongly affected by operating temperatures of cold and warm lines. The 5GDHC operating temperature must therefore be optimized, given the available sources (shallow geothermal and waste heat).

Numerical procedures are being developed to automatically create TRNSYS models of the whole system including multiple stations, 5GDHC segments and co-simulate the evolution of the grid and the doublets with ComPASS.

REFERENCES

ADEME, COSTIC, 2016. Guide technique : Les besoins d'eau chaude sanitaire en habitat individuel et collectif.

Aldubyan, M., Chiasson, A., 2017. Thermal Study of

Hybrid Photovoltaic-Thermal (PVT) Solar Collectors Combined with Borehole Thermal Energy Storage Systems. Energy Procedia 141, 102–108. https://doi.org/10.1016/j.egypro.2017.11.020

Buffa, S., Cozzini, M., D'Antoni, M., Baratieri, M., Fedrizzi, R., 2019. 5th generation district heating and cooling systems: A review of existing cases in Europe. Renew. Sustain. Energy Rev. 104, 504–522. https://doi.org/10.1016/j.rser.2018.12.059

GRETA project, 2017. Catalogue of operational criteria and constraints for shallow geothermal systems in the Alpine environment.

Interreg NWE D2Grids, n.d. 5GDHC in short [WWW Document]. URL https://5gdhc.eu/5gdhc-in-short/ (accessed 5.18.22).

Mathworks, n.d. MATLAB [WWW Document]. URL https://fr.mathworks.com/help/matlab/ref/

QGIS Association, 2022. QGIS Geographic Information System [WWW Document]. URL http://www.qgis.org/

Santé, D. générale de la, 2010. Circulaire DGS/EA4 no 2010-448 du 21 décembre 2010 relative aux missions des agences régionales de santé dans la mise en œuvre de l'arrêté du 1er février 2010 relatif à la surveillance des légionelles dans les installations de production, de stockage et d. France.

University of Wisconsin--Madison. Solar Energy Laboratory, 1975. TRNSYS, a transient simulation program. Madison, Wis. : The Laboratory, 1975.

Van Rossum, G., Drake, F.L., 2009. Python 3 Reference Manual. CreateSpace, Scotts Valley, CA.

Xing, F., Masson, R., Lopez, S., 2017. Parallel numerical modeling of hybrid-dimensional compositional non-isothermal Darcy flows in fractured porous media. Journal of Computational Physics 637–664.

Acknowledgements

The authors would like to thanks Orléans Métropole and Eurométropole de Strasbourg for the data they provided related to the case study. This research work is supported by the Interreg NWE 795 D2Grids project and the BRGM.