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Scenarios for Integration of Medium-Depth Geothermal Energy in an Evolving District Heating System: Case Study in Geneva (Switzerland)

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ABSTRACT

As for many European cities, heat demand in Geneva is currently mostly supplied by individual fossil fuel boilers, contributing to an inefficient and non-sustainable energy system. However, the coming years will see major extensions of the existing district heating system, with inclusion of various renewable and waste heat resources. In this context, the geothermal potential of deep Mesozoic aquifers (500-2'500 m depth) is currently under investigation (exploration wells and 3D seismic survey). Preliminary results indicate a promising potential for thermal use. In this context, this study assesses how geothermal energy could be integrated into the main district heating system in Geneva, and therefore help decarbonizing the heat sector. An hourly based input/output model has been developed in order to generate district heating load curves and supply mix, from today until 2035, taking into account the foreseen evolution of the heat demand (new connections and buildings retrofitting), as well as the integration of various identified renewable resources. The results highlight that the deployment of geothermal energy is fundamental for a massive integration of renewables into the district heating supply. In a best-case scenario, its contribution could represent 22% of the district heating supply by 2035.

ACRONYMS

2GDH	Second-generation district heating
3GDH	Third-generation district heating
CHP	Combined heat and power
DH	District heating
DHW	Domestic hot water
HP	Heat pump
SH	Space heating
SIG	Services industriels de Genève (Geneva energy utility)

1. INTRODUCTION

The exploitation of deep aquifers for the supply of district heating (DH) systems is a promising solution to help decarbonizing the heat sector in European urban areas (Dumas and Angelino, 2013). Some cities such as Paris or Munich have already large DH systems based on this resource and continue to develop both their geothermal capacities and the extension of their thermal networks. This parallel deployment is fundamental for achieving a massive use of the geothermal resource in a cost-efficient way (Faessler, 2017). This paper focuses on the case study of Geneva, Switzerland. The goal of this study is to assess the potential contribution of medium-depth geothermal heat (exploitation of doublets between 1'000-2'000 m depth) in relation with the future evolution of the district heating system, as well as complementary production using other renewable and waste heat resources. Hence, different issues are being addressed together, such as network extension, buildings retrofitting, network temperature optimization and integration of new production capacities, which are treated in relation to their technical potential and their implementation schedule.

2. GENEVA ENERGY CONTEXT AND THE ROLE OF DISTRICT HEATING

In 2017, in the canton of Geneva (498'000 inhabitants), the energy delivered for heating purposes of buildings (space heating and domestic hot water preparation) amounted to 5.3 TWh or 38.4 GJ/capita, representing about half of the total final energy consumption. Conventional oil- or gas-fired boilers remain the main way to meet heat demand of the building stock, which lead to massive CO_2 emissions and air pollution (Figure 1).

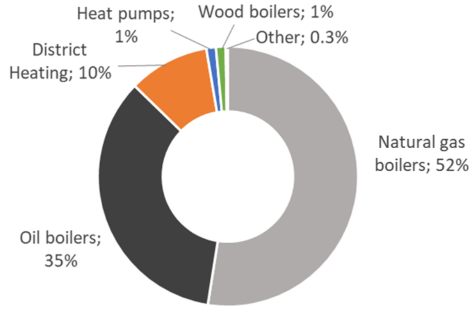

Figure 1:Heat delivery to buildings by technology, Geneva 2017. Total = 5.3 TWh. Source: Statistical Office of Geneva.

The 2035 target of the State of Geneva is to reduce the consumption in the heat sector to 29 GJ/capita, from which 34% should come from renewable energy or waste heat recovery (État de Genève, 2013). To achieve these goals, three main action axes have been identified:

1. retrofitting the existing building stock;
2. providing local and renewable resources, with large expectation regarding geothermal energy;
3. developing the infrastructures that will enable their use (production, transport and distribution facilities).

Today, despite the canton being characterized by a high heat demand density (Figure 2 left), the existing DH system represents only about 10% of the total heat market (Figure 1). Its base load is covered by heat recovery on the urban solid waste incineration plant, which represents about half of the DH energy mix, and its peak load by centralized gas boilers (Quiquerez and Faessler, 2014). The potential extension of DH systems has been estimated to around 50-70% of the total heat market (Quiquerez, 2017). It has been shown that its development is a key component of the energy transition, as it allows to use local heat resources available in the Geneva urban area which would otherwise be unused due to technical, spatial or economic constraints. Their characteristics are summarized in table 1.

In this context, the coming years will see major extensions of the DH system (Figure 2 right). The public-owned local energy provider Services industriels de Genève (SIG) is developing the main DH system in the canton, with an objective to supply 35% of the buildings heat demand by 2035. In parallel, there is an objective to integrate 80% of renewable or waste heat in the DH production mix. This highlights the double challenge which needs to be considered: network extension and integration of new production based on waste heat or renewable resources.

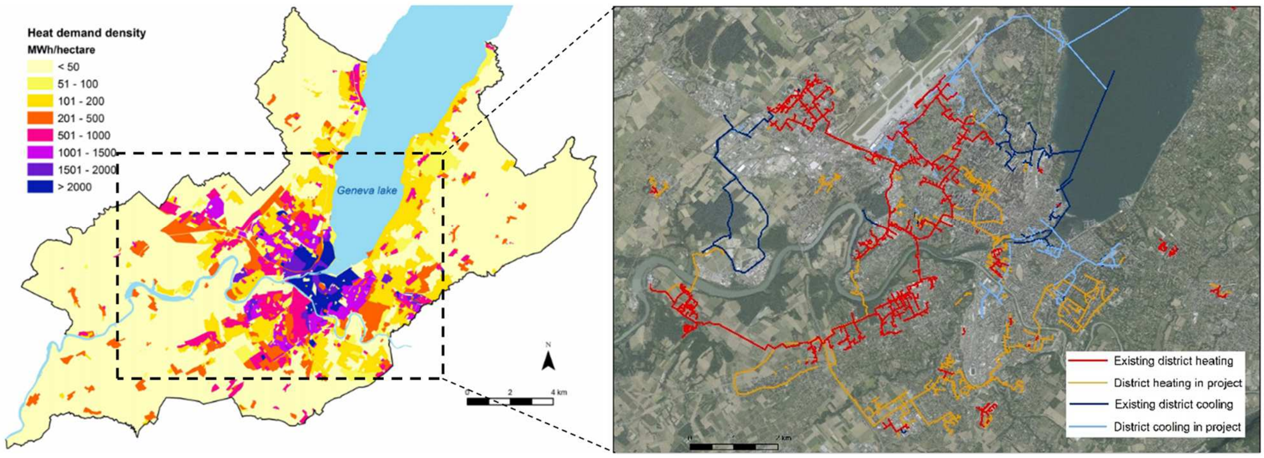

Figure 2: Current heat demand density in Geneva (left) and district heating and cooling planification (right). Sources: Quiquerez *et al.* (2016) and SIG.

Tab. 1: Main identified local resources potentially available for DH supply.

Resources	Resource temperature	Gross heat potential	Current projects status	Observations
Urban solid waste	> 800°C (combustion)	~ 450 GWh/yr	Partially used (existing CHP plant supplying the main DH)	Partial oven stops for maintenance during the summer
Waste wood	> 800°C (combustion)	~ 70 GWh/yr	Not used / CHP plant in project	Waste partially exported abroad today
Medium-depth geothermal (500-2'500 m)	30-90°C	Under investigation	Not used / resource under investigation	HP may be required for heat generation
Sewage water	15-20°C	~ 700 GWh/yr.	Not used / heat plant in project	HP required for heat generation
Lake water	5-10°C	Almost unlimited	Partially used for the district cooling supply / heat plants in project	HP required for heat generation
Biomass (wood)	> 800°C (combustion)	~ 110 GWh/yr.	Partially used in decentralized areas / boilers. Centralized heat plants in project	Air quality and transport issues

The existing DH system currently operates with high temperatures (nominal values for winter operation: 120°C for supply, 72°C for return) and is therefore classified as a 2nd generation district heating (2GDH) system (Lund *et al.*, 2014). This implies technical constraints for the efficient integration of renewable resources, which are mainly available at lower temperatures. Lowering these network temperatures, especially by optimizing the operation and regulation of substations, has therefore become a main challenge as well. In this regard, it should be noticed that the major new DH extension planned towards the south of the city will be designed as a 3rd generation system (3GDH), with lower temperature levels (see section 4.3).

3. GEOLOGICAL CONTEXT AND MEDIUM-DEPTH GEOTHERMAL POTENTIAL

The Geneva Basin is located between the Jura Mountains (NW) and the subalpine units (SE) (Figure 3). Promising aquifers are present between 500 and 2'500 m depth in karstified and/or fractured Mesozoic carbonates units (Rusillon, 2017).

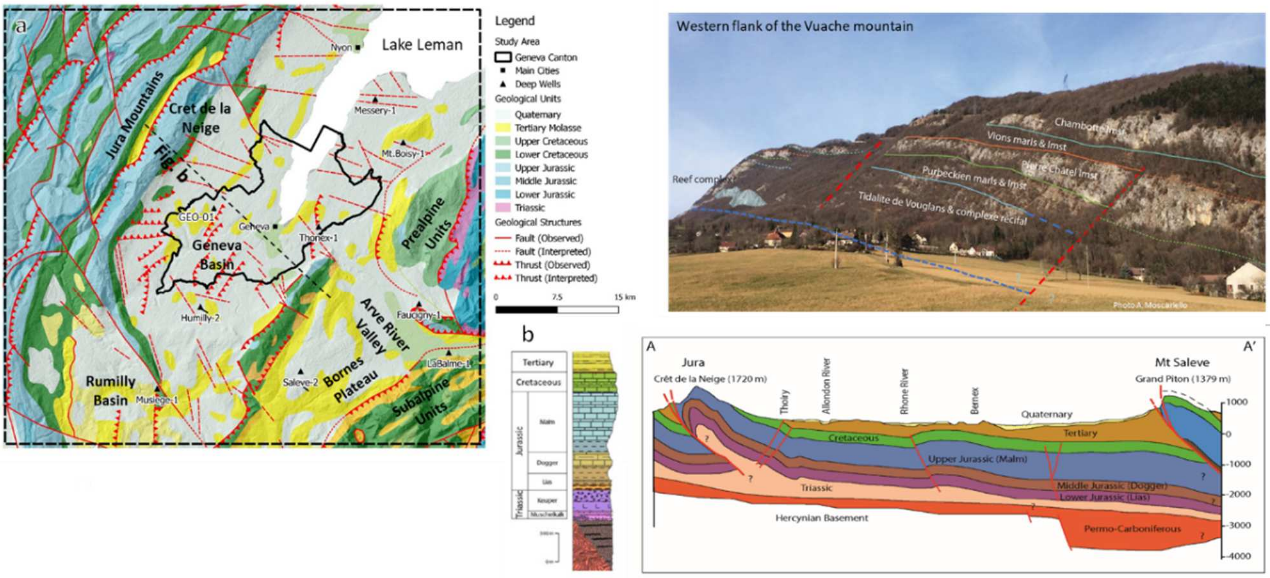

Figure 3: Geological context of the Geneva Basin. Source: Brentini (2018) and Moscariello (2019).

With an average geothermal temperature gradient of about 33 K/km (Chelle-Michou *et al.*, 2017), the temperature range which could be reached at these depths is therefore 30-90°C. One of the major issues is related to the uncertainties regarding the spatial repartition of the reservoirs and the flow rates that could be exploited. Without oil and gas exploration history in the canton of Geneva, relatively few data about the subsurface are available compared to other places like the Paris Basin for example. In order to assess the local potential of this resource, the State of Geneva and the local energy provider SIG launched the GEothermie2020 project (www.geothermie2020.ch), aiming to prospect and explore the subsurface of the canton. In 2018, after the compilation of existing data and the acquisition of 2D seismic lines, a first exploration well was drilled at 744 m depth (GEo1), in the upper Jurassic, and confirmed a good potential with an artesian flow of 55 l/s at 34°C. Futures operations are already planned to continue these investigations: the acquisition of a 3D seismic survey by 2020 (covering about 190 km^2) and the drilling of three additional exploration wells (GEo2, GEo3 and GEo4) between 1'000 and 1'500 m for testing different geological contexts (Figure 4). It should be noticed that the first goal of these exploration wells is to characterize the geothermal potential at the basin's scale. At this stage, they are a not directly linked with any exploitation projects.

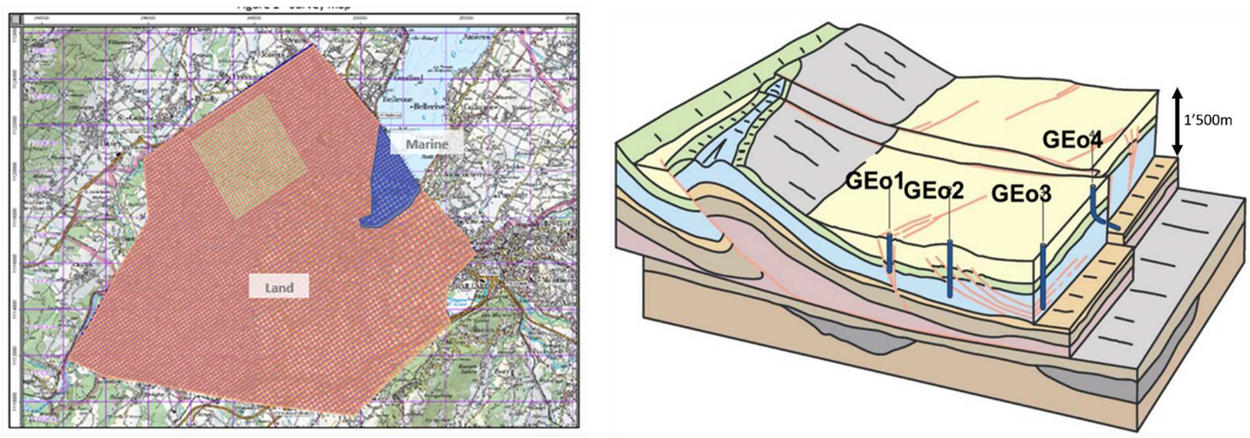

Figure 4: Planned 3D seismic survey (left) and exploration wells between 1'000 and 1'500 m depth (right).

4. METHODOLOGY

4.1 Input-Output model

The potential contribution of preceding resources to supply the main DH system is analyzed by using an input-output model designed for energy system modelling at a regional scale, which is inspired from the EnergyPLAN model (Østergaard, 2015). The model is based on an hourly time step calculation which ensures the matching between the availability of the various resources, the production capacities and the fluctuating heat demand. In addition to the temporal dynamic issue, temperature constraints are also considered (see section 4.3). As outputs of the model, annual production mix of the DH network, equivalent full load hours for each production plants and CO_2 content of the delivered heat can be derived. A schematic representation of the model is presented in Figure 5.

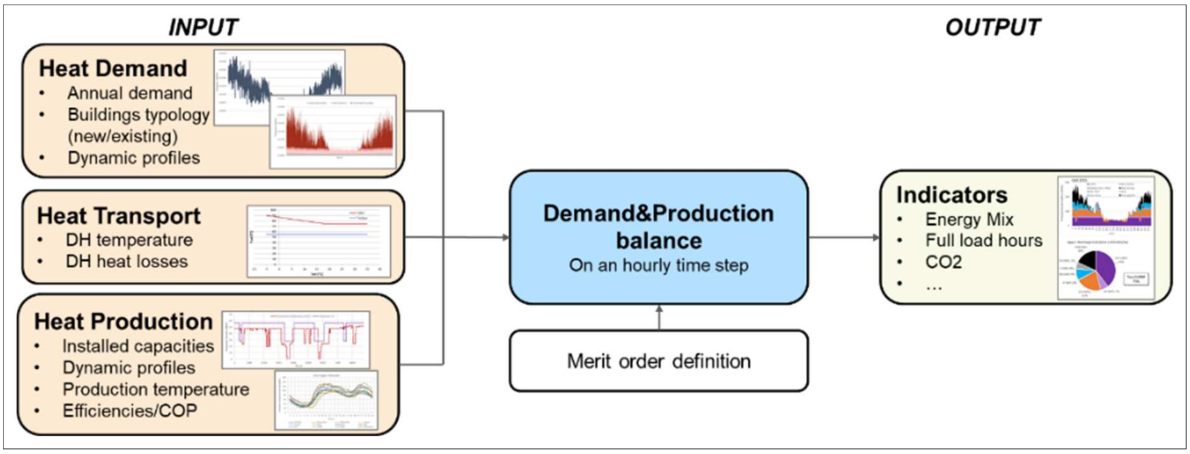

Figure 5: Input/Output hourly based energy model.

4.2 Heat demand evaluation

The current heat consumption of the connected building stock is well known, since buildings in Geneva must report their annual heating consumption, which is integrated into a public database. In 2019, the climate corrected total DH deliveries should amount to 463 GWh/yr. Overall, based on the analysis of the current DH load curve, it is estimated that 73% of this consumption is used for space heating (SH) and 27% for domestic hot water (DHW).

The assessment of its future evolution is based on planned new connections (existing or new buildings), while taking into account expected energy savings due to retrofit of existing buildings.

In the case of the existing building stock, the energy savings due to retrofit are evaluated with of a retrofit rate of 1.5% per year and a reduction of the SH demand to half of its present value (after retrofit of an existing building, its relative heat shares are estimated to 57% for SH and 43% for DHW). In the case of new buildings, we assume relative heat shares of 50% for SH and 50% for DHW. Considering these assumptions, the projected DH annual heat deliveries by 2035 amount to 942 GWh/yr (Figure 6).

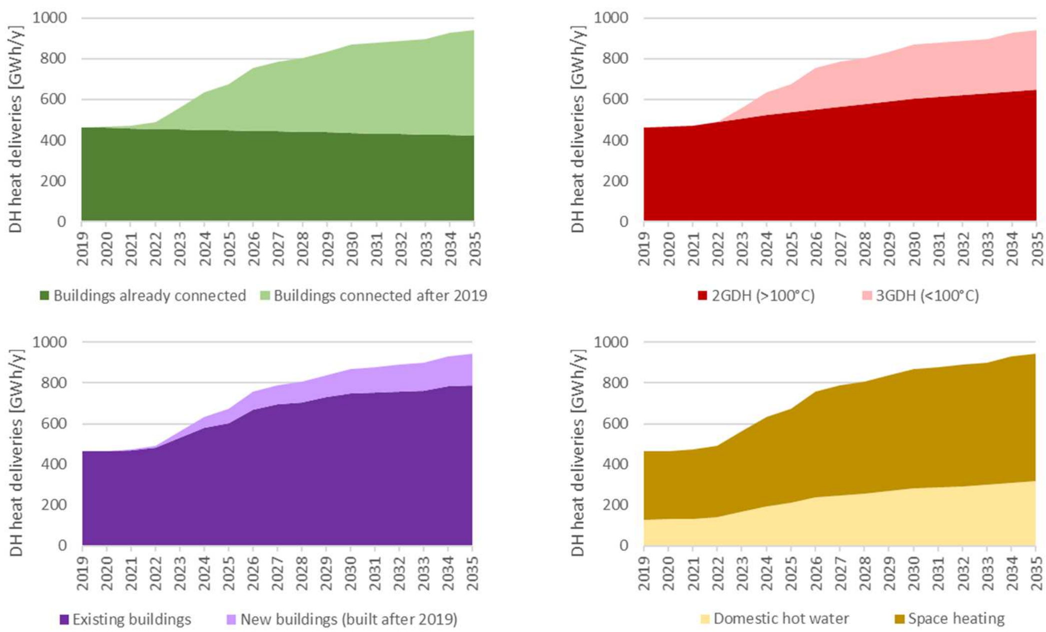

Figure 6: Evolution of the district heating deliveries, desegregated by: building connection status (top left); building construction status (bottom left); DH generation (top right); heat demand type (bottom right).

The dynamic profile of the demand is generated by separate upscaling of the current DHW and SH load curves (monitored data of the existing DH). The profiles for 2019 and 2035 are presented in Figure 7.

Furthermore, the DH efficiency is assumed to be 92% (heat deliveries/heat production) with constant distribution losses throughout the year in absolute terms.

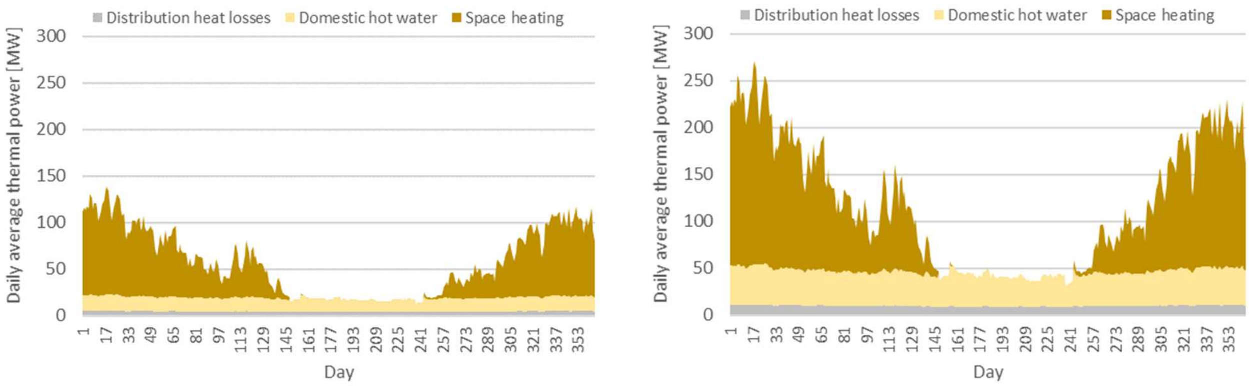

Figure 7: District heating load curve for 2019 (left) and prospected values by 2035 (right).

As mentioned before, part of these buildings will be connected to a new 3GDH network operating at lower temperatures. To account for possible heat transfer from the 2GDH to the 3GDH network, their heat demand is therefore treated separately in the model (although the results will be displayed in an aggregated way).

4.3 DH temperature levels

The relation between DH and outdoor temperatures are depicted in Figure 8. During summer, the DH supply and return temperatures are assumed to be constant, while during the heating season the supply temperature varies linearly as a function of the outdoor temperature. In the case of the existing 2GDH, the return temperature (and to a lesser extent the supply temperature) are considered to progressively decrease over time, due to projected optimization of the existing DH substations.

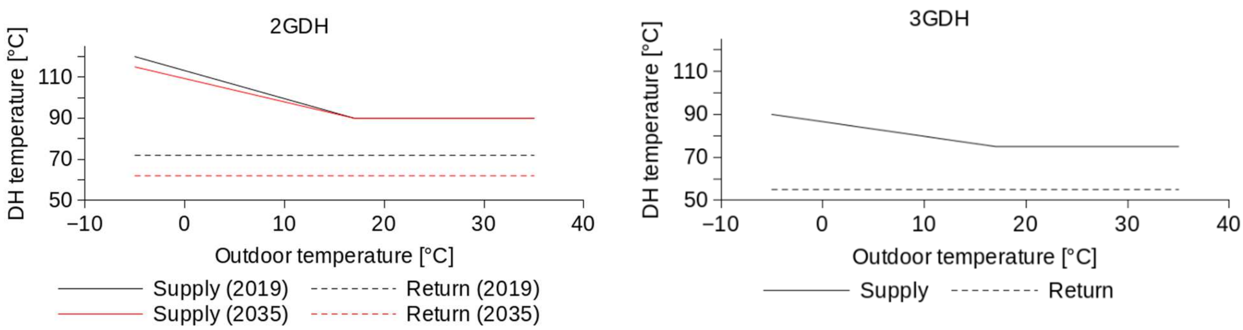

Figure 8: Evolution of the networks temperature levels.

These temperature levels imply that heat exchanges between both networks can naturally only be done from the 2GDH to the 3GDH (heat transfer from the 3GDH to the 2GDH using heat pumps (HP) is not considered here, nor the possibility of just preheating the return water of the 2GDH). Such heat transfer is subject to the available excess from renewables and waste heat connected to the 2GDH, considering the merit-order defined in section 4.6.

4.4 Renewable production capacity

Today the DH system is supplied by the urban solid waste incineration plant (49 MW) and centralized gas boilers (200 MW). Projection regarding the implementation of new thermal production capacities is linked to different existing projects:

- A new urban solid waste incineration plant replacing the old existing one, leading to a total capacity of 57 MW by 2024;
- A waste wood incineration plant of 12 MW (2023);
- A large-scale HP plant based on sewage water: 25 MW (2023) and then 50 MW (2035);
- A large-scale HP plant connected to the lake water cooling network: 5 MW (2023);
- Three wood boilers plants for a total of 5.5 MW (2023).

As a complement, projecting of the geothermal deployment is still subject to high uncertainties regarding its effective potential, which will be clarified by the exploration program presented in section 3. At this stage, a set of three scenarios has been constructed (see Appendix), of which only the best-case one will be analyzed here. This ambitious scenario (Figure 9) consists in the implementation by 2035 of six doublets between 1'000 and 2'000 m depth (three connected to the 2GDH, three other ones to the 3GDH), each with a 40 l/s flow rate, resulting in a total thermal power of 44 MW.

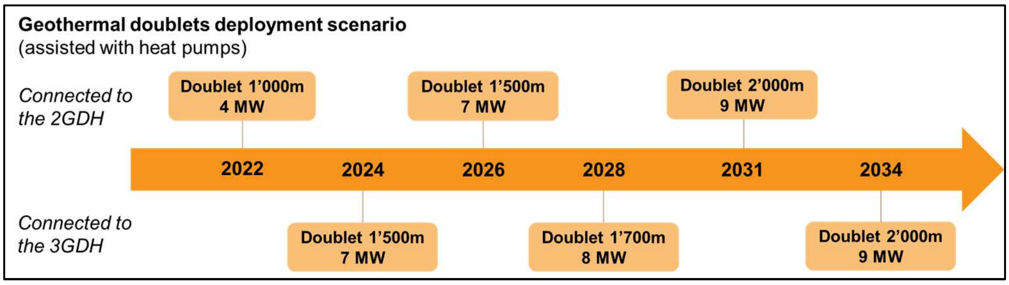

Figure 9: Geothermal deployment scenario.

Figure 10 recapitulates the evolution of the total waste heat / renewable production capacity from 2019 to 2035, considering the above described assumptions.

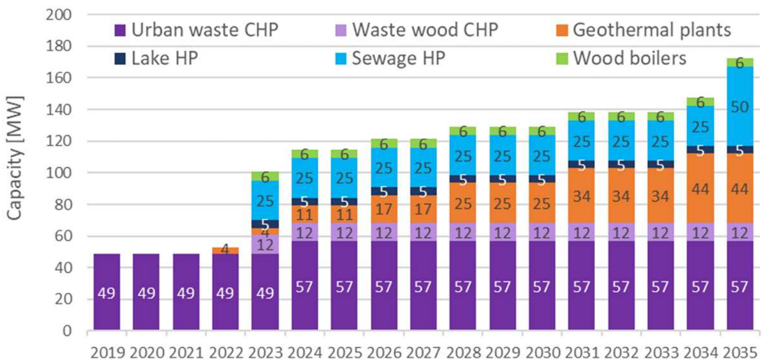

Figure 10: Evolution of the renewable production capacity from 2019 to 2035.

4.5 System integration

As sewage and lake water are available at temperatures way below the DH requirements, the related heat supply needs to be done by way of large-scale HPs, for which we assume an annual seasonal performance factor of three (heat output/electricity consumption), for a maximum supply temperature of 90°C. Since this threshold is lower than the winter supply temperatures of the 2GDH, the remaining temperature gap must further be filled by integration of local gas boilers

In the case of geothermal energy, only a small part of the thermal potential can be used directly (without HPs), by preheating the return water of the network. This is possible when the geothermal fluid temperature is higher than the DH return temperature, which is only the case for doublets with a minimum depth of 1'700 m connected to the 3GDH, or a minimum depth of 2'000 m connected to the 2GDH. For enhancing of the available potential (as well as for lower depths, with an aquifer temperature below the DH requirement), further heat extraction from the aquifers (down to a reinjection temperature of 25°C) is done by way of large-scale HPs, as it is the case in several geothermal plants in Europe (Faessler, 2017). As for sewage and lake water, we consider HPs with a maximum supply temperature of 90°C. In the case of the 2GDH they are combined with gas boilers for temperature boosting up to the required DH supply temperature. The seasonal performance factor, which depends on the aquifer depth / temperature, is considered at an overall average value of five.

As thermal networks will operate at different temperature levels, the localization of the production plants (connection to the 2GDH or the 3GDH) is an important issue (Figure 11). As previously mentioned, transfer of excess heat can occur from the 2GDH to the 3GDH.

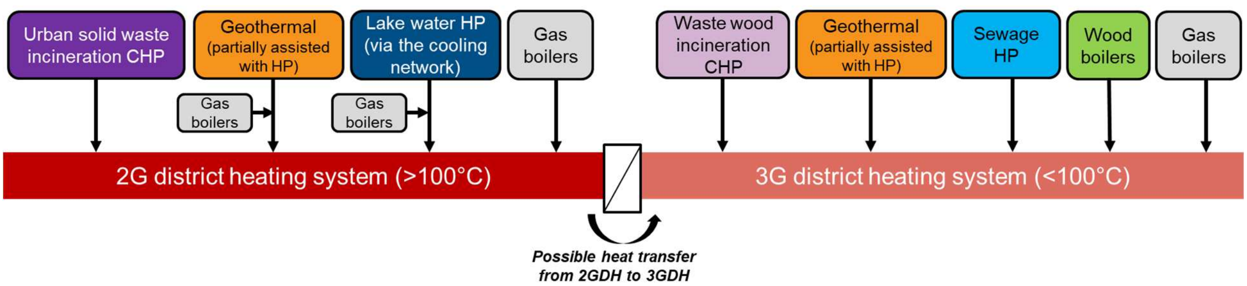

Figure 11: Connection of the production plants on the different parts of the overall district heating system.

4.6 Merit-order

The activation of the different plants is defined through the following merit-order: 1) heat recovery from the urban solid waste incineration plant; 2) heat recovery from the waste wood incineration plant; 3) geothermal energy (assisted with HPs and gas boilers for temperature boosting if required); 4) Sewage or lake water HPs (assisted with gas boilers for temperature boosting if required); 5) wood boilers; 6) peak load gas boilers.

The key criteria for the choice of the merit-order is the minimization of fuels consumption (gas, electricity and wood). Waste heat which is produced independently of the heat demand and available at high temperature (direct use on the DH possible) is therefore chosen to cover the DH base load. Due to the quantity of required electricity (which is linked with the resource temperature), geothermal plants are activated before HPs on sewage or lake. As the quantity of local biomass resource is limited and its use faces air pollution and transport issues, wood boiler plants are the last renewable production to be activated before peak load gas boilers.

5. RESULTS

Figure 12 shows the daily DH supply curves for 2019 and 2035, while Figure 13 shows the evolution of the annual mix from 2019 to 2035. Note the increase of waste heat recovery from the solid waste CHP plant, with the evolution of the equivalent full load hours from 6'000 h in 2019 to 7'500 h by 2035 thanks to the DH network expansion. In 2035, the sum of both CHP plants (urban solid waste and waste wood) represents almost half of the DH supply in 2035.

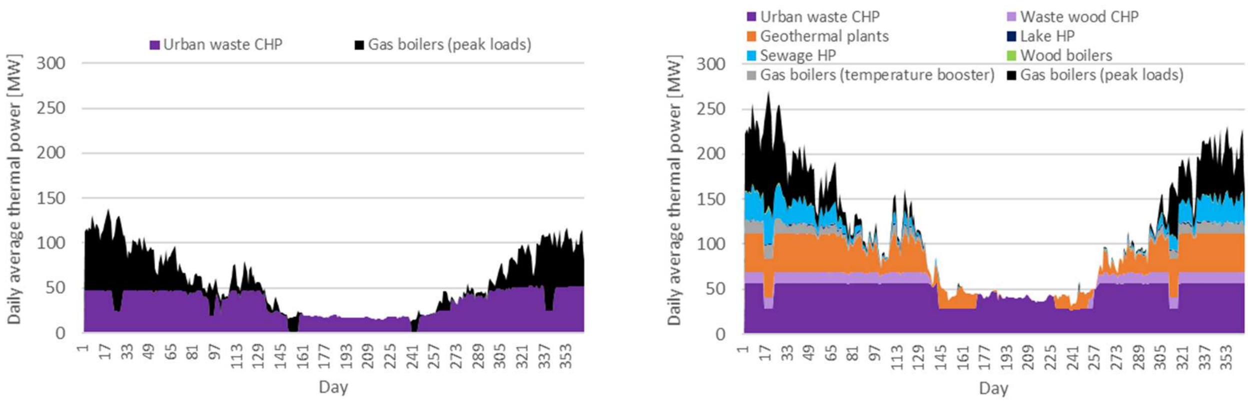

Figure 12: Daily DH supply for 2019 (left) and 2035 (right).

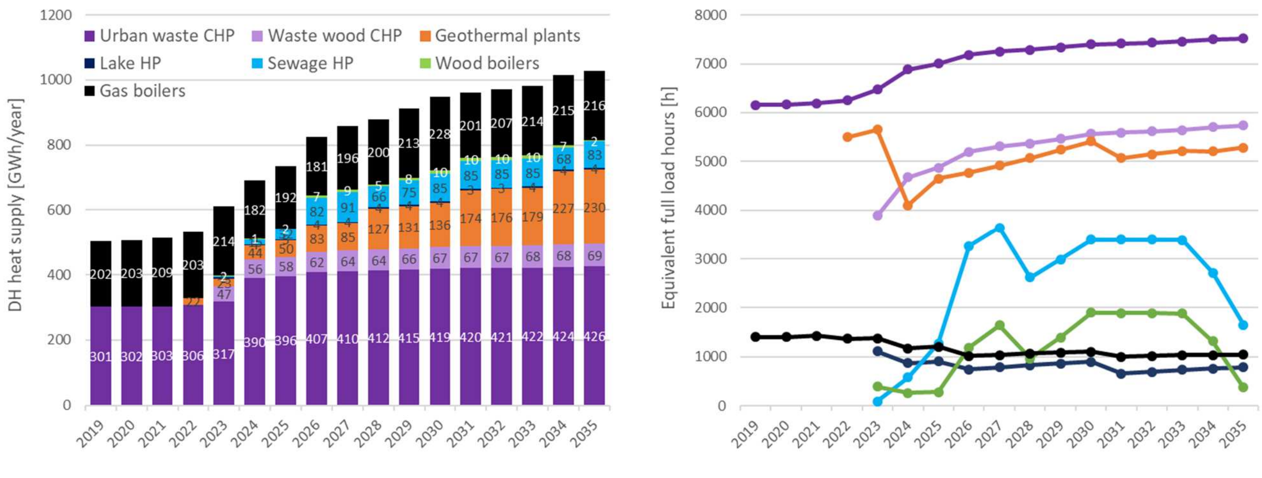

Figure 13: Evolution of the DH annual supply (left), equivalent full load hours (right) from 2019 to 2035.

In this scenario, the geothermal plants (which are activated just after the waste heat recovery from CHP plants) would produce 230 GWh in 2035, which represents 22% of the total DH supply mix. Competition between geothermal plants and waste heat recovery from CHPs occurs mainly during the summer season, limiting the geothermal energy use during this period, but the equivalent full load hours still amount to 5'200 h. The contribution of geothermal energy in a more conservative scenario is indicated in the Appendix.

Due to the temporal dynamic of the SH demand, the remaining share of the heat demand is more difficult and expensive to cover by way of renewables, as it requires capacities which will be used for fewer hours. In this scenario, which strives for a high share of waste heat / renewables (around 80% by 2035), the contribution of HPs based on lake and sewage water hence remains relatively low (87 GWh, i.e 8% of the total DH mix) as compared to the installed (5 + 50 = 55 MW) capacity, leading to less than respectively 2'000 h and 1'000 h of operation at full load power. In addition, the fact that the sewage water plant is only connected to the 3GDH network prohibits the opportunity to transfer excess capacity (available in certain periods of the year) towards the 2GDH.

Finally, in 2035 the share of gas-fired boilers (216 GWh) represents 21% of total DH heat supply, of which 4% (43 GWh) is used for boosting of HP temperature on the 2GDH network.

6. DISCUSSION

Considering that the electricity used by HPs is 100% renewable (today all the electricity sold in Geneva is certified from renewables, essentially produced with hydropower), the results indicate that the chosen scenario would be very close to reach the 80% renewable district heating supply target. In this scenario, geothermal plants would play a key role contributing to 22% of the DH supply mix. However, unlike the other renewable resources, the effective potential of this resource still needs to be accurately determined and this potential contribution is then conditional on successful results of the current exploration phase.

Further increase of the relative share of renewables in the DH heat supply would be possible by taking more ambitious actions regarding both production and demand sides.

The first action consists in further lowering of the building SH demand during (mainly affecting peak loads in the winter season), which requires an increased retrofitting rate and a better quality of the measures taken. At this point it should be noticed that climate change impacts, which will certainly contribute to further reduce the buildings heat demand (Frank, 2015), were not considered in this study.

The second action concerns further reduction of the temperature levels of the 2GDH network, ideally towards a 3GDH one, which would require a complete optimization of all substations (Werner et al., 2017). This would offer multiple benefits: i) avoiding the use of gas boilers required for temperature boosting; ii) decreasing the electricity consumption of HP heat plants; iii) reducing the network heat distribution losses; iv) ensuring the possibility of bi-directional transfers between the different parts of DH system. This latter is important as the relative share of renewable capacity connected to the 3GDH will be proportionally higher than the one connected to the 2GDH. This latter is important as the relative share of renewable capacity connected to the 3GDH will be proportionally higher than the one connected to the 2GDH. That means that in some periods of the year (mid-season), some renewable heat will be available and unused on the 3GDH while at the same time gas boilers will be operating on the 2GDH.

The third action concerns increase of the total renewable capacity. However, the annual operation time of additional capacity required to increase the renewable share will be low (peak load). Without possibility of heat transfer from the 3GDH to the 2GDH, these additional capacities should be implemented on the 2GDH network.

Finally, the fourth action consists in implementing seasonal heat storage capacities for increasing the recovery of waste heat during the summer period and discharging it on the network during the winter. The potential contribution of aquifer thermal energy storage in Geneva is currently under investigation and will be addressed within the European HeatStore project (Koornneef, 2019).

7. CONCLUSION

The aim of this study was to assess the potential contribution of medium-depth geothermal energy for the supply of the main DH system in Geneva, by taking into account the extension of the thermal network, the evolution of the building heat demand and the integration of other renewable production capacities. We analyzed a scenario based on the implementation of six doublets between 1'000 and 2'000 m depth by 2035, for a total thermal production capacity of 44 MW. An hourly input-output model ensuring the matching between demand and production allowed to generate DH load curves and identify the annual heat production of each heat plant technology.

The results indicate that the geothermal contribution could reach 230 GWh in 2035, representing 22% of the DH mix. In combination with other renewable resources, geothermal energy is therefore a key resource for achieving a 80% renewable district heating system by 2035. This combined deployment of new renewable capacities and network extension is fundamental to help decarbonizing the heat sector in the city. Of course, the actual contribution of geothermal energy will be conditional on the confirmation of the resource potential. Finally, as demonstrated in this study, a massive and efficient integration of this resource will also depend on: i) a large extension of the district heating system; ii) a reduction of its temperature levels.

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APPENDIX

Projecting the geothermal deployment in the context of the Geneva Basin is conditional on a confirmation of the actual geothermal potential. Therefore, three prospective scenarios were elaborated:

- A worst-case scenario without geothermal energy
- A conservative scenario (Geo−) with the deployment of five doublets between 1'000 and 2'000 m depth by 2035, each with a 25 l/s flow rate, for a total geothermal capacity of 25 MW;
- A best-case scenario (Geo+) with the deployment of six doublet by 2035 between 1'000 and 2'000 m, each with a 40 l//s flow rate, for a total geothermal capacity of 44 MW.

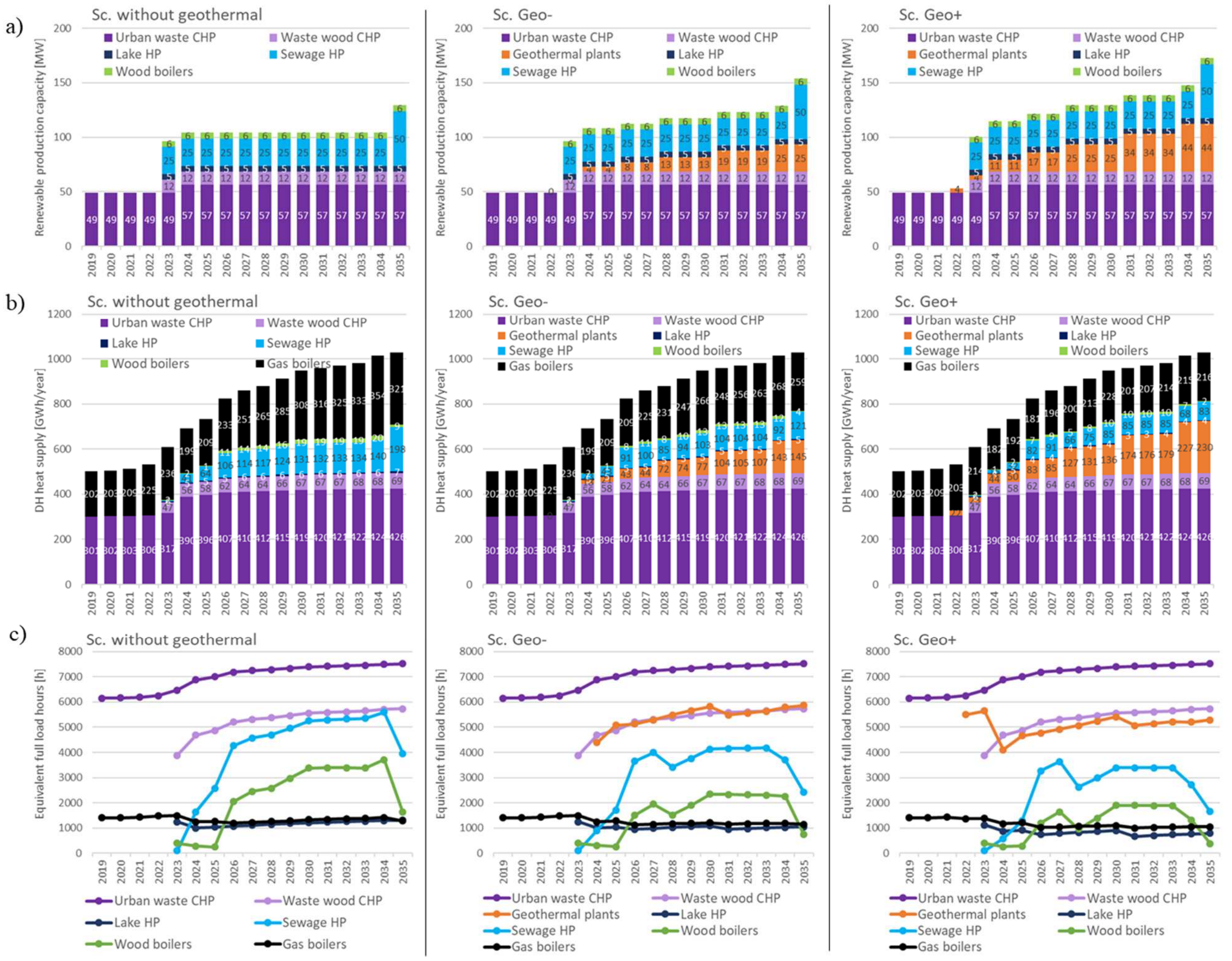

Figure 14: Difference between geothermal integration scenarios. Installed renewable capacity evolution (a), DH energy mix evolution (b), equivalent full load hours (c).