Geothermal Energy Use, Country Update for France

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ABSTRACT

The last market study (edition of 2021, figures of 2020) carried out in France by the French Association of Geothermal Professionals (AFPG) regarding the geothermal domain has demonstrated that the installed power for heating and cooling reaches 2500 MW_{th}. Nearly 600 MW_{th} are related to the exploitation of the deep reservoirs in the Paris area in 2020 and the remaining majority is linked to recent and strong development of shallow geothermal resources over the whole country.

The market for single housing using vertical geothermal probes has however dramatically decreased since 2009 due to the competition with natural gas and tax credit at 30 % for geothermal heat pump without any bonuses compared to the installation of efficient gas boiler or air-air heat pumps. The market for single housing has decreased by almost 88 % between 2010 and 2018, from more than 20'000 installations to less than 2500. On the contrary, the number of installations to feed collective housing and residential blocks including office buildings is growing constantly.

There are 72 deep geothermal installations in 2020 for direct uses and the majority is concentrated mainly in the Île-de-France region. Geothermal doublet constructions have been facilitated with the support of the Heat Funds managed by ADEME. Since 2018, around 10 new doublets were drilled in Île-de-France. The main barrier remains the energy calculation rules for new buildings (RT2012) which still encourage gas over geothermal energy.

For electricity generation, no more installations have been commissioned, but the Soultz-sous-Forêts plant has been revamped. The Bouillante plant has been sold by BRGM to ORMAT in 2016 and the plant capacity will be increased from 15.5 MW_e in 2020 (and in 2021) to 25 MW_e in the coming years with the building of new units. Two geothermal sites are currently in stand-by (doublets between 3500 and 5000 m depth) around Strasbourg. Another site in Massif-Central has just received the authorization to drill.

1. DIRECT USES OF DEEP GEOTHERMAL ENERGY

Direct uses of deep geothermal energy in France can be considered over nearly half of the territory due to large sedimentary basins (Paris Basin, Aquitaine Basin, Rhine graben, Limagnes, Bresse and Rhodanien corridors, South-East Basin). In France, geothermal direct uses deliver energy to district heating networks, greenhouses and fish farms, industrial processes, swimming pools and thermal baths.

1.1 Objectives

French authorities, with consultation of geothermal players, have planned an ambitious objective to reach 3 TWh of heat production by 2023, and between 4 and 5.2 TWh within 2028 which means doubling geothermal heat production within the 2030 horizon. CAPGEMINI Invent has estimated that between 6 and 10 new installations (mainly doublets) per year should be implemented to reach these objectives.

It is now essential that new geothermal projects be developed beyond the Dogger limestone aquifer in the Paris Basin, in new aquifers and formations that have been less explored or exploited up to now.

1.2 State of the art

Geothermal energy for direct uses found its first application in France in the 1970's. Indeed, the oldest installation is located in Melun-l'Almont (Île-de-France region) and was commissioned in 1969. The installation has now been extended and a doublet remains in operation in 2022.

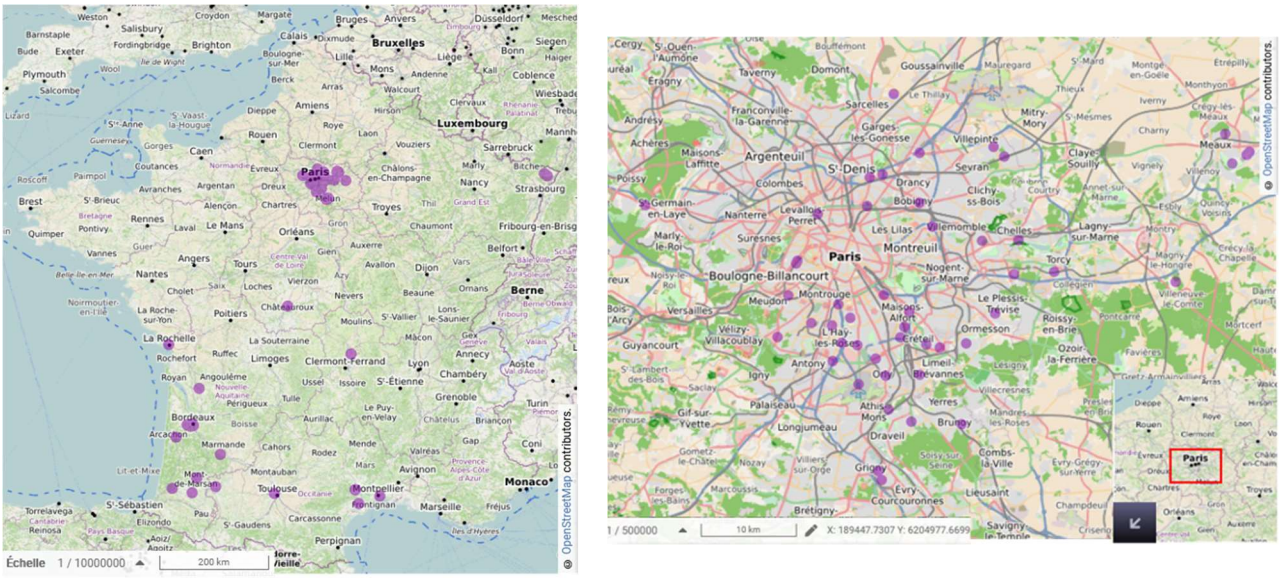
Geothermal competitiveness was supported by high fossil fuels prices in the 1980's. Then, for 20 years on, the development of the resource has been deserted due to the abundance (and relatively low price) of natural gaz. Deep geothermal exploitation resumed in 2008 and 2009 thanks to the launch of the Heat Fund (*Fonds chaleur*) from ADEME (French ecological agency) which aimed at supporting the development of thermal renewable energies and facilitated the creation of new doublets.

a) Synthesis of deep geothermal plants in France for heat distribution

In 2020, 72 geothermal operations are responsible for the production of 2.0 TWh of heat in France (Figure 1a) and 87% of the energy is delivered through district heating networks (DHN), mostly in the Île-de-France region (Paris area as shown in Figure 1b) according to the deep geothermal database *Sybase* (BRGM). There are 41 doublets and 7 triplets (generally two producers and one injector) in operation in 2020 in this region alone. Most of them valorises heat at a depth between 1500 and 1900 m in the Dogger limestone (Middle Jurassic) aquifer.

The Dogger reservoir covers an area of over 150 000 km² with the temperature measured directly below the Paris region varying between 56°C and 85°C according to the depth of the reservoir. To a lesser extent, the sand aquifers of the Albian and the Neocomian (Early to Lower Cretaceous) are also targeted in the Île-de-France region with depths between 500 and 800 meters and temperatures varying between 25°C and 30°C.

Other deep installations are dispatched mostly over the Aquitaine Basin where 14 sites are currently active, for a total heat production of 107 GWh delivering energy to greenhouses, fish farming and swimming pools or thermal baths.



a. b.

Figure 1.a and 1.b: Deep geothermal operations in France and in the Île-de-France region for heat production (source: Sybase ADEME & BRGM 2022).

An installation for industrial purpose is located in the Grand-Est region (Rittershoffen in the Rhine graben, former Alsace region) and produces about 10 % of the total French heat production from deep resources in 2020 (182 GWh_{th}). The plant supplies high temperature heat to an agro-industrial site. Other production sites are located in the Occitanie region (near Toulouse, Montpelier, Pézenas), in the Centre Val-de-Loire region (in Chateauroux) and in Auvergne (Aigueperse). Small geothermal installations located in the former Lorraine region are now closed.

b) Exploitations over the Paris and Aquitaine Basins

Over the last 3 years, 3 operations have been developed in Paris area to replace old doublets (Bonneuil-sur-Marne 2, Cachan 3, Vigneux-sur-Seine 2). Since 2018, 10 new doublets have been drilled (including the 3 previous sites, Bordeaux PGE, Bobigny-Drancy 1 and 2, Champs-sur-Marne, Evry, Rueil-Malmaison, Vélizy-Villacoublay) and a simplet (Saint-Germain-en-Laye). This site has the specificity of being a drinking water well in which heat is valorised to supply a district heating network. Two projects of oil and geothermal energy co-production have also been connected to buildings in Aquitaine Basin (near Arcachon).

For old doublets, the development strategy is in general to drill a new production well in larger diameter (generally 8" or 8"½) in order to increase the flowrate of the installation from 200-250 to 300-350 m^3/h and operate as a triplet. Finally, when a well of the triplet sees its performances decrease, a fourth well can be drilled so that the initial doublet is abandoned to operate with a new doublet.

In 2020, between 4000 and 8240 housing equivalents can be heated and supplied with domestic hot water by one deep geothermal installation supplying a district heating network in the Paris region (Sybase, 2021). The extracted power per installation can be increased thanks to high temperature heat pumps that will lower the reinjection temperature. Approximately 1 million people are living in spaces heated with deep geothermal energy in France (mainly in Île-de-France).

The DHN supplied by the geothermal resource of the Dogger limestone aquifer are mainly exploited by private companies such as *Dalkia* (*EDF Group*), *ENGIE Solutions* (*ENGIE Group*), *IDEX Energie* and *Coriance*, but also by local public-private ventures (*Sociétés d'Economie Mixte*). Some of the DHN have been in operation for more than forty years. The average availability rate approaches 95 % in the Paris Basin.

Recently Albian and Neocomian aquifers (Early to Lower Cretaceous) have been used for geothermal district heating and cooling application using heat pumps. In 2020 there were 6 doublets targeting this resource: Paris Mirabeau, Issy-Les-Moulineaux, Le Plessis-Robinson, Paris-Batignolles. Saclay 1 and Saclay 2. Due to reinjection problems and screen clogging with fine particles, some of these installations have not been able to produce at nominal flow rates and investigation are currently being carried out to investigate the mechanisms at stake. In 2021, a new well has been completed in Saint-Germain-en-Laye in the Albian sand aquifer with the double objective to produce heat and supply drinking water. Heat will be valorised before the production of drinking water and will allow overcoming the reinjection issues faced in these clastic environments.

The second largest zone for direct use in France is the Nouvelle-Aquitaine region (South-West of France) where 13 single production wells, one doublet (Bègles) and three co-production installations (oil and heat) are currently in operation in 2020. These installations were set up in the beginning of the 1980's and the vast majority were built as single well installations as geothermal water discharge could be managed at the surface. Nowadays, secondary uses of the resource, as irrigation and agricultural uses are also investigated, along with reinjection of fluids using the doublet technology for new installations.

In this region, a new plant will be launched in 2022 on the right bank of the Garonne river in Bordeaux. The plant will supply a DHN build by ENGIE using the doublet technology. The target was initially the limestones dating from the Jurassic, which were never targeted before in the sector. Finally, as the limestones were not productive in the specific area investigated, the doublet was reoriented to produce from the well-known reservoir of Cenomano-Turonien sandstones (notably exploited over the area for geothermal uses).

1.3 Innovations

Recent technologies have been developed to exploit the Dogger reservoir of the Paris Basin: the use of multi-lateral wells to increase production and injection indexes and the deployment of composite materials in order to cope with corrosion problems.

- **Use of composite casings**

In 2018 in Bonneuil-sur-Marne a new production well has been drilled in order to replace an old well in small diameter and out of order. The use of composite casings (see Figure 2) has been already tested in the Villeneuve la Garenne installation in 1976, in the Melun installation (which remains active in 2021) and also in La Courneuve Sud where the pumping chamber was equipped partly with a composite casing. At this site, the composite casing was extracted 13 years after being installed and showed no sign of wear. More recently, in 2015, CFG installed composite in Chevilly-Larue and L'Hay-Les-Roses to reline two production wells with an excellent result. This technology can be considered as an interesting alternative to standard steel casings to facilitate high production flow rates and to avoid corrosion and scaling.

Recent laboratory studies conducted by CFG have shown that a composite casing cemented in a new well has 1000 times more wear than a steel casing. The study also revealed that rubber protections can largely reduce the wear phenomena (to reach the same level as in a steel casing). Payback time is expected at 15 years in comparison with the use of traditional materials.

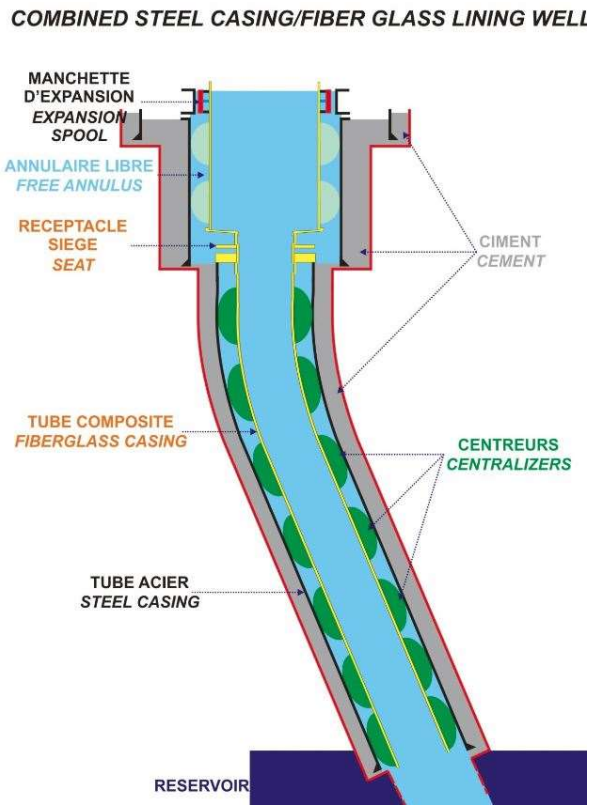


Figure 2: Concept of composite casing installed in Bonneuil (source: GPC IP).

- **Multi-lateral well in Vélizy-Villacoublay**

Below Vélizy-Villacoublay (Paris area), the Dogger limestone aquifer is known to be less favourable for the development of geothermal energy as petrophysical properties are degraded compared to areas targeted until now. With a conventional doublet using two deviated wells, the project would have most probably been un-economical.

ANTEA Group and ENGIE Solutions have designed a special well architecture to maximize the exchange surface in contact with the targeted Dogger reservoir (see Figure 3 and 4). At the bottom of both production and injection well, U shape drains were drilled in addition to the classical termination of well (i.e. sedimentation leg). The angle (70°) is higher than in a deviated well to better penetrate the reservoir. RSS Archer (Schlumberger) was used to drill these drains. After acidification, the results are the following:

- Productivity index multiplied by 6.4;
- Flowrate above 320 m^3/h (expected 200 m^3/h with a traditional architecture).

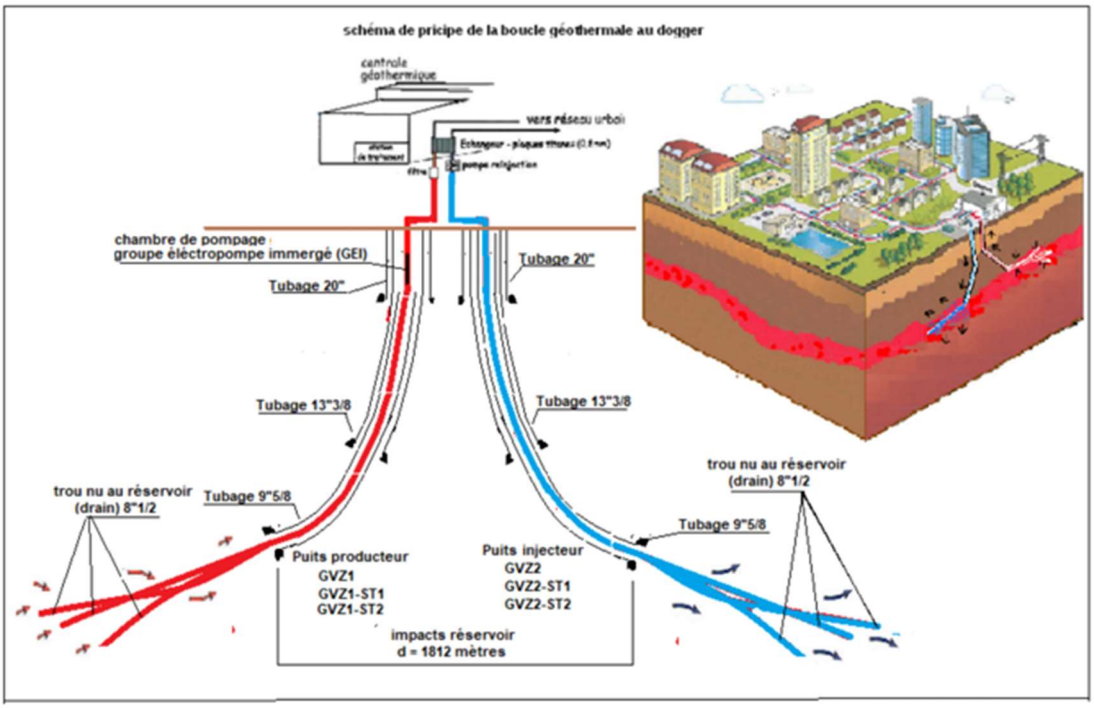


Figure 3: Presentation of Vélizy-Villacoublay project (source: ENGIE).

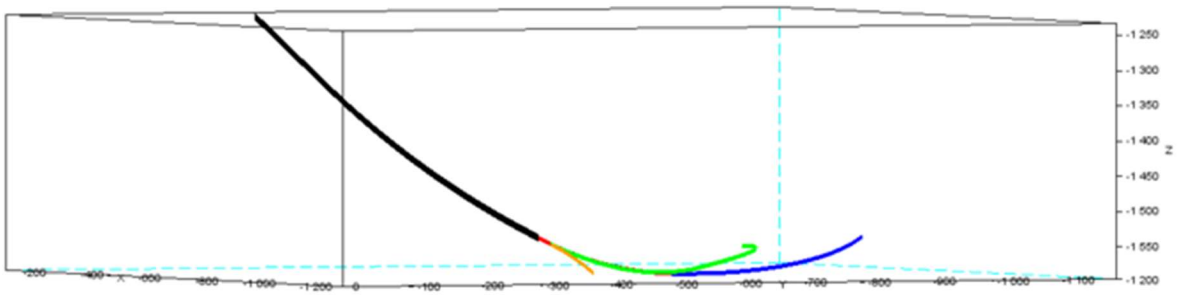


Figure 4: Multilateral well architecture, also called U-drains (source: ENGIE).

1.4 Perspectives

In the next years, deep geothermal operations are expected to quickly grow to reach the objectives formulated by the French government (PPE 2019). A dozen projects are planned to be drilled in the next 3 years and a dozen more, under studies, are foreseen in 3 to 6 years. A majority will be located in the Paris area and other will explore other basins (Aquitaine, South-East, Limagnes).

In the North of Alsace, several research licences (PER) have been attributed to the company *Lithium de France* to develop a project of heat and Lithium production in fractured reservoirs.

2. ELECTRICITY GENERATION

In terms of electricity production from deep geothermal resources, three thematical areas can be distinguished in France: electricity production in volcanic regions, from EGS reservoirs and from crustal faults.

2.1 State of the art in volcanic areas

For volcanic reservoirs, a single plant is currently in operation: the Bouillante geothermal plant located in Guadeloupe and operated by ORMAT. The capacity of the plant in 2021 is 15.5 MW_e. A magneto-telluric (MT) exploration campaign has been carried out over the geothermal field in order to understand the distribution of the resources in an attempt to extend the geothermal field in the coming years.

The plant is producing about 115 GWh per year of electricity, which corresponds to about 10 % of the Guadeloupe island needs. A project known as Bouillante 2 expects to drill two new geothermal wells at depth in between 1000 and 1600 m. The additional power expected is around 10 MW_e.

At the south of Bouillante (and at the South of the island), a new exploration licence has been attributed to *Albioma*. Additional exploration works are also going one in Martinique with a consortium of *Storengy* and *TLS Geothermics*. In La Réunion Island, a licence has been attributed to *ENGIE* to explore the Cafres-Palmiste area.

2.2 State of the art in EGS reservoirs

In France, and particularly in the Upper Rhine Graben, geothermal development takes place since decades thanks to the expertise developed for Enhanced Geothermal Systems, with the European pilot at Soultz-sous-Forêts (Vidal and Genter, 2018). The main geothermal projects running on the French side of the Upper Rhine Graben (Alsace) are the world-wide known Soultz-sous-Forêts power production plant and the most recent Rittershoffen heat plant. In parallel to electricity production of this site with an ORC, tests were performed using a mobile ORC to cool down the reinjection brine (H2020 MEET project).

Geothermal development around Strasbourg is in standby since the seismic crisis that occurred in 2020. The project of Vendenheim was stopped due to the links between the tests and these seismic events. The Illkirch site will probably restart in the next years. Moreover, a large exploration phase was performed by Electricity de Strasbourg with the acquisition of the first 3D seismic survey for deep geothermal energy in France (in Northern Alsace in summer 2018) (Richard et al., 2019).

The Soultz site has been successfully commissioned as industrial geothermal electricity site in 2016 thanks to a geothermal fluid at temperature higher than 150 °C. Since the geothermal water shows a high salinity (TDS around 100 g/l), the heat of the geothermal water is exploited via heat exchangers by an ORC (Organic Rankine Cycle) unit of 1.7 MW_e gross power (Figure 5). The brine is discharged at 150 °C on surface and then reinjected into the crystalline reservoir at 60-70 °C through two reinjection wells. The geothermal loop is composed of one production well GPK-2 and two reinjection wells GPK-3 and GPK-4. All three wells are 5 km deep and are cased to roughly 4.5 km in the granitic section. Below that depth, the reservoir is made of crystalline basement and underwent various kinds of hydraulic and chemical stimulations in the past and several periods of long-term circulations.

Figure 5: Aerial view of the Soultz-sous-Forêts binary plant (source: GEIE EMC).

Induced seismicity monitoring of this site is permanently performed through a network of seismological stations installed on surface (Maurer et al., 2017). It must be noticed that none of those events were felt. For both year 2017 and 2018, the availability of the Soultz-sous-Forêts geothermal plant reached 90 % of the time, including several weeks of planned maintenance stop.

Occurrence of micro-seismicity in the Upper Rhine graben has always been a subject followed closely. The seismic event of November 2019, situated at 5 km of the geothermal well of Vendenheim, has led to acceptability problems with the local population and in the whole territory (as well in new shallow geothermal projects as in deep geothermal projects in other geological contexts).

In October 2020, several seismic episodes were felt and are clearly linked with the tests carried out at the plant. In December 2020, the operator stopped all activities on site. Following these events, 3 working groups were etsablished: one with companies from AFPG (and EGEC), aiming at identifying good practices about these kinds of projects; one piloted by the Ministry of the Ecological Transition aiming at writing practical recommendations for both operators and public entities; and one piloted by the Prefecture of Strasbourg aiming at analysing the decisions taken on site.

2.3 State of the art in crustal faults system

Numerous exploration licences were attributed to a consortium of *Storengy* and *TLS geothermics* in the Massif-Central. The targeted reservoirs are crustal faults zones with expected hot fluids circulating through.

In April 2022, the first drilling operation licence was attributed to *Geopulse* for the drilling of two doublets at around 3500 m and 180 °C expected. The first megawatts of electricity could be produced in 2024-2025.

2.4 Generalities

In 2015, the geothermal cluster GEODEEP has been founded. It is made of large companies with experience in Research & Development, studies, project development, power plant equipment, operation and maintenance, engineering firms developers/integrators specialised in geothermal energy, ESCO's and the Geothermal French association of professionals. Apart from a strong common action to promote the French geothermal offer abroad, the cluster did achieve the creation of a risk mitigation fund.

A lithium cluster is currently under development. As for GEODEEP, the goal is to gather French companies working on the different parts of the value chain of lithium extraction, refining and utilization. Lithium is indeed naturally present in some geothermal brine (especially in the Rhine Graben). So, it represents the possibility of a low carbon lithium extraction, essential metal for the energy transition.

Finally, the feed in tariffs for geothermal energy have been abrogated to follow the European Union regulations. Normally, the system will ensure for the next years and for some projects a guaranteed tariff equivalent to about 250 €/MWh close to the same dispositions in force in Germany. All other electric projects will benefit of the national tariff.

3. GEOTHERMAL HEAT PUMPS

The French geothermal heat pump market consists mainly on single-family home installations. The French geothermal actors estimate 205'000 geothermal heat pumps in operation in France in 2020, including 195'000 individual housing heat pumps. This trend could change in the coming years, the individual housing geothermal heat pump market being at a low level after a significant increase up to 2008 (Figure 6). The substantial decrease since 2009 could be stopped in the last 5 years, but the market which is facing the competition of air/water and air/air systems remained at a low level.

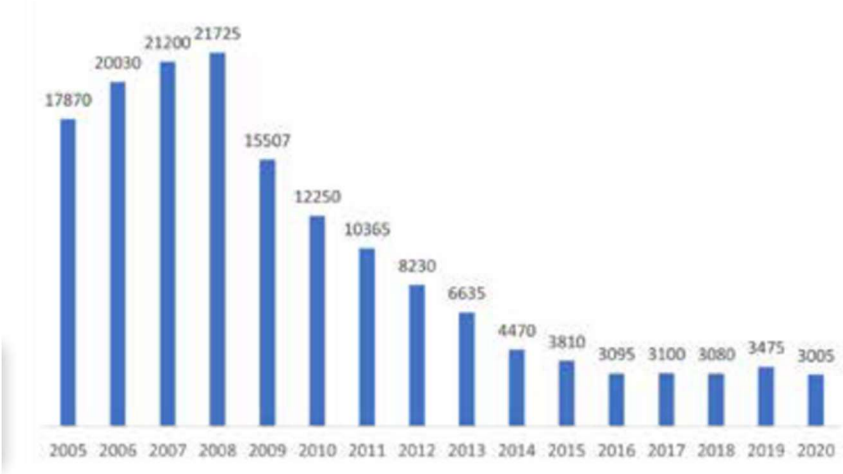


Figure 6: Sales evolution for geothermal HP (<30kW) in individual housing (2005-2020) (source: Observ'ER).

In contrast, the number of geothermal heat pumps dedicated to the collective housing and tertiary sectors is growing slowly. However, it should be noted that the collective housing geothermal heat pumps in operation is close to zero (2300 heat pumps).

In 2021, BRGM and AFPG, in liaison with ADEME, achieved a capitalization and dissemination of every geothermal heat pump systems through cartographical websites (https://www.geothermies.fr/viewer/). Figures 7 and 8 illustrate the geographical distribution of the systems (mainly vertical borehole heat exchangers and aquifer doublets) in coherence with the geological context, sedimentary basins being favorable for the aquifer systems deployment. Figures 7 and 8 do not represent the completeness of the operations for several reasons: data collection yet incomplete, difficulty to collect the data of very shallow ground heat exchanger operations (<10 m).

Horizontal loops are still representing a quarter of the geothermal market for individual housing and thermo-active foundations remain currently largely underdeveloped.

Individual housings can benefit from a state aid called "MaPrimeRénov" related to their revenue and if they undertake renovation projects in their home. The amount of this bonus is increased for the installation of a geothermal heat-pump. As higher incomes and new building are not considered in "MaPrimeRénov", the benefits on shallow geothermal heat pump sector are still not enough to revitalize that market.

For vertical borehole heat exchangers, Observ'ER determined distributions between installations in new building or renovation. For private housing installations, this is 18 % for new and 82 % for renovation. For collective installations, this is 40 % for new and 60 % for renovation.

For the collective buildings (housings, office, hospital, municipality buildings), a study published by Observ'ER (2020) estimates that there have been an additional 110 operations in the residential sector while we can count 445 new operations in the collective sector. This represents an additional 71 MW_{th} installed capacity for French residential and collective sectors in 2021.

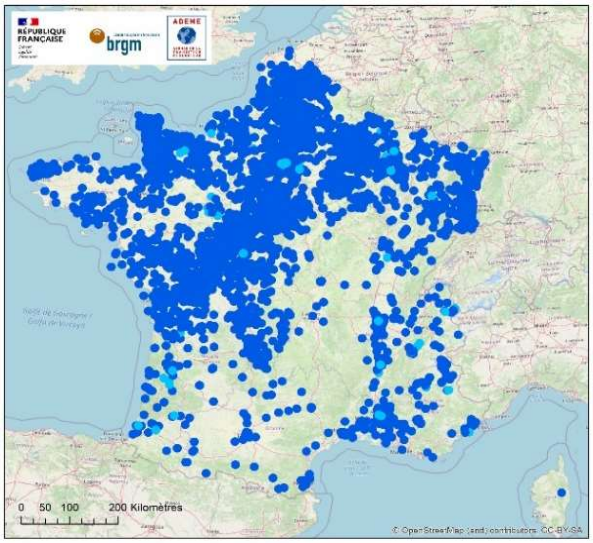


Figure 7: Geographical situation of the 6050 aquifer ground source heat pumps declared in April 2022.

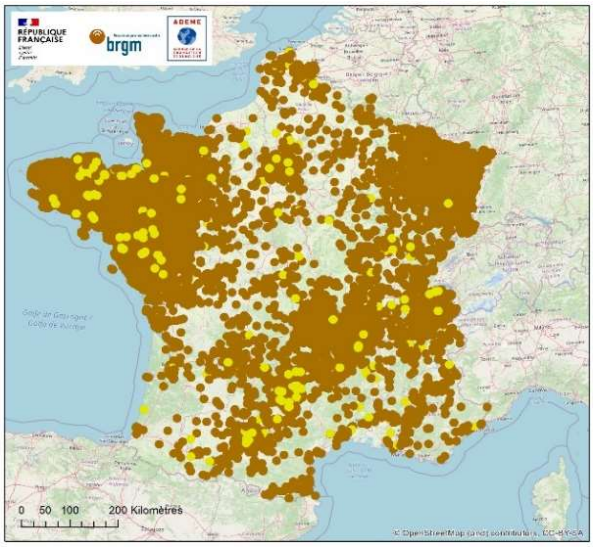


Figure 8: Geographical situation of the 22'447 borehole ground source heat pumps declared in April 2022.

New concepts and technologies could boost the ground source heat pump market in the coming years. The new concept of a low temperature geothermal loop delivering cold and heat energy is now in application in several towns with average installed power between 1 and 4 MW. New concepts of very shallow closed-loop heat exchangers such as helicoidal heat exchangers are also emerging. Since the beginning of 2022, ADEME Heat Funds also supports the installation of geothermal helicoidal heat exchanger.

3. GEOTHERMAL SECTOR DEVELOPPING STRUCTURES

3.1 Schemes to support the geothermal energy industry

France has developed different schemes to help the development of the geothermal sector. One of them is the **mitigation tool for geological risks**. This risk is linked to the fact that the exploitable geothermal energy resource can only be known after the drilling of the first borehole. This costly operation (more than 5 Million € at 2000 m geothermal target) which may result in failure (e.g. due for instance to a lack of resources, to insufficient temperature or exploitable flow rates in relation to the forecasts, or to the inability to exploit the geothermal fluid due to aggressive geothermal fluid for example). For deep aquifers used for heating production, the guarantee (SAF Environment) is existing since now 36 years and has proved is efficiency. In order to reach the target set up by the French Energy programming, i.e. a 4–5.2 TWh range by 2028, ADEME has launched works to reshape the "*Fonds SAF"* scheme to be in capacity to support financially and in the long run this volume of deep geothermal projects. The philosophy of the new Fund is based on an extension of the 90 % guarantee to all of France with a segmentation of zones according to their level of geological risks.

For shallow drilling ranging between surface and 200 m depth, there is the guarantee "Aquapac" (funded by ADEME, EDF and SAF), in place since 30 years, which covers the geological risk of the first drilling and the geothermal production during an exploitation period of 10 years. Furthermore, there is a financial supporting scheme even if the operation is a success. For heating production, the **Renewable Heat Fund** (*Fonds Chaleur Renouvelable* in French) was created in 2009 for collective housing, tertiary, industry and agriculture. At the end of 2020, 678 geothermal installations (for district heating and geothermal heat pump) have been subsidized by the Renewable Heat Fund:

- 361 vertical borehole heat exchanger operations: 37'500'000 € for 51.8 MW of installed capacity;
- 224 aquifer operations: 29'300'000 € for 104.6 MW of installed capacity;
- 19 operations on sea water: 12'600'000 € for 46.7 MW of installed capacity;
- 74 sewage operations: 26'600'000 € for 80.3 MW of installed capacity.

This represent a total amount of 106 M€ for the geothermal industry. In Figure 9, the repartition of these subsidies by regions is shown, as recorded by the number of facilities supported between 2009 and 2018.

3.2 French regulation

Geothermal energy is ruled by the French Mining Code and subject to declaration or authorization in accordance with Figure 10. Concerning the shallow thermal energy, a new law has been adopted on January 2015 and applications measures orders are now operational since July 2015.

- **general requirements** for shallow geothermal energy activities: conditions relating to the layout of an installation, measures to the implemented on performance, conditions of sale and exploitation as well as the terms of surveillance and maintenance of the installation.

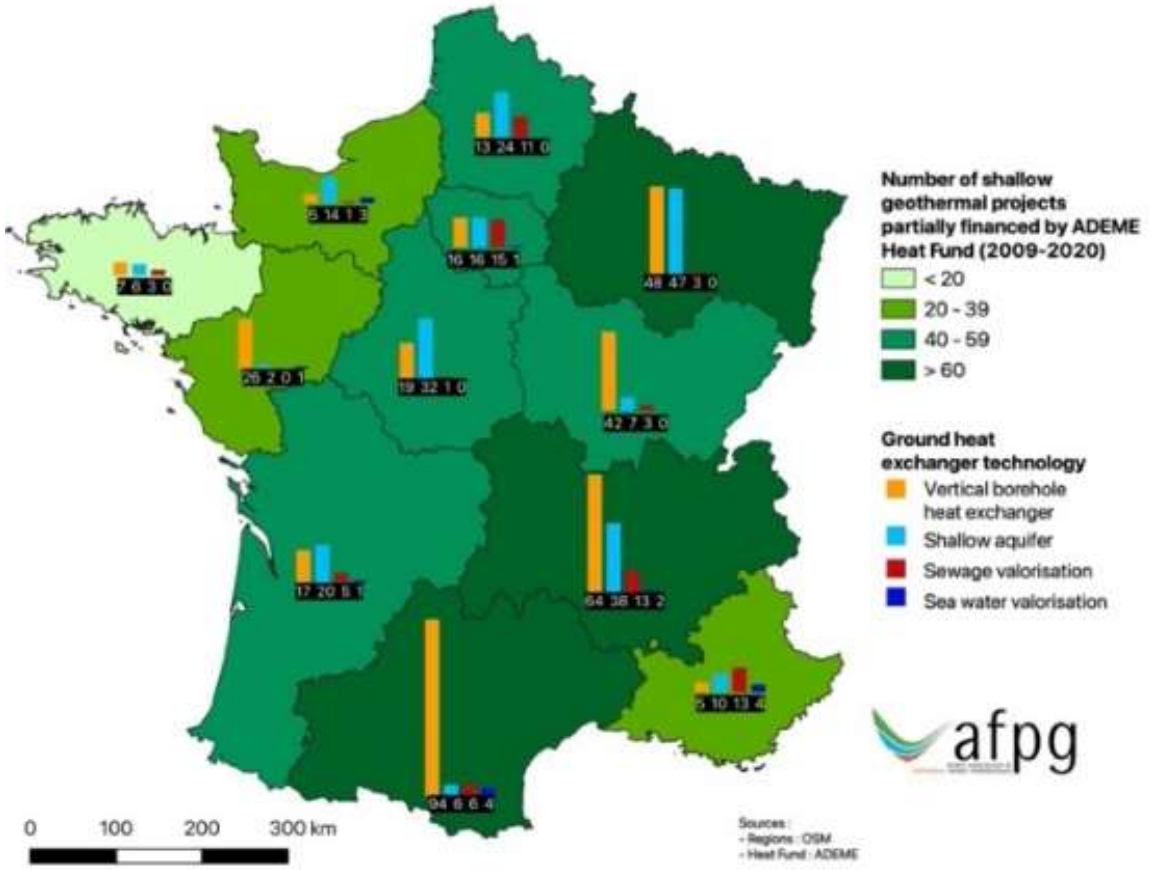


Figure 9: Total geothermal projects supported by ADEME Heat Fund between 2009 and 2020 (AFPG based on ADEME data).

- **qualification of drilling companies** working on shallow geothermal energy systems: obligation to perform drillings by qualified companies (RGE QualiForage).
- **cartography of statutory zones**. (Figure 15) On a national scale, this relates to two maps, one for closed-loop exchangers and one for open-loop exchangers handling zone 10 at 200 m. These maps may be broken down, on a regional level, for 3 depth intervals: 10-50 m, 10-100 m and 10-200 m. They define 3 distinct statutory zones:

  - "green" zone: the declaration system applies;

  - "orange" zone: the declaration system applies whereby the bidder is required to provide a "certificate of compatibility" from an export to perform the project;

  - "red" zone: the geological risks shown on the cartography of the statutory zones exclude the benefit of the simplified administrative system for shallow thermal energy.
- **expert approval** for shallow geothermal energy systems: lays down the terms of approval of experts and the skills required.

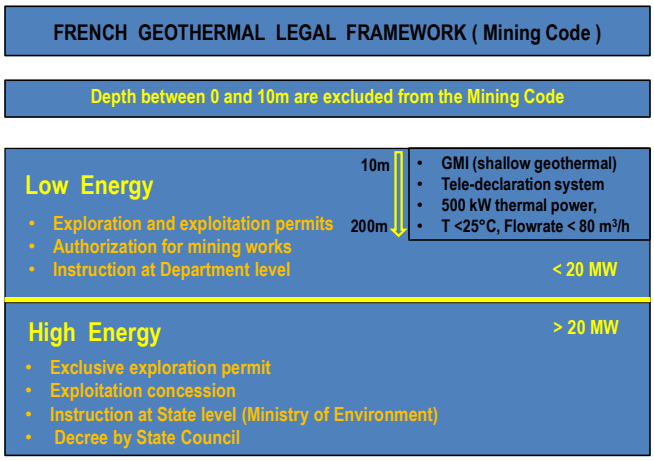


Figure 10: Synthesis of the French regulations for different geothermal exploitations.

4. SUPPORT FOR R&D AND INNOVATION

To boost innovation, the French government put in place the "Investments for the Future" program that funds several R&D actions. In 2011, it called for proposals to fund innovative deep geothermal heat and/or power generation demonstration projects. Among the proposals submitted in March 2012, only two about high-temperature geothermal developments

were accepted, giving new opportunities to the French industry and opening new perspectives:

- the GEOTREF project in the "Vieux-Habitants area" in Guadeloupe (French overseas department, Lesser Antilles), with the Teranov company as leader.
- *And the other of the two?*

ADEME (the French Agency for Environment and Energy) launched in 2018, as part of "Investments for the Future", a new call for projects to accompany the development of renewable energies. Theme 4, focused on geothermal energy, deals with projects whose objective is to improve the competitiveness of the geothermal industry by:

- reduction and control of all the costs related to energy production (heat and / or electricity);
- increasing the potential of exploitable geothermal resources;
- better acceptance and territorial integration of geothermal projects.

The main part of the national R&D budget for geothermal energy is managed by ADEME. However, some funding can also be associated with a part of the upstream research funded by ANR (national agency for research) and technological innovation funded by FUI (fund for industrial clusters).

After two calls for projects on all research domains in France, 171 Laboratories of Excellence (LabEx) have been awarded. The "G-Eau-Thermie Profonde" Laboratory received its official quality label in March 2012. Based in Alsace, it has a focus on deep geothermal energy and receive an initial 3 M€ funding for a 9-year period. Nowadays, its annual funding is around 2 M€, sustained by national and European research projects, and from Electricité de Strasbourg, Strasbourg University - IDEX and CNRS. It illustrates and strengthens the industry-university partnership engaged in the framework of the "Investments for the Future" with new partners such as Total and Storengy (Engie group).

An Institute of Excellence for the use of the underground in the energy transition, called Géodénergies, has been also created in July 2015. Its aim is to support the development of the three industrial sectors: CO_2 storage, energy storage and geothermal energy (heat and electricity). This joint venture brings together industrial and public research organizations and benefits from the national funding program "Investments for the Future". In 2019-2020 Géodénergies will evolve into a new research institute jointly owned by public and private actors.

In order to promote the development of geothermal activities, Géodénergies has launched several research projects to bridge technological gaps (such as drilling hammer or pumps adapted to deep geothermal context, monitoring of reservoir cooling), develop methodologies (for microseismic measurements exploitation and conceptual reservoir models in grabens) and develop co-activities of exploitation (with Lithium production or with CO_2 storage).

In addition, several national technological clusters have been established to develop collaborative industry and research institute R&D projects, and include:

- AVENIA, based in Nouvelle-Aquitaine region, deals notably with deep geothermal applications;
- SYNERGILE, based in Guadeloupe, aims at developing renewable energies in the overseas department;
- S2E2, based in Tours, deals with shallow geothermal energy and smart buildings.

In June 2014, GEODEEP, the French geothermal Cluster for heat and power, was officially launched. GEODEEP is a cluster of competences in the subsoil and energy sectors that complement each other to cover the entire value chain and develop full-cycle projects in France and internationally, from subsoil exploration and drilling to power plants and district heating systems, through distribution, training, maintenance and technological monitoring.

Carried by AFPG, the cluster comprises large companies with a worldwide presence, specialized companies with extensive experience in geothermal engineering services, power plant EPC, equipment manufacturing, drilling companies, societies proposing project financing solutions, specialized developers/integrators of geothermal projects and geothermal associations for professionals. Three markets are targeted:

- Geothermal heat and power production in the French mainland (hydrothermal EGS);
- Geothermal power production in the volcanic islands in French overseas territories;
- Geothermal power production in other volcanic regions in the world.

5. JOBS

According to In Numeri (2020, from ADEME data), global employment (direct and indirect jobs) has reached 3830 FTE (Full Time Equivalent) in 2020. The distribution for each sectors is presented as follow:

- to 660 FTE for shallow geothermal energy (residential sector) are estimated
- to 810 FTE for shallow geothermal energy (collective and tertiary sectors)
- to 2210 FTE for deep geothermal energy for heating applications
- to 150 FTE for deep geothermal energy for power generation

These are direct jobs associated with geothermal markets: manufacturing and installation (including preliminary studies) of equipment and operation, all types of maintenance (including production units).

These direct jobs correspond to the following activities: equipment manufacturing and installation, drilling, preliminary studies, operation-maintenance of production units and energy sales.

6. CONCLUSIONS

During the last years, the existing toolbox for geothermal energy deployment has been continuously improved, benefiting from a good cooperation between ADEME, BRGM, the French renewable energy syndicate (SER), the Ministry of Environment and *Caisse des Dépôts et Consignations*.

The announcement by the State of the end of oil heating in new buildings from the 1st January 2022 will open opportunities for geothermal applications as sustainable solutions in compliance with energy transition objectives. For GSHP, the industry is in favour of a remodelling of the administrative framework. And the sector still needs a strong boost in direction of individual housing installations to be competitive with air-air systems.

For direct uses, the development is continuing in Ile de France, but new ongoing projects are coming also in Aquitaine and Alsace. The sector will also benefit in the next five years from the numerous EGS cogeneration plants to be built in France onshore.

For the electricity generation sector, the work carried out by the professionals under the GEODEEP banner will allow to multiply by 4 the total installed power in the horizon to 2023. The creation of training schools and laboratories of Excellence focused on geothermal research is relatively new and will reinforce the high temperature sector deployment.

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Tables A-G

Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2021 *	17.2 *	127 *	136,211 *	500,100 *	0,013 *	0,025 *
Under construction end of 2021	0	0				
Total projected by 2023	17,2	127				
Total expected by 2028	42.2	307				
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2021 (indicate exploration/exploitation if applicable):					Under development: 2	
					Under investigation: 19	

* If 2020 numbers need to be used, please identify such numbers using an asterisk

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units **	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2021 pro-duction * (GWh_e/y)
Bouillante (Guadeloupe island, French West Indies)	Bouillante	1986 and 2004	2	O	1F + 2F	15.5 *	15,5 *	115 *
Soultz-sous-Forêts (Alsace region)	Soultz-sous-Forêts	2010	1	O	B-ORC	1,7 *	1,7 *	12 *
total						17.2 *	17.2 *	127 *

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
		2F	Double Flash	O	Other
R	Retired / decommissioned				

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** In case the plant applies re-injection, please indicate with (RI) in this column after number of power generation units

Table C: Present and planned deep geothermal district heating (DH) plants and other uses for heating and cooling, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for buildings		Geothermal heat in balneology and other **	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *		1 733 *		236 *		0		31 *
Under construction end 2021		328		0		0		0
Total projected by 2023		2 061		236		0		31 *
Total expected by 2028	4 – 5.2 TWh_{th}/yr							

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Note: spas and pool are difficult to estimate and are often over-estimated. For calculations of energy use in the pools, be sure to use the inflow and outflow temperature and not the spring or well temperature (unless it is the same as the inflow temperature) for calculating the energy parameters, as some pool need to have the geothermal water cooled before using it in the pools.

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commissioned	CHP **	Cooling ***	Geoth. capacity installed (MWth)	Total capacity installed (MWth)	2021 production * (MWhth/y)	Geoth. share in total prod. (%)
Occitanie	Blagnac 2 Ritouret	1976	N	N			14189*	
Nouvelle Aquitaine	Monte-de-Marsan	1976	N	N			13641*	
Ile-de-France	Montgeron	1981	N	N	9	13.1	11761*	68.6%
Nouvelle Aquitaine	Pessac-Saige Formanoir	1982	N	N	6.5	11.1	17000*	58.4%
Ile-de-France	La Courneuve Sud	1982	N	N	6.5	9.9	5660*	65.6%
Ile-de-France	Meaux Collinet	1982	N	N			12157*	
Nouvelle Aquitaine	Begles	1983	N	N			2272*	
Centre Val de Loire	Chateauroux	1983	N	N			Unknown	
Ile-de-France	La Courneuve Nord	1983	N	N	6.4	11.0	35804*	58.4%
Ile-de-France	Meaux Beauval 1	1983	N	N	15	22.9	37931*	65.6%
Ile-de-France	Meaux Hopital	1983	N	N	15	31.1	21571*	48.2%
Ile-de-France	Ris Orange	1983	N	N	11	11.0	23655*	100.0%
Nouvelle Aquitaine	Merignac - BA 106	1984	N	N	10	13.3	5968*	75.0%

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	CHP **	Cool ing ***	Geoth. capacity installed (MWth)	Total capacity installed (MWth)	2021 produc-tion * (MWhth/y)	Geoth. share in total prod. (%)
Ile-de-France	Epinay-sous-Senart	1984	N	N	15	22.9	35952*	65.6%
Ile-de-France	Meaux Beauval 2	1984	N	N			26212*	
Ile-de-France	Sucy-en-Brie	1984	N	N	15	15.3	27033*	98.3%
Nouvelle Aquitaine	Chasseloup-Laubat	1985	N	N	15	20.8	Unknown	72.0%
Ile-de-France	Champigny-sur-Marne	1985	N	N			53958*	
Ile-de-France	Chevilly-Larue	1985	N	N	14	20.7	49501*	67.6%
Ile-de-France	Creteil Mont Mesly	1985	N	N	20	61.0	59928*	32.8%
Ile-de-France	L'Hay-les-Roses	1985	N	N	14	20.7	49501*	67.6%
Ile-de-France	Maison Alfort 1	1985	N	N	11.8	20.0	38261*	59.0%
Ile-de-France	Villiers-le-Bel-Gonesse	1985	N	N	14	24.3	38435*	57.6%
Ile-de-France	Maison Alfort 2	1986	N	N	10.8	18.3	30062*	59.0%
Ile-de-France	Thiais	1986	N	N	11.6	12.3	34699*	94.0%
Ile-de-France	Alfortville	1987	N	N	14.8	16.5	42829*	89.9%
Ile-de-France	Fresnes	1987	N	N	10	16.6	47517*	60.2%
Ile-de-France	Villeneuve St-Georges	1987	N	N	17	33.9	15316*	50.2%
Ile-de-France	Melun l'Almont 2	1988	N	N	15	30.2	44728*	49.7%
Ile-de-France	Tour AGF Mirabeau	1990	N	O	1.03		13000*	
Ile-de-France	Orly 2 Le Nouvelet 2	2008	N	N	12.2	15.3	65530*	80.0%
Ile-de-France	Orly ADP	2011	N	N	12	50.6	15693*	23.7%
Ile-de-France	Coulommiers 2	2012	N	N	11.5	12.0	37501*	95.9%
Ile-de-France	Val-Maubuee	2012	N	N	11	12.6	48246*	87.3%
Ile-de-France	Aubervilliers	2013	N	N	11		2085*	
Ile-de-France	Chelles 2	2013	N	N	13.6	38.7	20959*	35.1%
Ile-de-France	Issy-les-Moulineaux	2013	N	N	3.48	6.8	10981*	51.0%
Ile-de-France	Le-Mee-sur-Seine 2	2013	N	N	11	16.6	53054*	66.1%

Table D1: Existing geothermal district heating (DH) plants, individual sites (continued)

Locality	Plant Name	Year commis-sioned	CHP **	Cool ing ***	Geoth. capacity installed (MWth)	Total capacity installed (MWth)	2021 produc-tion * (MWhth/y)	Geoth. share in total prod. (%)
Ile-de-France	Plessis Robinson	2013	N	O	5.35	25.5	8172*	21.0%
Ile-de-France	Neuilly-sur Marne	2015	N	N	11.8	19.7	43259*	60.0%
Occitanie	Mas Rouge - Galiere	2016	N	N	14.5	17.1	3500*	85.0%
Ile-de-France	Arcueil-Gentilly	2016	N	N	12.5	19.9	56832*	62.9%
Ile-de-France	Bagneux	2016	N	N	4.19		47867*	
Ile-de-France	Clichy-Batignolles	2016	N	N			17655*	
Ile-de-France	Rosny-sous-Bois	2016	N	N	10.5	12.8	51081*	82.0%
Ile-de-France	Tremblay-en-France 2	2016	N	N	11.8	14.8	39069*	79.6%
Ile-de-France	Villepinte	2016	N	N	14.6	18.3	37988*	79.8%
Ile-de-France	Bailly-Romainvilliers	2017	N	N	19.5	19.5	49073*	99.8%
Ile-de-France	Dammarie-les-Lys	2017	N	N	14.6	15.6	35111*	93.5%
Ile-de-France	Grigny II	2017	N	N	10.5	13.8	66676*	76.2%
Ile-de-France	Ivry-sur-Seine 2	2017	N	N	11.2	21.5	35660*	52.2%
Ile-de-France	Le Bland Mesnil 2	2017	N	N	10.8	18.8	23445*	57.4%
Ile-de-France	Villejuif	2017	N	N	15.5	22.9	49501*	67.6%
Nouvelle Aquitaine	Archachon (lycée)****	2018	N	N			Unknown	
Ile-de-France	Bonneuil-sur-Marne 2	2018	N	N	12.3	13.1	33518*	93.8%
Nouvelle Aquitaine	Teste de Buch****	2018	N	N			Unknown	
Ile-de-France	Vigneux-sur-Seine 2	2019	N	N	13.1	15.7	31141*	83.5%
Ile-de-France	Cachan 3	2020	N	N	12.5	17.5	41292*	71.5%
TOTAL					**569.45**		**1'733'000**	**68.2%**

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If the geothermal heat used in the DH plant is also used for power production (either in parallel or as a first step with DH using the residual heat in the brine/water), please mark with Y (for yes) or N (for no) in this column.

*** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

**** Hydrocarbon and geothermal heat co-production plants

Table D2: Existing geothermal large systems for heating and cooling uses other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MWth)	Total capacity installed (MWth)	2021 produc-tion * (MWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Nouvelle Aquitaine	Pessac-Stadium	1962	N			1082*		
Auvergne-Rhone-Alpes	Aigueperse	1979	N			11512*		
Occitanie	Lodeve St Fulcran	1979	N			586*		
Occitanie	Lodeve Grand Champ	1980	N			1744*		
Nouvelle Aquitaine	Mios Le Teich	1984	N			21440*		
Occitanie	Pezenas	1984	N			11576*		
Nouvelle Aquitaine	Gujan Mestra La Hume	1985	N			2004*		
Nouvelle Aquitaine	Hagetmau	1986	N			2793*		
Occitanie	Nogaro 2	1986	N			18494*		
Nouvelle Aquitaine	Bordeaux Meriadeck	1987	N			8025*		
Nouvelle Aquitaine	Saint-Paul-Les-Dax 1 (Lac de Christus)	1996	N			897*		
Nouvelle Aquitaine	Parentis****	2000	N			Unknown		
Nouvelle Aquitaine	Jonzac	2002	N			4463*		
Grand Est	Rittershoffen	2017	N			182000*		
TOTAL						**266'000**		

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** If cold for space cooling in buildings or process cooling is provided from geothermal heat (e.g. by absorption chillers), please mark with Y (for yes) or N (for no) in this column. In case the plant applies re-injection, please indicate with (RI) in this column after Y or N.

Table E1: Shallow geothermal energy, geothermal pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2021 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2021 *	205'000*	3075*	4770*	4100*		
Of which networks **						
Projected total by 2023						

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Distribution networks from shallow geothermal sources supplying low-temperature water to heat pumps in individual buildings ("cold" DH, Geothermal DH 5.0 etc.)

Table E2: Shallow geothermal energy, Underground Thermal Energy Storage (UTES)

There is currently no shallow geothermal UTES in France.

Table F: Investment and Employment in geothermal energy (2018)

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	70*	250*	100*	300*
Geothermal direct uses	50*	400*	50*	400*
Shallow geothermal	150*	1000*	200*	1200*
total	**270***	**1650***	**350***	**1900***

* If 2020 numbers need to be used, please identify such numbers using an asterisk

** Expenditures in installation, operation and maintenance, decommissioning

*** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education (not applicable)

No information ???