Geothermal Energy Use, Country Update for France

Christian Boissavy[1], Laurianne Henry[3], Albert Genter[4], Armand Pomart[1], Philippe Rocher[2], Virginie Schmidlé-Bloch[1]

[1] AFPG – 77, rue C. Bernard Paris 75005 - France

[2] BRGM – 3, avenue C. Guillemin 45060 Orléans Cedex – France

[3] ADEME – 5 Avenue de Tsukuba, 14200 Hérouville-Saint-Clair – France

[4] ES Géothermie – 26 Rue du Président Wilson 67000 Strasbourg - France

Christian.boissavy@orange.fr

Keywords: Electricity generation, EGS, heating and cooling production, geothermal HP, R&D, energy targets 2030 PPE, France

ABSTRACT

The last market study (2016) carried out in France by the French Association of Geothermal Professionals regarding the geothermal domain has demonstrated that the installed power for heating and cooling reaches 2500 MWth. Nearly 600 MWth are related to the exploitation of the deep reservoirs in the Paris area but the main part is linked to the recent and strong development of shallow geothermal resources in the whole country. The market for single housing using vertical geothermal probes is dramatically decreasing since 2009 due to the competition with natural gas and tax credit at 30% for geothermal without any bonus compared with efficient gas boiler neither air-air heat pumps. The market for single housing has been divided by 7 in 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 offices buildings is growing constantly. The direct uses are concentrated mainly in Ile de France, the geothermal doublet construction restarted with the support of the Heat funds managed by ADEME and the two last years, more than 20 new deep wells have been drilled in Ile de France. The main barrier remains the energy calculation rules for new buildings (RT2012) which still encourage gas. In 2023, the market will reach 3000 MWth installed; if ecologically driven, the target objectives at 3500 MWth could be largely attained. For electricity generation no more installations have been commissioned even the Soultz-sous Forêts plant has been revamped. The Bouillante plant has been sold by BRGM to ORMAT mid-2016 and the plant capacity will be upgraded from 15 to 25 MWe in the next years. Two geothermal are in drilling operations (doublets between 3500 and 5000m depth) around Strasbourg with successful preliminary tests, in order to co-generate electricity (10 MWe) and heat (20 MWth).

1. ELECTRICITY GENERATION

France can be divided into two separated items using deep geothermal resources: electricity production from volcanic reservoirs and electricity production from EGS reservoirs.

1.1 Electricity production from volcanic reservoirs

For volcanic reservoirs, it turns out that only the Bouillante geothermal plant located in Guadeloupe belonging to ORMAT is operating and producing 15MWe. A MT exploration campaign has been carried out on the Bouillante geothermal field in order to understand the distribution of the resource namely for extending the geothermal field.

The plant is producing about 85 GWh per year of electricity which correspond to about 5% of the Guadeloupe island needs. An exploration permit has been submitted in 2017 in order to drill two new geothermal wells at depth in between 1000 and 1600m. The additional power expected is around 10 MWe and if successful this new plant using the ORMAT ORC technology will be on line in 2022.
There are additional exploration works in Martinique as well as in La Réunion Island.

1.2 Electricity production from EGS or deep geothermal resource

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 et Genter, 2018). The main geothermal projects running on the French side of the Upper Rhine Graben (Alsace) are the worldwide known Soultz-sous-Forêts power production plant and the most recent Rittershoffen heat plant. In parallel to electricity production of this site; several sub-areas are in development such as the Strasbourg area with the drilling of deep geothermal wells at Vendenheim and Illkirch. Moreover, a large exploration phase is on-going for Electricity de Strasbourg with the acquisition of the first 3D seismic survey for deep geothermal energy in France that was done in

Northern Alsace in summer 2018 (Richard et al., 2019).

The Soultz site has, been successfully commissioned as industrial geothermal site in 2016 electricity thanks to a geothermal fluid at temperature higher than 150°C Since the geothermal water shows a high salinity (TDS around100 g/L), the heat of the geothermal water is exploited via heat exchangers by an ORC (Organic Rankine Cycle) unit of 1.7 MWe gross power (Figure 1). 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 5km 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 1: 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 geothermal Soultz-sous-Forêts plant availability reached 90% of the time, including several weeks of planned maintenance stop.

1.3 Recent development of deep geothermal projects in Northern Alsace

Several new geothermal sites are under development in the area of Strasbourg such as the Vendenheim project, the Illkirch project and in Northern Alsace.

Development in this area is going further with drilling of new wells with the same objectives for electricity and heat production, 6MWe and 40MWth respectively. Thus from 2018/2019, Fonroche Geothermie drilled two deep deviated wells at 5.3km in Vendenheim (suburb of Strasbourg) for targeting local normal faults at the interface between the sedimentary formations and the Paleozoic crystalline basement (Figure 2).

Figure 2: Vendenheim drill site in Alsace

Électricité de Strasbourg is currently developing a new deep geothermal project in the southern part of the city of Strasbourg, in the town of Illkirch-Graffenstaden. The main objective of this project is to produce 25 MW heat, injected into a neighbouring district heating network and to produce 3MWe of electricity in the summer time. Extensive exploration works were carried out in 2013-2016: gravimetric surveys, aeromagnetic survey, reprocessing of vintage 2D seismic data, new 2D seismic data acquisition (35km in 2015) and all available data, including numerous oil exploration well data, could be integrated to get a detailed picture of the deep underground in the vicinity of the project.

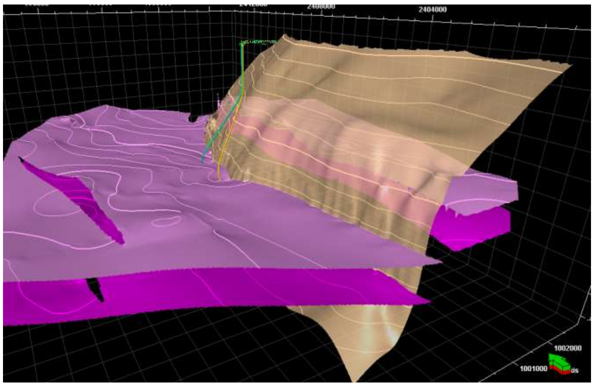

Figure 3: 3D model of the local normal fault representing the geothermal target of Illkirch (Baujard et al., 2018)

As in Northern Alsace, an appropriate environmental monitoring set-up was installed, including permanent and temporary seismic monitoring stations (5 permanent and 9 temporary), a GPS receiver on the drill site, noise emission measurements and 4 piezometers to control shallow aquifer water level and quality during drilling operations. Both wells target a fractured/faulted zone at the interface between the Permo-Triassic clastic sandstone sediments (Buntsandstein/Permian) and the top Paleozoic crystalline basement at a vertical depth of 2750 m (Figure 3). Expected temperature is 150°C and a nominal flow rate of 70 l/s. Well deviations plans are 3D in order to hit the geological target with an appropriate azimuth and inclination (Figure 4).

Figure 4: Illkirch drill site in Alsace (Electricité de Strasbourg)

As Électricité of Strasbourg is owner of 3 contiguous exclusive exploration licenses (over 400 km²) and 2 concessions (40 km²) for deep geothermal projects in Northern Alsace (France), a large 3D seismic campaign covering an area of 180 km² and partially overlapping these licenses, (Figure 5) has been acquired during summer 2018 in order to get a detailed litho-structural image of the sedimentary cover of the basin and to apprehend in 3D the geothermal reservoir. The target is the fault structure till the top basement. Processing and interpretation of this unique dataset will be done by the end of 2019 in order to define the emplacement of future geothermal wells.

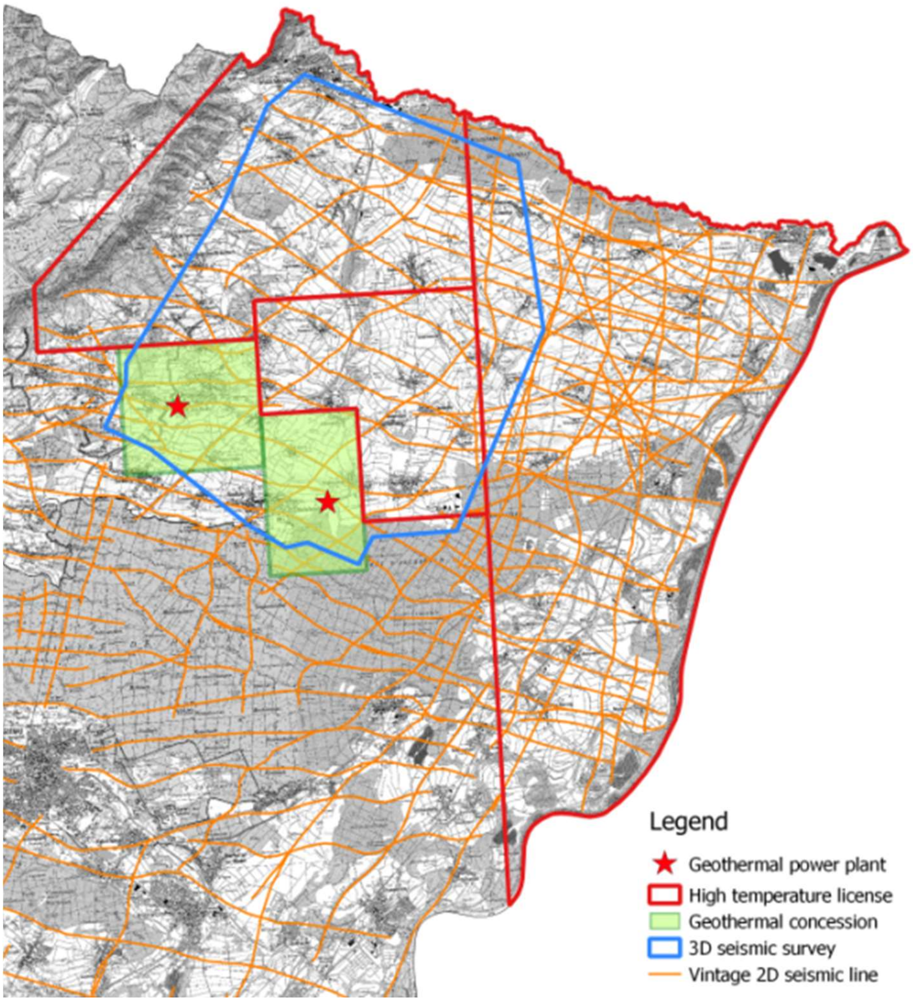

Figure 5: Regulatory and geophysical context of the 3D seismic exploration survey in Northern Alsace (Richard et al., 2019)

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 a strong common action to promote the French geothermal offer abroad, the cluster is achieving the creation of one risk mitigation funds.

This fund called GEODEEP SAS will be operational Q2 2019 after the green light given by the European Commission. The fund is based on public/private financing and aims at mitigating the geological risk of geothermal resource deployment in France mainland. It will compensate the operator in case of exploration drillings failures. This Fund lowers the financial risk to secure developers and industrials in their investment commitment.

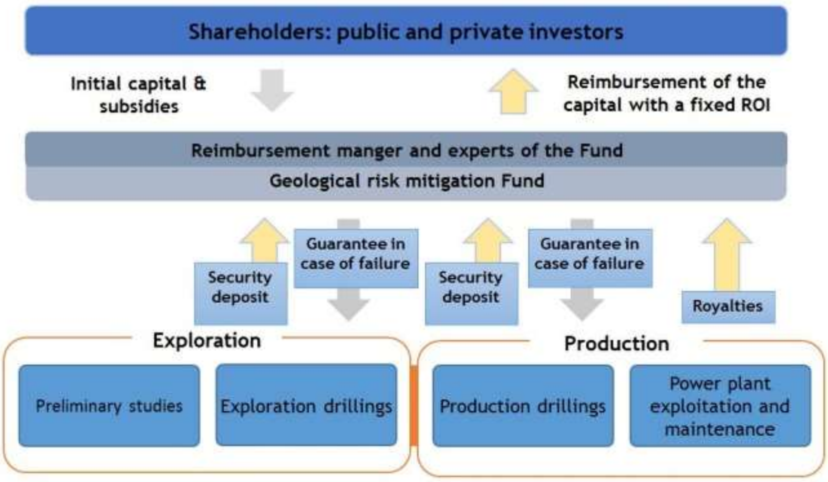

Figure 6: Organization of the fund GEODEEP SAS

Geothermal electricity is expected to **reach 53 MW** in France in 2030. There are two main issues: the first is to provide French islands (French West Indies and La Réunion) with a decarbonized energy, replacing the actual thermal electricity production, at a reasonable cost; moreover, the 2030 objective for these islands is 50% of renewables instead of 23% at a national level, because the current production is mainly made from fossil fuel. The second objective is to acquire a good experience in EGS projects to develop this energy in a larger way in 2050.

Finally, the feed in tariffs for geothermal energy are disappearing to follow the European Union regulations, AFPG negotiated the new tariff system which is now made of a bonus versus the market price. Normally, the system will ensure for the next years a guaranteed tariff equivalent to about 250€/MWh close to same dispositive in force in Germany. The PPE (Programmation Pluriannuelle de l'Energie) at the moment is not yet adopted but there is a negotiation to maintain the bonus after the completion of projects already started.
The more important evolution is the multiplication of many permits allocated to 3 to 4 different companies in order to cogenerate electricity and heat in the next 5 years. At the moment, 12 permits have been awarded by the French Ministry of Environment, the permit map in on figure 7.

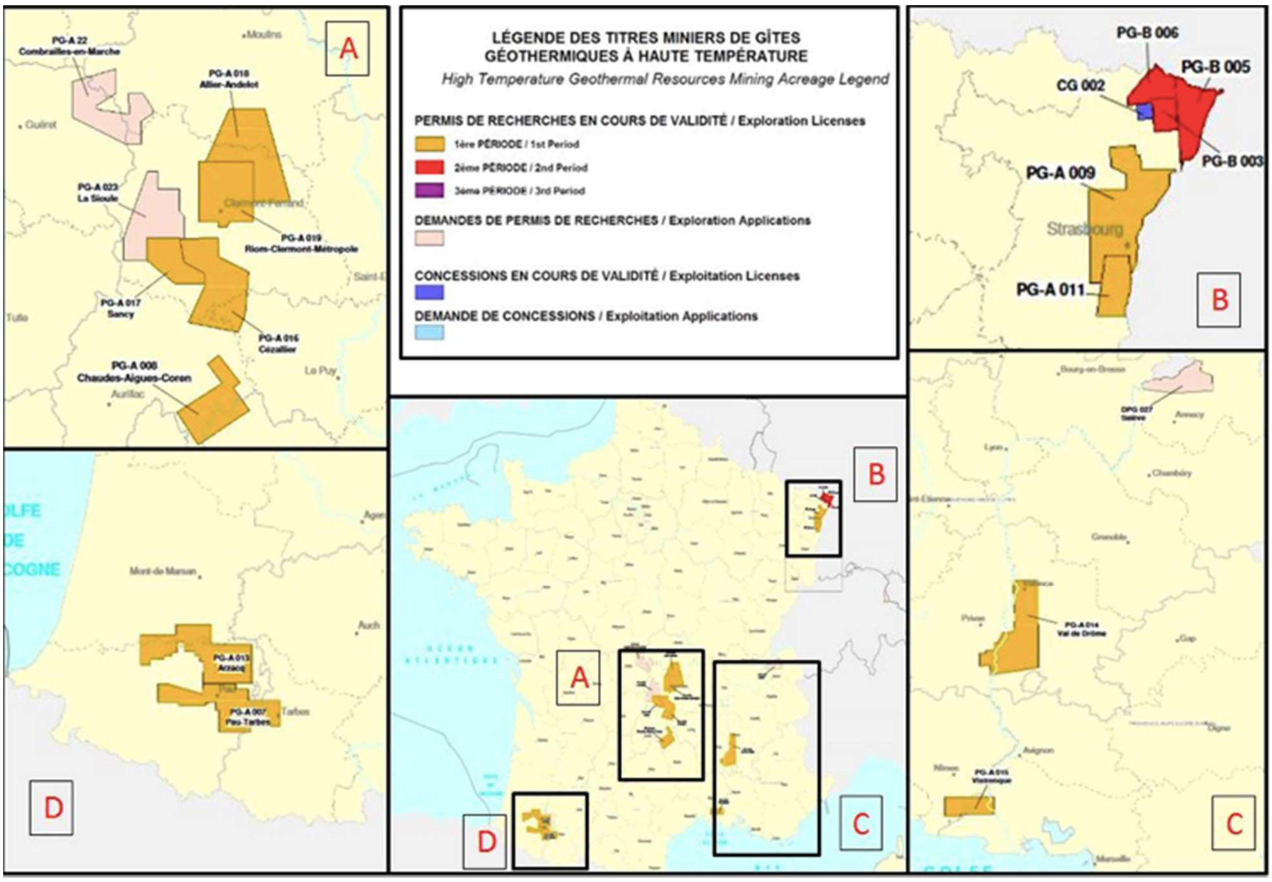

Figure 7: Permit maps (Ministry of Environment January 2016: A : Massif Central and Limagne ; B : Alsace ; C : Couloir Rhodanien et Haute Savoie ; D : Sud-Ouest

2. HEATING AND COOLING PRODUCTION

The establishment of a strategic geological road map in 2011 by ADEME (the French Agency for Environment and Energy) gave 2020 targets for the expectation of a geothermal heat production multiplied by 5 between 2006 and 2020.

A new energy programming named PPE defines new objectives and measures to comply, until 2030, this plan will be officially adopted Q3 2019 with the following figures in TWh calculated for the geothermal sector.

Production of geothermal sector/years [in TWh]	2016	2023	2028
Heat and cold without HP	1.6	2.9	4 to 5
Heat and cold using HP	3.0	4.0	5 to 7
Total	4.7	7.5	9 to 12

Figure 8: Heat and cold production (HP: Heat Pump)

2.1 Direct uses – Geothermal District heating (GeoDH)

The direct use of geothermal heat is quite well developed in France. The 2018 production is estimated at 1700 GWh and represents about 74 plants in France (details on tables D1 and D2).

The Paris basin has five large aquifers, including the Dogger which has the largest number of low-energy geothermal operations in the world, with 46 operations providing geothermal energy to about 6-7 % of the total population of 11 millions of people. The geothermal use is limited to collective heating and cooling applications. A conventional operation in the Paris region allows the heating and the production of sanitary hot water of approximately 4,000 to 6,000 housings. The Dogger 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 (between 1,600 and 1,800 m).

Only four new geothermal doublets have been created from scratch, the last 3 years: 2 tapping the Dogger aquifer (Grigny and Dammarie Les Lys and 2 tapping the Albian sands (Saclay). The other drillings have been realized to revamp old installations creating new doublets such as in Cachan (new doublet using the horizontal drilling technology in geothermal with section in the reservoir up to 800m) and triplets. (Figure 10).

The strategy in that case is in general to drill a new production wells in big diameter in order to upgrade the flowrate of the installation from 200 - 250 to 300 - 350 m^3/h. The following sites have been revamped: La Courneuve Nord, Villiers Le Bel, Vigneux, Thiais and Bonneuil.

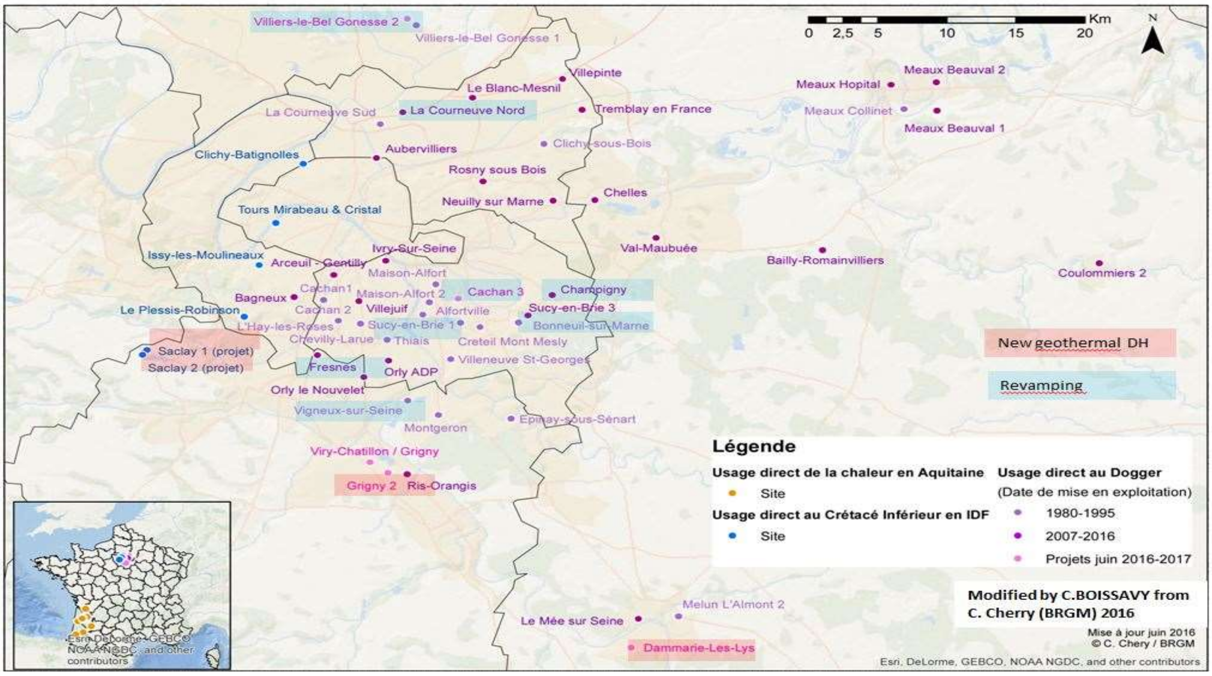

Figure 9: Overview of the geothermal plants running in the Paris basin end of 2018

The district heating networks supplied by the Dogger geothermal resource are mainly exploited by private companies such as Dalkia (EDF Group), Cofely (ENGIE Group), IDEX Energie and Coriance, but also by local public-private ventures (Sociétés d'Economie Mixte). They have been operated for more than forty years and for many of them have thus been fully amortized, with an average availability rate still approaching 95%. The oldest of these installations is located at Melun-l'Almont, commissioned in 1969.

Recent technologies have been developed to exploit the Dogger resource: the use of horizontal drilling and the deployment of composite materials in order to cope with corrosion problems.

Sub-horizontal geothermal wells in Cachan (Val de Marne)

GPC IP successfully tested, in 2018 the second sub-horizontal geothermal (injection) well, GCAJ2 in Cachan site, thus validating this innovative well architecture, initiated on the previously drilled production well. Well design features two 1001 (GCAH1) / 1 005 m (GCAH2) long, 87 to 93° slanted, 8"1/2 open hole drains, drilled in the Dogger at 1 550 m true vertical (TVD) and 3 000 m drilled (mD) depths. Targeted at 450 -500 m^3/h production rate, the new doublet, managed by a DALKIA (EDF Group) and the municipality of Cachan replace two existing, ageing (34 years) doublets rated 180 and 170 m^3/h respectively.

The concept raises considerable interest among geothermal operators reclaiming areas undergoing moderate to poor reservoir performance.

New sophisticated technologies while drilling has been deployed to secure optimum project achievement. These recorded parameters while drilling linked to the conceptual reservoir model, made it possible to (re)adjust in real time the well trajectory. Within the context of the Paris Basin Dogger carbonate platform, geochemical monitoring, based on (XRF, X Ray fluorescence) elemental and (XRD, X Ray diffraction) mineralogical analyses on cuttings sampled while drilling, was implemented with a view to appraise varying reservoir properties in response to facies changes and diagenetic impacts on porosity/permeability trends.

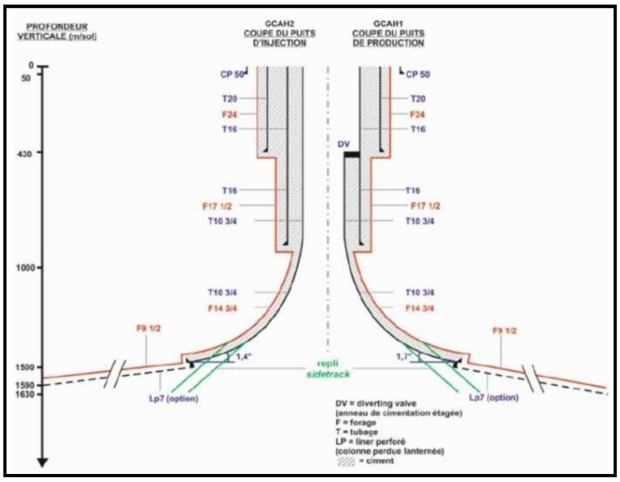

Figure 10: Well concept in Cachan (GPG IP)

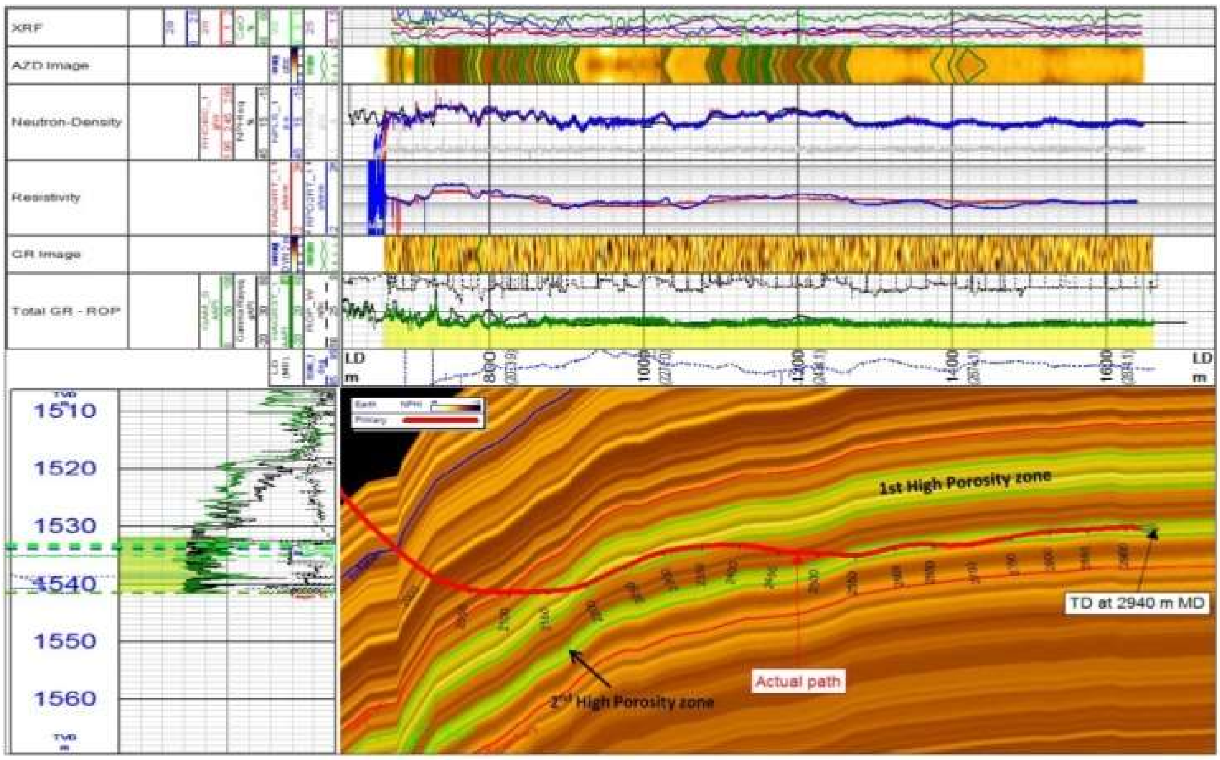

Figure 11: Wireline log (NMR-CMC and Sonic dipole porosity, permeability tools) correlation with drain productive segments (GPC IP)

Use of composite casings in Bonneuil sur Marne

In 2018 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 has been already tested in Villeneuve la Garenne in1976, in Melun still in operation, in La Courneuve-Sud where the pumping chamber was equipped partly with a composite casing extracted 13 years after and showing no evolution and more recently in 2015 by CFG in Chevilly-Larue and L'Hay Les Roses to reline 2 production wells with an excellent result. This technology can be considered as an interesting alternative to standard steel casings in order to facilitate high production flow rates and to avoid corrosion and scaling.

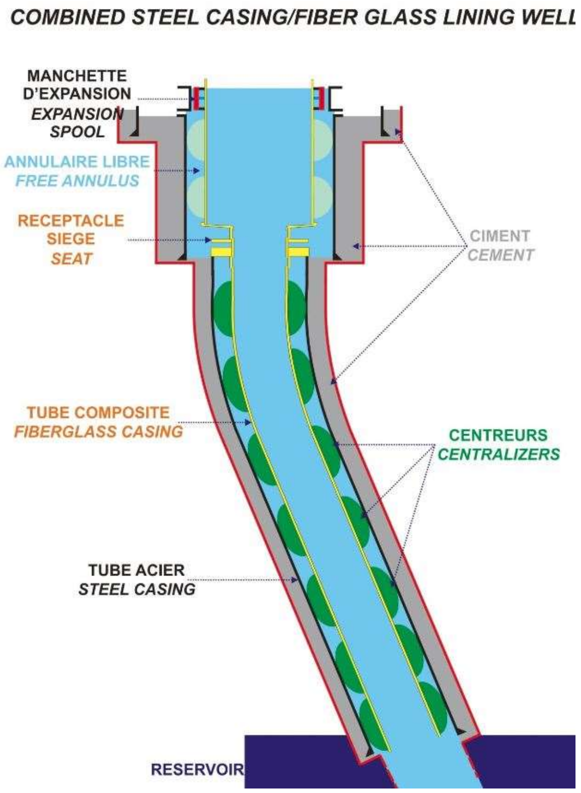

Figure 12: Concept of composite casing installed in Bonneuil (GPC IP)

Figure 13: Composite casing on the platform in Bonneuil (GPC IP)

Recently Albian and Neocomian aquifers (Early Cretaceous) have been used for geothermal district heating and cooling application but with big power heat pumps and for smaller project in term of housings. There are now 6 doublets using this resource: Paris Mirabeau, Issy Les Moulineaux, Le Plessis Robinson, Paris-Batignolles, Saclay 1 and Saclay 2. In 2020, a new drilling will be completed in Saint-Germain-en-Laye with the double objective to produce heat and tap water.

The second zone for direct use is **Aquitaine** with around 15 single production wells: these operations have been realised in the beginning of the 1980s and this technical situation (no reinjection,) was chosen as the geothermal water can be discharged at the surface. The regional geology is moreover quite complicated and the aquifers to be produced are made of sands and sandstones inter-bedded with clays, in these conditions, reinjection becomes a difficulty. In addition, the temperature is lower than in the Paris basin which makes the profitability of a doublet harder to achieve. Nowadays, secondary uses of the resource, as irrigation and agricultural uses are also investigated.

A new plant with be launched mid 2019 in the right bank of the Garonne river in order to feed a district heating system constructed by Cofely Services. The target will be the limestones of Jurassic which has been never drilled under the Bordeaux sector. If the limestones are not producing the doublet will be reoriented to produce from the already exploited reservoir of the Bordeaux area made of sandstones in the Cenomano-Turonien.

Heat production from a crystalline reservoir

Based on EGS technology, another deep geothermal energy project located at Rittershoffen in northern Alsace has been commissioned in 2016 .This heating plant, located at less than 10 km from Soultz, has been designed for industrial need purpose of a biorefinery. With an installed capacity of 24 MW thermal, the geothermal plant provides superheated fluid to an agricultural industry for their processes 24/7, covering 25% of their energy needs with low environmental impact. With a flow rate of at 252 m^3/h pumped with a line shaft pump, the geothermal fluid is discharged on surface at 168°C and reinjected at 70°C into the granitic fractured reservoir (Baujard et al., 2018). From 2017 to 2018, the availability of Rittershoffen geothermal plant was close to 90%.

Figure 14: The Rittershoffen geothermal heat plant (source: ECOGI)

2.2 Geothermal heat pumps

The French geothermal heat pump market dedicated to individual housing shows a decrease since 2008 (Figure 15). In 2018, the decrease has been stabilized but the market which is facing the competition of air/water and air/systems is anticipated to stay at that level.

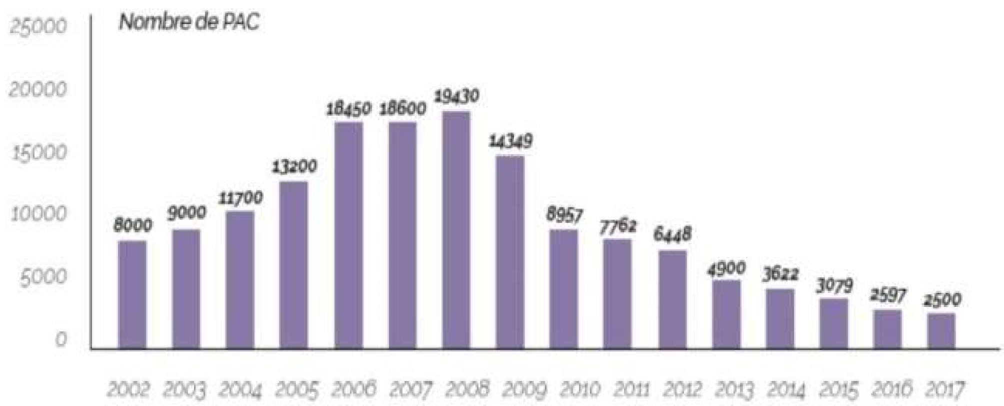

Figure 15: Sales evolution for geothermal HP in individual housing (2002-2017)

The figure 16 illustrates this competition with geothermal HP representing only 2/1000 of the installations completed in 2018 for heating purposes.

Systems/years	2015	2016	2017	2018	2017/2018
Biomass boiler	11 380	9 720	11 025	10 900	=
Geothermal HP	3 079	2700	2 489	2 497	=
Air HP	405 680	476 645	487 090	570 000	+ 17%
Fossil fuels boiler	594 000	600 000	631 000	544 000	-15%
Total	1 014 870	1 089 460	1 131 615	1 127 400	=

Figure 16: Comparison between heat emitter's sales from 2015 to 2018

The French regions which are leaders in this market of the geothermal installations (individual housing and collectives) except horizontal geothermal are Ile de France, Rhone-Alps, Midi-Pyrenees, Brittany, Alsace and Pays de la Loire. It is shown on figure 17.

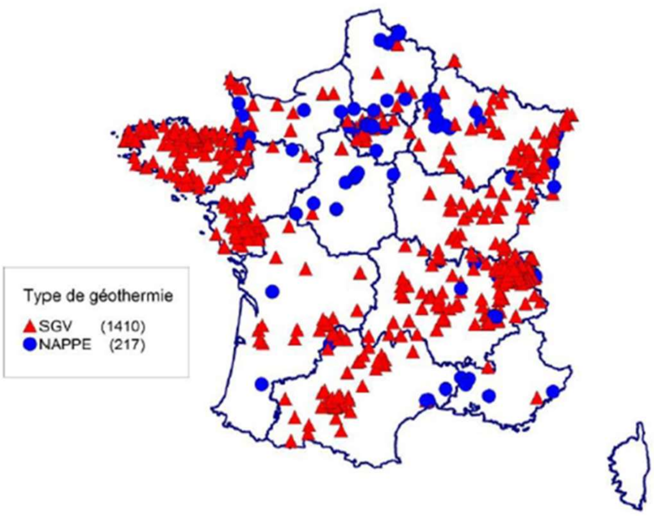

Figure 17: Number of Geothermal wells declared from 2015 to 2017 (BRGM)

The distribution of different techniques at the scale of France is: 5% for single housing open loop, 25% for collective open loop based on water, 25% for individual vertical exchanger and 45% for collective vertical exchanger. Horizontal loops are still representing ¼ of the geothermal market for individual housing and thermo-active foundations remain at the moment largely underdeveloped.

For individual housing, the state efforts have been reduced and geothermal GSHP benefits from a tax reduction representing 30% of the CAPEX. The problem is that this tax advantage which is also distributed for the installation of a new and efficient oil and gas boilers, air-air heat pumps, and biomass burners etc. The French policy is very supporting the geothermal collective housing but neglects the individual housing deployment.

For vertical heat exchanger, AFPG determined distributions between installations in new building or renovation. For private housing installations, this is 40% for new and 60% for renovation. For collective installations, this is 55% for new and 45% for renovation.

For the collective buildings (housings, office, hospital, municipality buildings), a study published by Observ'ER (2018) shows there is a 10% increase in the market of GSHP for this sector. It is around 600 plants installed in France in 2018. The new concept of low temperature geothermal loop is now in application in several towns with average installed power between 1 and 4 MW.

Figure 18 shows that the geothermal facilities for individual housing are always in favor for the regions Bretagne and Auvergne-Rhône-Alpes.

3. GEOTHERMAL SECTOR DEVELOPPING STRUCTURES

3.1 Schemes in supporting geothermal energy industry

France has developed different schemes to help the development of geothermal sectors. 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 2000m 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).

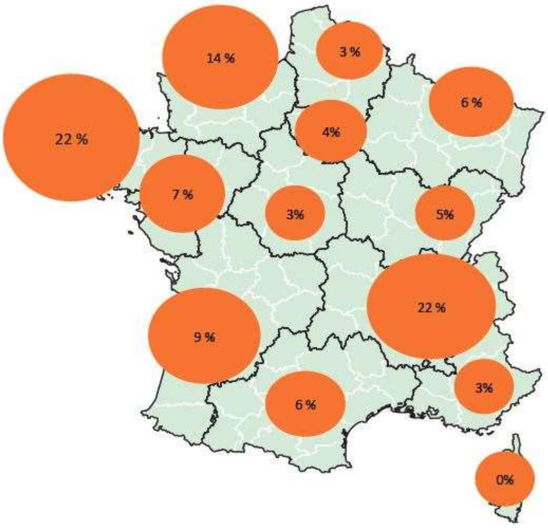

Figure 18: GSHP for individual housing in 2017: geographical distribution

For electricity generation, the cluster Geodeep is building in cooperation with ADEME, and Caisse des Dépôts and Consignations), a double Fund created first for EGS technology and for volcanic projects in a second step. For deep aquifers used for heating production, the guarantee (SAF Environment) is existing since now 36 years and has proved is efficiency. For shallow drilling rangingbetween surface and 200m 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) was created in 2009 for collective housing, tertiary, industry and agriculture. At the end of 2017, 495 geothermal installations (for district heating and geothermal heat pump) have been subsidized by the Renewable Heat Fund.

A total amount of 141 M€ has been given to the new plants representing an additional heat production of 1,75 TWh of heat/year. On figure 19, the repartition by regions of these subsidies recorded by the number of facilities supported between 2009 and 2018 is shown.

3.2 French regulation

Geothermal energy is ruled by the French Mining Code and subject to declaration or authorization in accordance with the figure 20.

About the shallow thermal energy, a new law has been adopted on January 2015 and applications measures orders are now operational since July 2015.

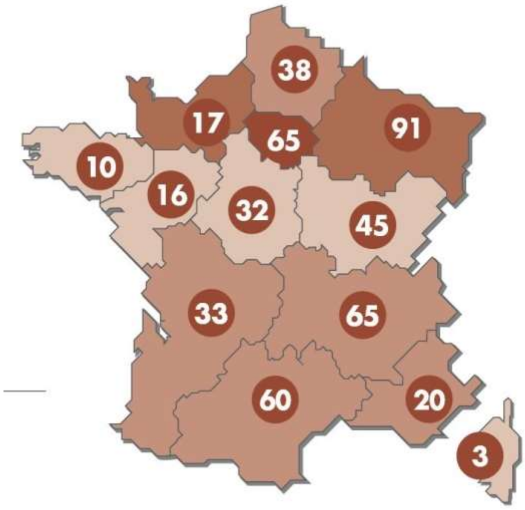

Figure 19: Production and number of geothermal facilities supported by the Renewable Heat Fund between 2009 and 2017 (ADEME, 2019)

- **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.
- **qualification of drilling companies** working on shallow geothermal energy systems: obligation to perform drillings by qualified companies (RGE QualiForage)

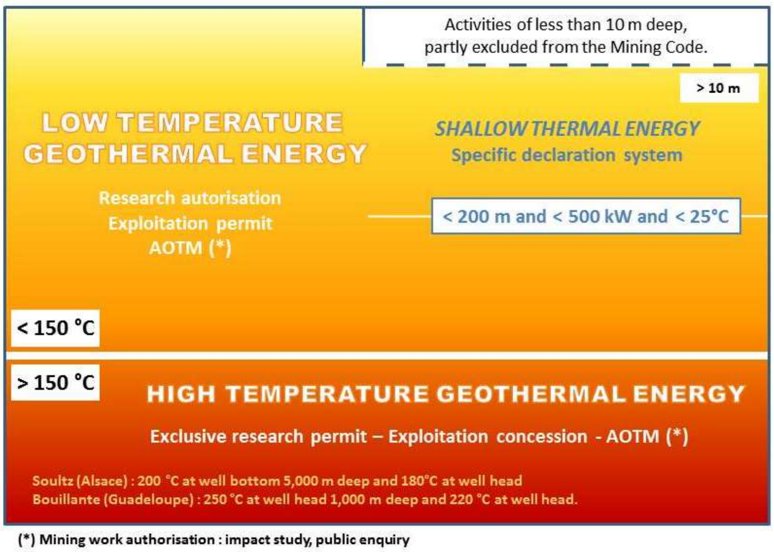

Figure 20: Synthesis of the French regulations for different geothermal exploitations (BRGM, 2015)

- **cartography of statutory zones**. (Figure 21)
  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.

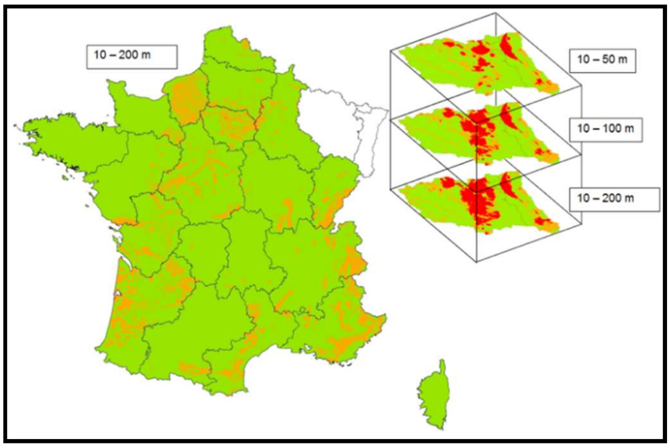

Figure 21: Map of France of statutory zones relating to Shallow geothermal energy for doublets for groundwater, details by depth for regions Lorraine and Alsace (BRGM, 2015)

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;
- the FONGEOSEC project in two areas of the French mainland, the "Pau area" (Aquitaine basin) and the "Strasbourg area" (Rhine basin), coordinated by the Fonroche Géothermie company.

Respectively, these projects benefit of 43 and 82 M€ funding and started on December 2014 and April 2015.

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 2M€, 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 Aquitaine, 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

In 2015, the total market for geothermal energy in France represented 388 M€, compared to 282 M€ in 2013 (+ 38 %). Direct jobs for all sectors (electricity generation, direct uses and geothermal heat pumps) increased from 1740 FTE (Full Time Equivalents) to 2290 FTE between 2013 and 2015 (ADEME, 2017). 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).

According to EurObserv'ER (2016, from ADEME data), global employment (direct and indirect jobs) has reached 2600 FTE in 2014 and 2850 FTE in 2015.

The most recent study dealing with market and employment for geothermal energy in France, driven by the In Numeri society (in progress, to be published by ADEME in 2019), reports that direct employment, which was of 2050 FTE in 2014, is estimated at 2340 FTE in 2016 (semi-definitive estimate) and 2017 (provisional estimate).

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 3 years, the existing tool box for geothermal energy deployment has been continuously improved benefiting from a good cooperation between ADEME, BRGM, Ministry of Environment and Caisse des Dépôts et Consignations.

For GSHP, the administrative framework has been revamped and will allow now a fluent development of the technology, in particular for close loop systems. All the actors of the sector (engineering companies, installers and drillers) need to be certified by national label beginning of 2007 to guarantee a top level quality of the installations. However, the sector needs a strong boost in direction of individual housing installations to be competitive with air-air systems.

For direct uses, the development is continuous in Ile de France, but new ongoing project are coming also in Aquitaine and Alsace. The sector will also benefits 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 at the horizon 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.

REFERENCES

ADEME (2017) - Marchés et emplois dans le domaine des énergies renouvelables. Situation 2013-2015 et perspectives à court terme. Report (2017).

Baujard C., Genter A., Cuenot N., Mouchot J., Maurer V., Hehn R., Ravier G., Seibel O., Vidal J.: Experience from a successful soft stimulation and operational feedback after 2 years of geothermal power and heat production in Rittershoffen and Soultz-sous-Forêts plants (Alsace, France), Geothermal Resource Council, GRC2018, October 14-17, Reno, Nevada, USA, 2241-2252.

Boissavy C., Grière, O. History and detailed results for the Short and Long term guarantee system for Geothermal Heating Operations using deep aquifers set up in France in the early 1980's- Report ADEME (2017) 48p.

Boissavy C.,Brange C., Laplaige P., Rocher P., : Geothermal Energy use, Country Update for France- European Geothermal Energy Congress 2016 Strasbourg, 19-24 Sept 2016

EurObserv'ER: The State of Renewable Energies in Europe, 2018 – 18th edition - 147 p

Observ'ER : Suivi du marché et des prix du secteur des PAC individuelles. May 2018.

Maurer V., Cuenot N., Richard A., Grunberg M.: On-going seismic monitoring of the Rittershoffen and the Soultz EGS projects (Alsace, France). 2nd Induced Seismicity Workshop, 14-17 March 2017, Schatzalp, Switzerland.

Richard A., Gillot E., Maurer V., Cuenot N., Klee J.: Upper Rhine Graben: the largest exploration by 3D seismic reflection, European Geothermal Congress, EGC 2019, 11-14 June 2019, The Hague, The Netherlands.

Ungemach P., Antics M., Davaux M.: Subhorizontal well architecture and geosteering navigation enhance well performance and reservoir evaluation- Proceedings, 44th Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 11-13, 2019

Vidal J., Genter A.: Overview of naturally permeable fractured reservoirs in the Upper Rhine Graben: insights from geothermal wells, Geothermics 74, (2018), 57-73.

Acknowledgements

The authors are grateful to the GEIE Exploitation Minière de la Chaleur and ECOGI to access to the Soultz and Rittershoffen information respectively and the GPC IP Company for illustrations related to horizontal drilling in Cachan and composite casing experimentation in Bonneuil. The participation of ADEME Ile de France to evaluate the existing geothermal production has been also a very positive asset.

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 2018 *	16.7*	102*	130 761*	529 400*	0,013%*	0,019%*
Under construction end of 2018	10					
Total projected by 2020	26.7					
Total expected by 2025	98.7					
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2018 (indicate exploration/exploitation if applicable): 15 (Exploration) and 2 (Exploitation)					Under development:	
					Under investigation:	

* If 2017 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)	2017 pro-duction * (GWh_e/y)
City of Bouillante (Guadeloupe island, French West Indies)	Bouillante	1986 and 2004	2	O	1F and 2F	15*	15,0*	90*
Soultz-sous-Forêts (Alsace region)	Soultz-sous-Forêts	2010	1	N	B-ORC	1,7*	1,5*	12*
total						16,7*	16,5	102*

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)
R	Retired	2F	Double Flash	O	Other

* If 2017 numbers need to be used, please identify such numbers using an asterisk

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 2018 *	586,16	1651,6	24*	110*	0*			21*
Under constru-ction end 2018	30		0*		0*		0*	
Total projected by 2020	747,16		30*					
Total expected by 2025	1658,16		30*					

* If 2017 numbers need to be used, please identify such numbers using an asterisk

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

Locality	Plant Name	Year commis-sioned	CHP	Cooling	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2018 produc-tion (GW_{th}/y)	Geoth. share in total prod. (%)
Ile de France (75)	Paris Nord-Est (CPCU)	2010	N	O	6.5	8777	20457	43%
IDF (75)	Paris Tour Mirabeau	1989	N	O	3.2	3712	7424	50%
IDF (75)	Paris Batignolles	2016	N	N	5	4983	?	
IDF (77)	Chelles	1987	N	N	7	32305	64315	50%
IDF (77)	Coulommiers	1981	N	N	11.5	35591	36097	98%
IDF(77)	Dammarie-les-Lys	2018	N	N	10	7241	42007	17%
IDF (77)	Le Mée sur Seine	1978	N	N	11.7	47513	64884	73%
IDF (77)	Lognes-Torcy (Val Maubuée)	2012	N	N	13.5	41339	48363	85%
IDF (77)	Meaux Beauval Collinet (8 wells)	1983	N	N	17.6	73485	127972	57%
IDF (77)	Meaux Hôpital	1983	N	N	5.6	27605	49973	55%
IDF (77)	Melun l'Almont	1969	N	N	10	49050	77797	63%
IDF (77)	Val d'Europe, Village Nature	2016	N	N	19.5	17073	?	
IDF (91)	Epinay sous Sénart	1984	N	N	8.42	28180	56752	50%
IDF(91)	Grigny	2018	N	N	10	0	0	
IDF (91)	Montgeron	2018	N	N	12	0	0	
IDF (91)	Orly Airport	2010	N	N	10	25609	111156	23%
IDF (91)	Ris-Orangis	1983	N	N	5.6	21457	25638	84%
IDF (91)	Saclay	2018	N	N	5	0	0	
IDF (91)	Vigneux-sur-Seine/ ZUP Croix Blanche	1985	N	N	10	11274	36497	31%
IDF (92)	Bagneux	2016	N	N	12	20000		
IDF (92)	Issy-les-Moulineaux	2013	N	N	5	3480	5800	60%
IDF (92)	Le Plessis-Robinson	2013	N	O	5.7	10500	35263	30%
IDF (93)	Blanc-Mesnil	2017	N	N	12	45000	?	
IDF (93)	La Courneuve Nord	1983	N	N	4.1	25000	29625	84%
IDF (93)	La Courneuve Sud	1982	N	N	1.8	5200	26394	20%
IDF (93)	Neuilly-sur-Marne	2013	N	N	10.7	41129	46132	89%

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

Locality	Plant Name	Year commis-sioned	CHP	Cooling	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2018 produc-tion (GW_{th}/y)	Geoth. share in total prod. (%)
IDF (93)	Rosny-sous-Bois	2016	N	N	11	47824	?	
IDF (93)	Tremblay-en-France	1984	N	N	11.5	38982	48500	80%
IDF (93)	Villepinte	2015	N	N	18.1	34694	67835	51%
IDF (94)	Alfortville	1986	N	N	10.26	37808	47942	79%
IDF (94)	Arcueil-Gentilly	oct. 2015	N	N	13.5	51960	?	
IDF (94)	Bonneuil-sur-Marne	2018	N	N	10	0	36500	70%
IDF (94)	Cachan	2018	N	N	18		81980	
IDF (94)	Champigny sur Marne	1985	N	N	10.1	56703	81265	70%
IDF (94)	Chevilly Larue & L'Haÿ les Roses (4 wells)	1985	N	N	35	129696	225026	58%
IDF (94)	Créteil	1985	N	N	13	58369	285839	20%
IDF (94)	Fresnes	1986	N	N	7.5	43996	93811	47%
IDF (94)	Ivry	2016	N	N	10	7270	56416	13%
IDF (94)	Maisons Alfort 1& 2	1984	N	N	19.53	62898	132263	48%
IDF (94)	Orly 2 & 3 (4 wells)	1986	N	N	21	68000	80000	85%
IDF (94)	Sucy-en-Brie	1983	N	N	10	24671	34500	72%
IDF (94)	Thiais	1986	N	N	9.7	19651	44182	44%
IDF (94)	Villejuif	2016	N	N	10	5000		
IDF (94)	Villeneuve Saint Georges	1987	N	N	10.4	34694	47389	73%
IDF (95)	Villiers-le-Bel	1985	N	N	6.22	9714	83172	12%
Aquitaine (33)	Bordeaux Mériadeck	1981	N	N	2.5	16000	20000	80%
Aquitaine (33)	Mérignac Base aérienne 106	1987	N	N	3.4	17000	20000	85%
Aquitaine (33)	Mont de Marsan 1	1976	N	N	1.8	16000	20000	80%
Aquitaine (33)	Mont de Marsan 2	1984	N	N	0.9			
Aquitaine (33)	Pessac - Saige Formanoir	1984	N	N	6	16200	20000	81%

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

Locality	Plant Name	Year commis-sioned	CHP	Cooling	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2018 produc-tion (GW_{th}/y)	Geoth. share in total prod. (%)
Aquitaine (33)	Bordeaux Mériadeck	1981	N	N	2.5	16000	20000	80%
Aquitaine (33)	Mérignac Base aérienne 106	1987	N	N	3.4	17000	20000	85%
Aquitaine (33)	Mont de Marsan 1	1976	N	N	1.8	16000	20000	80%
Aquitaine (33)	Mont de Marsan 2	1984	N	N	0.9			
Aquitaine (33)	Pessac - Saige Formanoir	1984	N	N	6	16200	20000	81%
Aquitaine (40)	Hagetmau	1986/ 1991	N	N	0.8	2800	3200	88%
Centre (36)	Châteauroux	1986	N	N	4	10600	12700	83%
Aquitaine (17)	Jonzac 1	1980	N	N	1.1	0	7000	78%
Aquitaine (17)	Jonzac 2	2002	N	N	2	14475	16744	86%
Grand-Est (54)	Nancy 2 - Caserne Kellerman	?	N	N	1.7	1900	2200	87%
Midi-Pyrénées (31)	Blagnac 1	1975	N	N	2	0	4000	
Midi-Pyrénées (31)	Blagnac 2	1981	N	N	3.2	0	10000	
Aquitaine (40)	Saint Paul Les Dax	1979	N	N	4.4	13700	?	
total (59 plants)					514	1446108	2495010	58%

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 (MW_{th})	Total capacity installed (MW_{th})	2018 produc-tion (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Midi-Pyrenees (32)	Nogaro	1986	N	?		18494		
Aquitaine (33)	Bordeaux Pessac Stadium	1985	N	?		1092		
Aquitaine (33)	Mios-le-Tech	1992	N	3,5		21440		
Languedoc-Roussillon (34)	Lodève 1		N	?		8770		
Languedoc-Roussillon (34)	Lodève 2		N	?		6280		
Languedoc-Roussillon (34)	Montagnac		N	?		7850		
Languedoc-Roussillon (34)	Pézenas		N	?		11576		
Aquitaine (40)	Argelouse / Sore	2001	N	?		16492		
Aquitaine (40)	Saint Paul lès Dax Sebastopol	1979	N	4,4		13775		
Aquitaine (40)	Saint Paul lès Dax Christus		N	0,6		4299		
Lorraine (54)	Lunéville		N	?		827		
Lorraine (54)	Nancy 1 Thermes		N	?		3134		
Lorraine (57)	Dieuze		N	1,5		5233		
Auvergne (63)	Aigueperse		N	?		11512		
Alsace (67)	ECOGI	2016	N	24	90	0	27%	
total (15 plants)					33,8		130 774	33,8

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2018 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2018	210 000	1980	3360	3500	70	?
Projected total by 2020	330 000	2640	4 488			

Table F: Investment and Employment in geothermal energy)

	in 2018		Expected in 2020	
	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**

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