Geothermal Energy Use, Country Update for Portugal

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ABSTRACT

The presence of high-temperature geothermal resources, and the production of electricity from geothermal resources in Portugal, are restricted to the volcanic islands of the Azores Archipelago located in the North Atlantic Ocean.

Three geothermal binary power plants are installed and running normally in the islands of S. Miguel and Terceira, the most economically developed, with a total capacity running of 26 MW_e and an average production of about 200 GWh/year. The total production of those power plants in 2021 represented about 20 % of the total demand of the Azores archipelago. New nine vertical and directional wells were drilled in 2021 in both islands to increase the total running capacity of power plants, or at least saturate them, especially the Pico Alto geothermal power plant, Terceira Island.

Following the call released in 2018 for geothermal projects, sponsored by the FAI – "Fundo de Apoio à Inovação", to promote the use of geothermal resources in Portugal, namely the low enthalpy resources associated with Thermal Baths/Spas facilities, two district heating networks for hotels and public buildings are under completion: (i) Chaves (74 ºC, 25 l/s) and (ii) S. Pedro do Sul (67 ºC, 19.4 l/s).

Furthermore, in Chaves, an independent small operation (110 kW_{th}) was open in January 2022 in an emblematic museum located over an impressive former Roman Thermal Bath with innovations regarding the environmental management of the geothermal fluid and its disposal.

Concerning GSHPs, the potential is huge and continues to be exploited, with new projects ongoing and new specific regulations are expected to be approved shortly. There are a few installations registered until now, but the technical data of the operations are scarce and do not represent the totality of what is installed in Portugal.

1. INTRODUCTION

There are many thermal occurrences in Portugal known and used for balneotherapy since the second century. Their use as geothermal resources was first boosted in the 1970s. The geothermal uses for electricity production started in the Azores archipelago with the exploitation of the high enthalpy geothermal field on the island of S. Miguel. However, the increasing need to use renewable energy resources has led to an increase in the exploitation of high and low enthalpy geothermal resources in Portugal, including shallow geothermal with the use of heat pumps.

The high enthalpy geothermal resources, in Portugal, are restricted to the volcanic islands of the Azores Archipelago (Figure 1), associated with active tectonic and volcanic systems. Considering the abundant surface manifestations of hydrothermal activity, it is reasonable to consider that the geothermal potential of the Azores Archipelago is significant and, on at least several of the islands, there is potentially exploitable geothermal energy for power generation. The geothermal sources have been used for power production since 1980, at the Ribeira Grande Geothermal Field (RGGF) in S. Miguel Island, and since 2017 at the Pico Alto Geothermal Field (PAGF) in Terceira Island. Extensive exploration studies for the evaluation of geothermal resources potential are limited to these two islands, where the technical-economic feasibility of geothermal power projects is easily demonstrated (Carvalho, 1996; Carvalho et al., 2005; Ponte, 2012). Further investigations in other areas, including a variety of surface studies and drilling activities, are required for a complete and accurate assessment of the capacity for power generation (and direct uses) on the islands of the Azores.

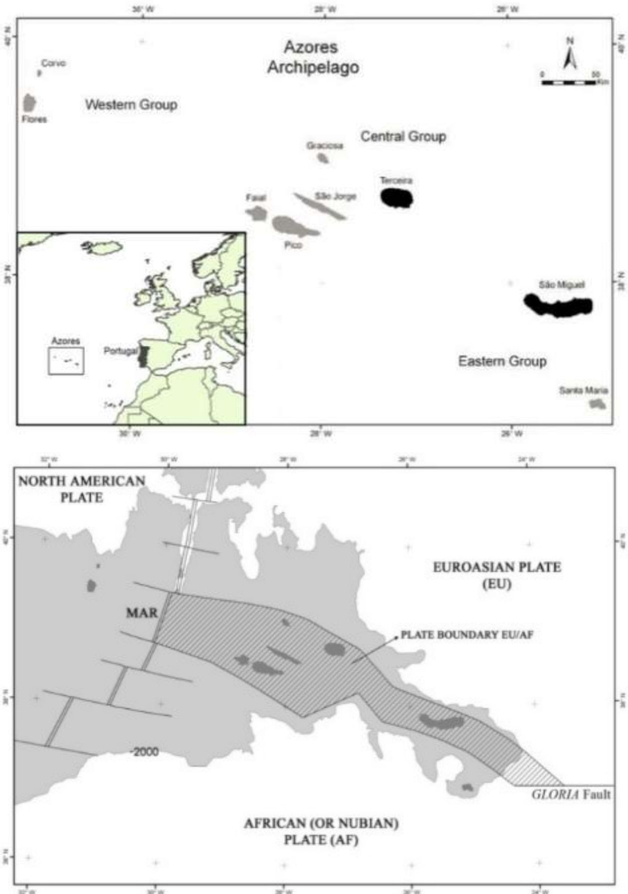

Figure 1: Location of Portugal Mainland, the Azores Archipelago and S. Miguel and Terceira islands (top) and the Azores Triple Junction area (bottom). MAR: Mid Atlantic Ridge. Shaded area represents the "Azores Plateau" (in: Nunes et al., 2016).

The low enthalpy resources are very well represented in Mainland Portugal, where classical geothermal resources, generally associated with the active faulting in the Variscan basement and diapirism in the sedimentary borders, are used at thermal spas and in a few cases in several small direct use operations (heating of hotels and swimming-pools) beside the thermal spa installations. Previous geothermal installations for fish-farming, green-houses and a VALOREN geothermal project supported by a 1500 m deep well in Lisbon are no more operational.

In the Azores islands, the low enthalpy resources are directly related to the high enthalpy systems. A few thermal springs with temperatures up to 92 ºC occur in almost all the islands, but the existing thermal spas are restricted to the islands of S. Miguel, Graciosa, and Faial. An Azorean governmental strategy to evaluate and value those resources and other hot spots revealed by groundwater prospecting wells, aiming for balneological and direct uses, was implemented since 2004 by INOVA – "Instituto de Inovação Tecnológica dos Açores", the local agency for innovation (Nunes et al., 2007).

The relatively mild weather in the Azores does not favour the use of geothermal energy for HVAC, however, GSHP may be seen technically as an adequate solution for cooling, and even dual purposes, in the country.

2. GEOTHERMAL FIELDS

2.1 High Enthalpy Fields

The Azores Archipelago is in the North Atlantic Ocean, associated with the triple junction of the North American, Eurasian, and African (or Nubian) plates (Figure 1). The nine islands that form the archipelago are spread over 600 km, along with a WNW-ESE trend, and emerge from the designated "Azores Plateau", which is defined by the bathymetric line of 2000 m. The Azores display intense seismic and volcanic activity. Since the discovery and settlement of the islands, in the early 15th century, 26 eruptions were recorded inland and onshore. Volcanic and seismotectonic activity are more concentrated in the Central Group islands and in the S. Miguel island, those at the plate boundary between the Eurasian and African plates (Figure 1).

On the island of S. Miguel, there are three active poly-genetic volcanoes with caldera that produced mostly explosive trachytic *s.l.* eruptions in recent times: Sete Cidades, Furnas, and Fogo volcanoes. A fourth silicic polygenetic volcano with caldera (e.g. Povoação volcano) and two Basaltic Fissural Areas (e.g. the Picos and Nordeste Complexes) complete the volcanic systems of S. Miguel island (Figure 2).

The Ribeira Grande Geothermal Field is located on the northern slopes of the Fogo central volcano (Figures 2 and 3) and this liquid-dominated high enthalpy system reaches maximum temperatures of about 245 ºC in depth.

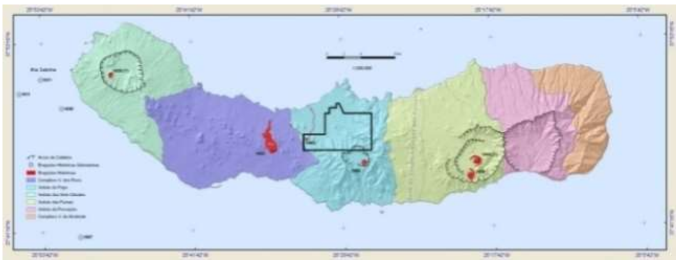

Figure 2: Volcanological map of S. Miguel Island (Nunes, 2004). The RGGF- Ribeira Grande geothermal field concession area is outlined.

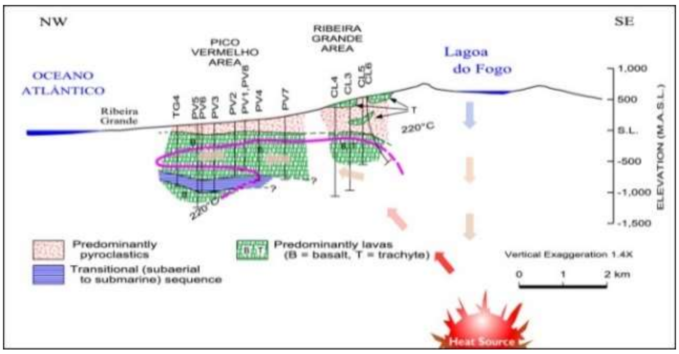

Figure 3: Generalized cross-section of the RGGF (adapted from GeothermEx, 2008).

Surface geothermal manifestations are spread on those three active central volcanoes of S. Miguel Island, which are particularly impressive at Furnas volcano caldera, with the presence of about 30 thermal springs and fumaroles.

On Terceira Island, which has a complex tectonic setting, there are four central volcanoes with caldera (Cinco Picos, Guilherme Moniz, Santa Bárbara, and Pico Alto – in decreasing age sequence) and the Fissural Basaltic Zone, in the central and SE part of the island (Figure 4 - Nunes, 2000). The Pico Alto volcano (the younger polygenetic volcano) is dominated by siliceous formations of pyroclasts, domes and *coulées* of trachytic to pantelleritic nature.

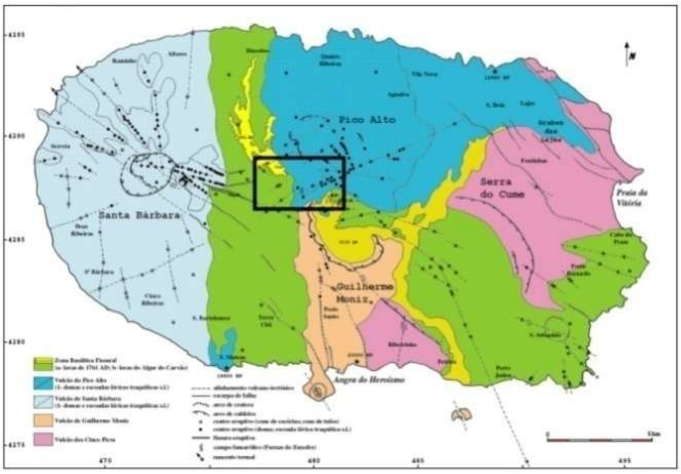

Figure 4: Volcanological map of Terceira Island (Nunes, 2000); The PAGF- Pico Alto geothermal field concession area is outlined.

At surface, the Pico Alto Geothermal Field encompasses mostly Pico Alto volcano and the Fissural Basaltic Zone formations (Figure 5), but the geothermal systems develop in a complex volcanological setting, that encompasses the interference of the Pico Alto (PA), Guilherme Moniz (GM) and even Santa Bárbara central volcanoes formations. This high enthalpy system reaches temperatures of about 300 ºC in depth.

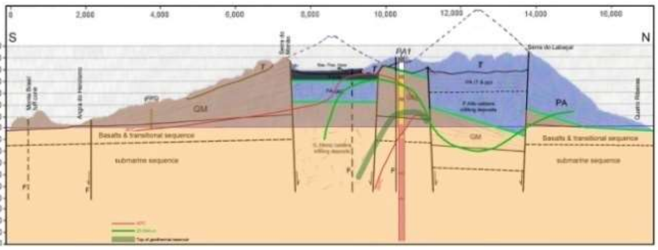

Figure 5: General N-S cross-section of Terceira Island, including the PAGF (adapted from TARH & ÍSOR, 2016).

2.2 Low Enthalpy Resources Occurrences

The low enthalpy geothermal resources, in Portugal, can be found in the Azores Archipelago, in the dependency on the high enthalpy resources, and on the mainland.

In the Azores Islands, surface geothermal manifestations are reported in all islands but Corvo and Santa Maria islands. In total, 48 surface geothermal occurrences of low enthalpy (with temperatures between 22 and 98 °C) have been identified, most of them (25 cases) in the Furnas Volcano in S. Miguel Island (DGEG, 2017).

Presently four Thermal Baths/Spas using geothermal resources are installed in Graciosa and S. Miguel islands (e.g., Carapacho, Furnas Boutique Hotel, Banhos da Coroa/Caldeiras da Ribeira Grande and Ferraria). At Furnas Volcano, in S. Miguel Island, in addition to the use of thermal water in swimming pools and other recreational infrastructures, the Quenturas spring is abstracted for use in the Furnas Boutique Hotel Thermal & Spa: Figure 6 shows the conceptual model of this exploited aquifer.

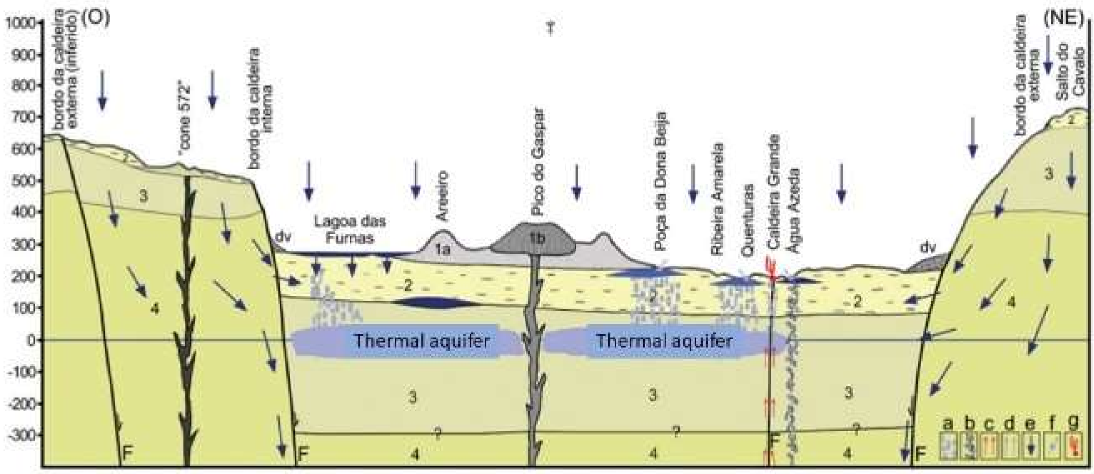

Figure 6. Conceptual model of Quenturas spring aquifer (Furnas volcano):
1a) and 1b) historical eruption, 15th century; 2) "Upper Furnas Group" formations; 3) "Middle Furnas Group" Formations; 4) "Lower Furnas Group" formations; dv slope deposits; F) fault/fracture.
Legend at lower right: a) steam (steam + gases); b) volcanic gases; c) deep geothermal water; d) thermal water; e) aquifer recharge; f) thermal and/or mineral springs; g) fumarole. Adapted from Freitas et al. (2020).

As represented in Figure 7, the Portuguese mainland is composed of the following geological units: (i) PreMesozoic Variscan basement, (ii) Western and Southern Meso-Cenozoic borders, and (iii) Ceno Antropozoic basins of Tejo and Sado rivers.

The following geotectonic zones are generally considered part of the Variscan Massif: (i) Central Iberian zone including the Middle Galicia-Trás os Montes domain, (ii) Ossa-Morena zone, and (iii) South-Portuguese zone.

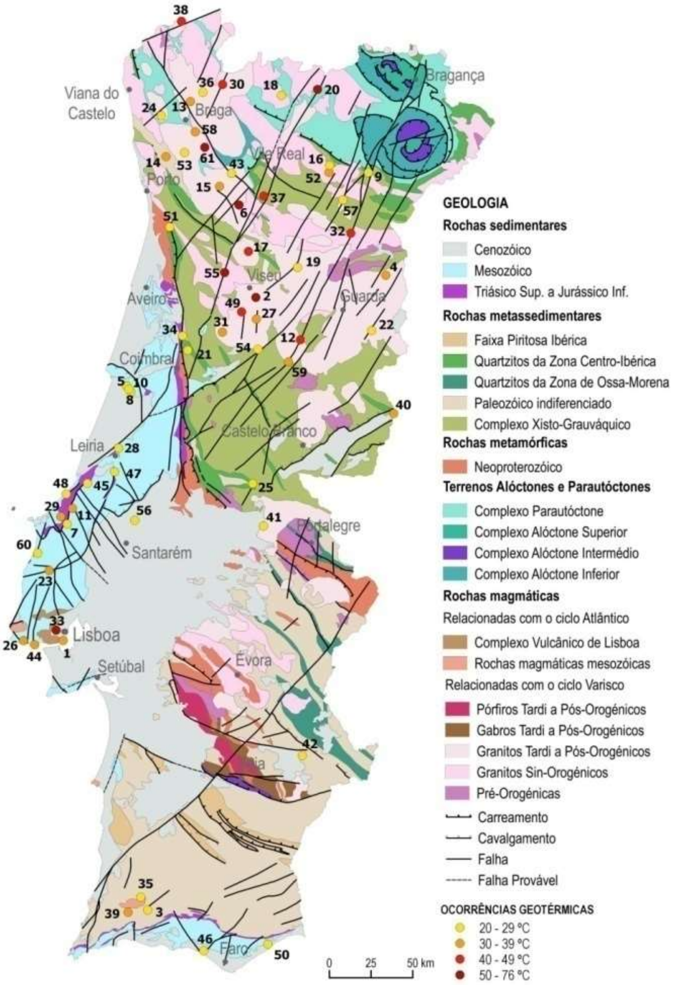

Figure 7: Geological map of Portugal Mainland and thermal occurrences (in: DGEG, 2017).

From the lithological point of view, the main rocks are granites of the Variscan orogeny and metasediments pre and post-orogenic. Weathering is quite irregular, depending on tectonics and present and past climates: average reported depths to found rock massifs range from 0 to 60 m, but in the vicinity of the main tectonic axis it is not infrequent to drill up to 300 m of weathered rock.

Most Portuguese thermo-mineral water of hard rock origin comes from the Central Iberian Zone. As pointed out by Ribeiro and Almeida (1981), this could not be a simple inheritance of the geological history, and another factor plays an important role in the productivity and distribution of springs: the recharge conditions which are largely higher in the northwestern area of Portugal.

The average annual rainfall (P) reaches 1811 mm in this area, but this figure decreases to less than 600 mm in some eastern and southern regions, the average annual rainfall for the entire country being 917 mm. About 55 % of precipitation is lost by evapotranspiration. The average air temperature is about 15 ºC, but the winter season is severe in the northern areas.

The recharge has an average value in the range of 223 mm, varying from 50 to 350 mm (LABCARGA, 2017). In the Central Iberian Zone, where most thermal manifestations are present, the average Rate of Infiltration ranges from 10 % to 15 % (LABCARGA, 2017) which seems satisfactory for recharge conditions for the existing thermal spring facilities. However, this is not enough to ensure sustainability for future geothermal operations dealing with higher extraction rates.

As expected, tectonics (and particularly active structures, for thermal waters, in a geological sense) is closely related to the occurrence of thermal springs. The distribution of mainland users of geothermal energy (thermal baths) is superimposed in Figure 7 with tectonic data from Cabral (1995; in: DGEG, 2017). Thermal anomalies follow axis trending NNE, NW, and ENE along the main active faults.

Naturally available discharging flows from former exploitation systems range from a few cubic meters/day to 864 m^3/day. In general, with new-drilled wells, it has been possible to increase former production. However, for the running exploitation, and considering real needs and/or environmental constraints, exploited yield is normally under the maximum permitted by the hydrodynamics of the aquifer and wells.

The temperature of occurrences, nowadays tube wells and boreholes, goes up to 77 ºC. Among Portuguese mineral waters, twenty-eight discharges with temperatures higher than 25 ºC are used for balneological purposes. Ten of those springs reach over 50 ºC. Other thermal springs occur all over the Northern area of Portugal Mainland and at the sedimentary basins. Examples of those exploited thermal aquifers are in Figures 8 (Chaves) and 9 (Vimeiro), respectively.

The Portuguese government through the FAI – "Fundo de Apoio à Inovação", developed in 2021 (DGEG et al., 2021) a national plan to demonstrate the feasibility of using natural mineral water in existing spas as geothermal resources for heating purposes, to replicate several direct use operations in due course since the 1980s. Those resources were evaluated at about 184 GWh/year on mainland and 9 GWh/year in the Azores mineral waters (DGEG et al., 2021). Those figures are only indicative of the existing potential and have a limitation: local resources were evaluated from an administrative point of view.

3. GEOTHERMAL UTILIZATION

Geothermal energy in Portugal is used for electricity production, for direct use associated with thermal baths/spas, and in Ground Source Heat Pumps. Tables

A to G at the end of this paper present the characterization of the geothermal uses in Portugal, in general terms as of December 2021.

3.1 Electric Power Installation and Generation

The geothermal sources have been used for power production since 1980, at the Ribeira Grande Geothermal Field (RGGF) in S. Miguel Island, and since 2017 at the Pico Alto Geothermal Field (PAGF) in Terceira Island.

The geothermal policy in Azores issued by the Azores Government is developed in the field by the regional electric utility EDA – Electricidade dos Açores S.A., through its affiliated company EDA RENOVÁVEIS S.A. (a joint of formers SOGEO - Sociedade Geotérmica dos Açores S.A. and GeoTerceira - Sociedade Geoeléctrica da Terceira S.A. companies).

At the RGGF two geothermal power plants – Ribeira Grande and Pico Vermelho – are in operation with a combined installed capacity of 27.8 MW (Table B). Both plants are based on ORC binary systems. A 4 MW geothermal pilot power plant was installed in the PAGF and operates since August 2017.

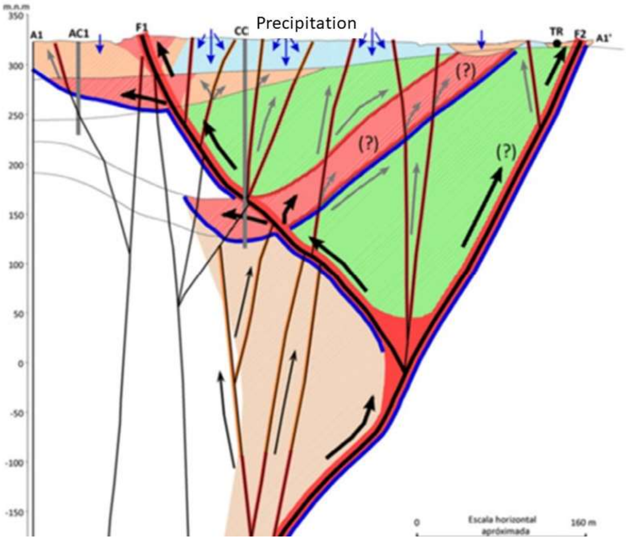

Figure 8: Conceptual model of the Chaves thermal aquifer, close to the exploitation wells (Freitas, 2015; in: DGEG et al., 2021).

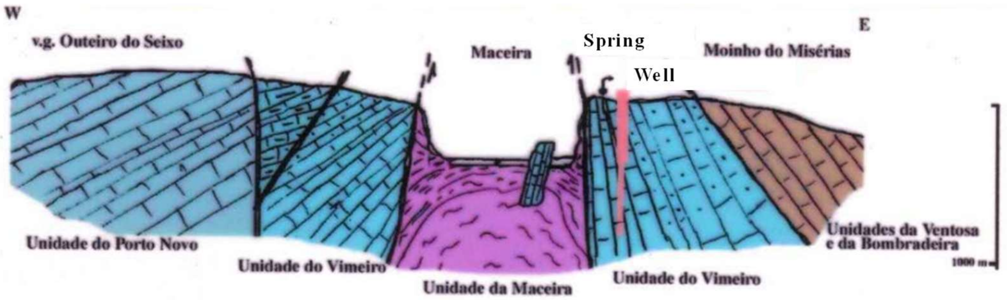

Figure 9: Conceptual model of the Vimeiro thermal aquifer (adapted from Chaminé et al., 2004).

The last years were extremely relevant for high enthalpy geothermal resources in the Azores, as previously documented (e.g., Carvalho et al., 2015; Nunes et al., 2016; 2019; 2021). In the RGGF (S. Miguel Island) the development of geothermal resources has been very successful, with an annual average contribution of about 40 % of the electricity produced on the island since 2013. Nevertheless, in 2021 the production in the RGGF was only 133 GWh/year (Table B) - about 30 % of the total production of electricity on the island - due to a failure on the Pico Vermelho power plant alternator (EDA, 2021). During 2021 six deep wells were drilled to increase the total running capacity up to 30 MW_e.

The total generation capacity of the PAGF Power Plant is 4 MW, following the evaluation tests carried out during 2013/2014, but is not still saturated with the existing production wells in this geothermal field (PAGF). Thus, in 2021 three deep wells were drilled to ensure the saturation of the existing power plant, and if possible, to increase the installed capacity in Terceira Island. In 2021 the production in the PAGF was about 26 GWh/year (Table B), 13,4% of the total production of electricity on the island (EDA, 2021)

3.2 Direct Heat Uses

Direct use application in the mainland and the Azores is restricted to small district heating operations and mainly balneological applications. The situation was reported recently, namely by Carvalho et al. (2015), Lourenço (2016), DGEG (2017), Nunes et al. (2019), DGEG et al. (2021), and no significant changes are to be mentioned.

Portugal, like other Mediterranean countries, has more levelled heating and cooling needs than Nordic countries. Therefore, in Portugal GSHPs are usually reversible, providing heating and cooling. The equilibrium between heating and cooling in a dwelling is important to maintain the temperature stability of the ground over the years.

In the residential sector, heating needs are higher than cooling needs, which can lead to a ground temperature decrease. However, that problem is smaller than in northern and central European countries. Commercial buildings can have more cooling needs, a function of the activity developed in the building, so special attention must be paid to geothermal borehole heat exchangers (BHE) design to avoid the ground temperature increase.

The Portuguese government is developing a national plan to demonstrate the feasibility of using natural mineral water in existing Spas as geothermal resources for heating purposes. The consortium SYNEGE/EST (IPS) has just run a Project to be carried out in the mainland and Azores (DGEG et al. 2021).

3.2.1 District Heating

Two main operations are running normally in thermal baths:

- Chaves, Northern Portugal: a dedicated well, 150 m deep, 76 ºC, TDS of 2500 mg/l, 5 l/s capacity, in metamorphic slates with quartz veins, is used in a small district heating network (swimming pool and hotel). Another well (208 m deep, 74 ºC, TDS of 2500 mg/l, 10 l/s capacity), taped hot water in metamorphic slates with quartz veins and feeds the Thermal Bath as well as the district heating network. A third well (100 m deep, 68 ºC) is maintained as a backup well. Furthermore, in Chaves, an independent small operation (110 kW_{th}) was open in January 2022 in an emblematic museum located over an impressive former Roman Bath with innovations regarding the environmental management of the geothermal fluid and its disposal.
- S. Pedro do Sul, central Portugal, the main Portuguese Spa: one inclined well, 500 m deep, 69 ºC, 350 mg/l TDS, 10 l/s with artesian flow, in fractured granite, supplies the Thermal Bath and is in use in a small heating operation, financed by the Thermie Program, in two hotels, and inside the Spa. The total available production (classical spring and well AC1) is 17 l/s.

Several minor district heating operations are running in Caldas de Monção, Termas da Longroiva and Alcafache thermal baths in Mainland, and at Furnas hotels, in S. Miguel Island, Azores.

3.2.2 Bathing and Swimming

Balneological activities using thermo-mineral waters are quite popular in Portugal for the cure and touristic purposes. About 30 Thermal Baths are operating within a legal framework (cf. DGEG, 2017). Several of them are open only in summer, but some are normally operating all over the year. All the balneological activity inside the baths is carried out under strict medical control.

Since 2004 the INOVA Institute and the Azores Government undertake several initiatives and studies allowing the exploitation and valuing of the Azorean low-temperature geothermal resources for direct use, including touristic activities and balneology (Nunes et al., 2015). Associated with these activities new shallow wells were carried out in Ferraria (S. Miguel), Varadouro (Faial) and Carapacho (Graciosa).

3.3 Ground Source Heat Pumps

According to the latest data recorded by EHPA, European Heat Pump Association, there were no new sales of GSHP in Portugal in 2014. The aggregated sales until 2014 were about 54 units with an installed capacity of 0.65 MW. Considering typical values, the average installed capacity was 12 kW, with an operating hours value of 1340 and a typical Seasonal Performance Factor (SPF) of 3.425. For the years after 2014, it was not possible to obtain data. Thus, it is difficult to follow the evolution of new projects concerning GSHP, since Portugal still doesn´t have legislation to oblige the registration of this kind of projects, especially concerning the residential sector. Therefore, it is possible that a greater number of small installations are performed each year, but are not registered.

With a view to increase the knowledge in this area and inherently promote the dissemination and proper use of GSHP, four national entities (DGEG, LNEG, APG, and ADENE) established a collaboration protocol concerning the creation of a baseline study, analysis, and dissemination of geothermal use through GSHP. The Portuguese Platform of Shallow Geothermal Energy (PPGS) was created in 2013 with the mission to disseminate the best practices involving GSHP, promote the dialogue on the geothermal community, collaborate on new legislation, spread knowledge of technical standards and procedures, contribute to the training of the agents involved and to promote the development of new projects. However, due to the weak interest in the application of shallow geothermal energy in Portugal, this platform ended its activity in 2017.

One of the gaps in Portugal for the development of shallow geothermal energy is the lack of a legal framework. A new legislative framework concerning shallow geothermal purposes began to be prepared about 8 years ago. The latest version from the working group was finalized in 2019 and the document was passed to the Portuguese parliament to be approved. Unfortunately, the document has not yet been approved, which continues to limit the progress of the implementation of GSHP installations. The proposed legislative framework imposes the obligation to register the installed GSHPs. Therefore, another important progress after the proposed legislation is approved, will be to have the registration of all the systems installed, from then on, which will allow to have statistical data on new installations in the future.

Despite the lack of registration, there is some information about GSHP projects developed in Portugal (e.g., Edifícios e Energia, 2013, Cardoso and Lapa, 2015a; 2015b, Ferreira, 2019), that was presented in more detail on previous reports (see also Carvalho et al., 2015; Nunes et al., 2016; 2021) and is summarized below:

- Brigantia Ecopark in Bragança: it is equipped with three GSHP, one just for domestic hot water (DHW) heating and two for building acclimatization. To dissipate the heat generated by the GSHP, 45 boreholes with a depth of 120 m were performed. Regarding GSHP for DHW, only heat is produced, and the system is interconnected with DHW reservoir. Concerning the other two GSHP, for acclimatization, heat and cool is produced and the system is connected to a buffer tank of 9000 l.
- Aveiro University: the university has 5 buildings (ECORR, ESAN, CCI, CICFANO, and ESSUA buildings) acclimatized with GSHP and has been also collaborating with "Chama Energia" company in other projects.
- Superior School of Technology of Setúbal (EST Setúbal): the Polytechnic Institute of Setubal, which was a partner in the GROUNDHIT European Project (6th Framework Program), has a demonstration site for high energy efficiency GSHPs. Two GSHPs of 15 KW_{th} for heating and 12 KW_{th} for cooling each, were installed to acclimatize 7 office rooms and 2 classrooms. The project aimed at monitoring the prototype of improved energy efficiency heat pumps (COP higher than 5.5) in real conditions in a Mediterranean climate, and test two different Boreholes Heat Exchangers (BHE) types: double-U pipes and coaxial pipes. The demo site results showed that the GSHPs COP is according to the expected ones during the design phase (COP of 5.19 for cooling and 6.05 for heating in real conditions), with a good performance in the terminal units (fan-coils, secondary circuit), boreholes (primary circuit) and GSHP.
- Regional authority administration building in Coimbra: under the scope of the GROUNDMED European Project (7th Framework Program) an installation was set on a regional authority building with offices and laboratories, located in Coimbra city. One GSHP with a heating capacity of 56 kW_{th} and cooling capacity of 61 kW_{th} (Eurovent conditions) serves the building's 3rd-floor offices. The GSHP is coupled to seven double U, 125 m vertical borehole heat exchangers. The heating/cooling distribution system consists of 33 ceilings Coanda effect fan coil units with high-efficiency permanent magnet EC motors, installed in 22 offices, with a total area of 600 m^2. Since all systems were designed to function with moderated temperatures, the real cooling capacity is 63.5 kW_{th} and the real heating capacity is 70.4 kW_{th}, resulting in increased performance. The results showed good results with a GSHP COP of 5.65 and an EER of 6.19.
- Sines Tecnopolo: this complex, which includes heating, cooling, and DHW production, has an existing renewed building with 251 m^2, a laboratory building with 534 m^2 and an office building with 1286 m^2, all served by GSHPs. The existing renewed building is served by one GSHP with a heating capacity of 24.5 kW_{th} and cooling capacity of 18.4 kW_{th}, coupled with 2 simple U, 150 m vertical borehole heat exchangers;
- Ombria Resort, Algarve: this resort (with one golf course, the clubhouse, one hotel, one spa, and some villas) represents the largest installation of shallow geothermal energy in Portugal. The total needed capacity based on GSHP is about 2370 kW of heating and 1100 kW of cooling. The clubhouse has an area of 1260 m^2 and the hotel, spa, and villas have an area of 15'940 m^2. For the clubhouse, 40 BHE with 100 m depth each were installed, for the hotel 60 BHE with 125 m depth each, and for the spa and villas, 144 BHE with 115 m depth each. A total of 108 solar collectors (vacuum type) for the clubhouse, and 48 solar collectors for the hotel was installed, for DHW, hot water for the swimming pools, and also to inject heat into the ground through the BHE to equilibrate the balance of energy injected and extracted by the GSHP throughout the year.

In addition to the mentioned installations, only a few small installations, essentially in houses, have been implemented. However, in the recent future, interest in GSHP installations seems to be growing again. New projects are planned, namely an installation in a tourist resort in the south of Portugal. It is estimated a total capacity of around 675 kW_{th}. Also, an installation is planned in a residential building in Lisbon, for heating and cooling with a total capacity of around 800 kW_{th}. Some installations are also foreseen for individual houses and for an industry.

4. CONCLUSIONS

In Portugal, the presence of high-temperature geothermal resources and the production of electricity from geothermal resources are restricted to the active volcanic systems in the islands of the Azores Archipelago.

Presently EDA RENOVÁVEIS S.A. has a total installed generation capacity in S. Miguel Island Azores of 27.8 MW net in two geothermal power plants. Those power plants ensured the production in 2021 of 133 GWh_e in S. Miguel Island, which represents 30 % of the total production of electricity on the island (about 443 GWh). During 2021 six deep wells were drilled to increase the total running capacity of the Ribeira Grande and Pico Vermelho power plants up to 30 MW_e.

On Terceira Island, three new deep wells were drilled with the main goal to support the existing 4 MW Pico Alto power plant (that started operating in August 2017), and if possible, to increase the installed capacity in the island. In 2021 the energy production was about 26 GWh_e, which represents 13.4 % of the electrical production of the island (194 GWh).

Low-temperature geothermal resources in Mainland Portugal are exploited for direct uses in balneotherapy and small district heating systems.

Concerning GSHPs there are a few installations registered until 2014, but the registration data of the installations is scarce and do not represent the totality of what is installed in Portugal. However, this tends to change due to the preparation of new legislation for regulating shallow geothermal operations.

The Ombria Resort installation, the largest shallow geothermal energy in Portugal is located in the Algarve and represents an interesting case study about the use of this renewable energy source to promote and disseminate this technology in Portugal.

In fact, a new legislation draft on GSHPs was already prepared by the Directorate-General for Energy and Geology (DGEG) – the Portuguese authority for those geological resources – that will contribute not only to ameliorating the quality of the operations but also to allow future statistical data to be more realistic. However, its approval in the Portuguese parliament has taken a long time. Approval is expected to be forthcoming but there is no certainty.

In addition, in 2018 a call for geothermal projects was released, sponsored by the FAI – "Fundo de Apoio à Inovação", to promote the use of geothermal resources in Portugal, namely the low enthalpy resources associated with Thermal Baths/Spas facilities. An assessment was carried out grouping the hydromineral and geothermal resources in 4 geographic zones by their location: North Zone; North Central Zone; Central South and South Zone; Azores archipelago. The results of this project have been published (DGEG et al., 2021) and allow for a more in-depth understanding of the potential for exploitation of hydromineral and geothermal resources and their use at temperatures above 25 °C, with the aim of stimulating the use of these resources in the future. It was identified that for installations with a resource temperature below 35 ºC, the most advantageous scenario is the preheating of DHW with the support of GSHPs, since for any application it is always necessary to use the thermal support system.

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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 *	26	158.9	22’421	53’054	0.12	0.3
Under construction end of 2021	0	0	not available	not available	not available	not available
Total projected by 2023	0	0	not available	not available	not available	not available
Total expected by 2028	40	310	not available	not available	not available	not available
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:	

* 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)
Ribeira Grande (S. Miguel Island, Azores)	Pico Vermelho	2006	1 (RI)	O	B-ORC	13.0	13	68.3
Ribeira Grande (S. Miguel Island, Azores)	Ribeira Grande	1994/ 1998	4 (RI)	O	B-ORC	14.8	10	64.7
Pico Alto (Terceira Island, Azores)	Pico Alto	2017	1 (RI)	O	B-ORC	4	3	25.9
total						31.8	26	158.9

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 / decommissioned	2F	Double Flash	O	Other

* 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 *	2.1*	12.3*	0	0	2.0*	3.2*	17.1*	125*
Under constru-ction end 2021	4	0	0	0	0	0	0	0
Total projected by 2023	5	30	Not available	Not available	Not available	Not available	Not available	Not available
Total expected by 2028	5	30	Not available	Not available	Not available	Not available	Not available	Not available

* 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 commis-sioned	CHP **	Cooling ***	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)
Chaves	Chaves	1982/ 2015	N	N	0.9	Not available	7.4*	Not available
S. Pedro do Sul	S. Pedro do Sul	2000/ 2015	N	N	1.2	Not available	4.82*	Not available
total					2.1*		12.3*	

* 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.

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})	2021 produc-tion * (GWh_{th}/y)	Geoth. share in total prod. (%)	Operator
Monção			N	Not available	Not available	Not available		
Vizela			N	Not available	Not available	Not available		
Alcafache			N	Not available	Not available	Not available		
Longroiva			N	Not available	Not available	Not available		
Carvalhal			N	Not available	Not available	Not available		
Caldas S. Paulo			N	Not available	Not available	Not available		
Furnas (Azores)		2016	N	Not available	Not available	Not available		
total				2*		3.1*		

* 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})	Share in new constr. (%)
In operation end of 2021 *	Not available	Not available	Not available	Not available	Not available	Not available
Of which networks **						
Projected total by 2023	Not available	Not available	Not available			

* 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 are no shallow geothermal UTES installations currently existing in Portugal.

Table F: Investment and Employment in geothermal energy

	in 2021 *		Expected in 2023	
	Expenditures ** (million €)	Personnel *** (number)	Expenditures ** (million €)	Personnel *** (number)
Geothermal electric power	EDA RENOVÁVEIS S.A.	EDA RENOVÁVEIS S.A.	EDA RENOVÁVEIS S.A.	EDA RENOVÁVEIS S.A.
Geothermal direct uses	not available	not available	not available	not available
Shallow geothermal	not available	not available	not available	not available
total				

* 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

	Geothermal electricity	Deep Geothermal for heating and cooling	Shallow geothermal
Financial Incentives – R&D	Portugal 2020-30 and Horizon 2020-30 (EU)	Portugal 2020-30 and Horizon 2020-30 (EU)	Portugal 2020-30 and Horizon 2020-30 (EU)
Financial Incentives – Investment			
Financial Incentives – Operation/Production			
Information activities – promotion for the public	Some punctual information activities	Some punctual information activities	Some punctual information activities
Information activities – geological information	Some punctual information activities	Some punctual information activities	Some punctual information activities
Education/Training – Academic	A few academic courses/workshops	A few academic courses/workshops	A few academic courses/workshops
Education/Training – Vocational	A few short courses	A few short courses	A few short courses

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)