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Portugal Country Update 2022

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ABSTRACT

In Portugal, the presence of high temperature geothermal reservoirs and the production of electricity from geothermal resources are restricted to the volcanic islands of 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 about 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 from October 2020 to December 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.

In Mainland, the Portuguese government developed in 2021 a national plan to demonstrate the feasibility of using natural mineral water in existing thermal spa as geothermal resources for heating purposes, to replicate a number of direct use operations in due course since the 80's of the last century.

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°C, 15 L/s) and (ii) S. Pedro do Sul (67°C, 17 L/s).

Furthermore, in Chaves, an independent small operation 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.

Concerning GSHP's the potential is huge and is starting to be exploited, with new projects ongoing and new specific regulation is expected to be approved shortly. There are a few installations registered until now, but the technical data of the installations are scarce and do not represent the totality of what is operating in Portugal. However, in recent years there has not been a positive evolution in new installations. It is hoped that the expected new legislation can contribute to the increase in the use of geothermal heat pumps.

1. INTRODUCTION

The climatic characteristics present in the country and the implementation of favorable conditions for investment in other renewable energy sources in Portugal, such as wind energy and photovoltaic, have meant that the development of geothermal energy has lagged behind other European countries.

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.

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) as well the thermal spa installations. Previous geothermal installations for fish-farming, green-houses and a VALOREN geothermal project supported by a 1,500 m deep well in Lisbon are no more operational.

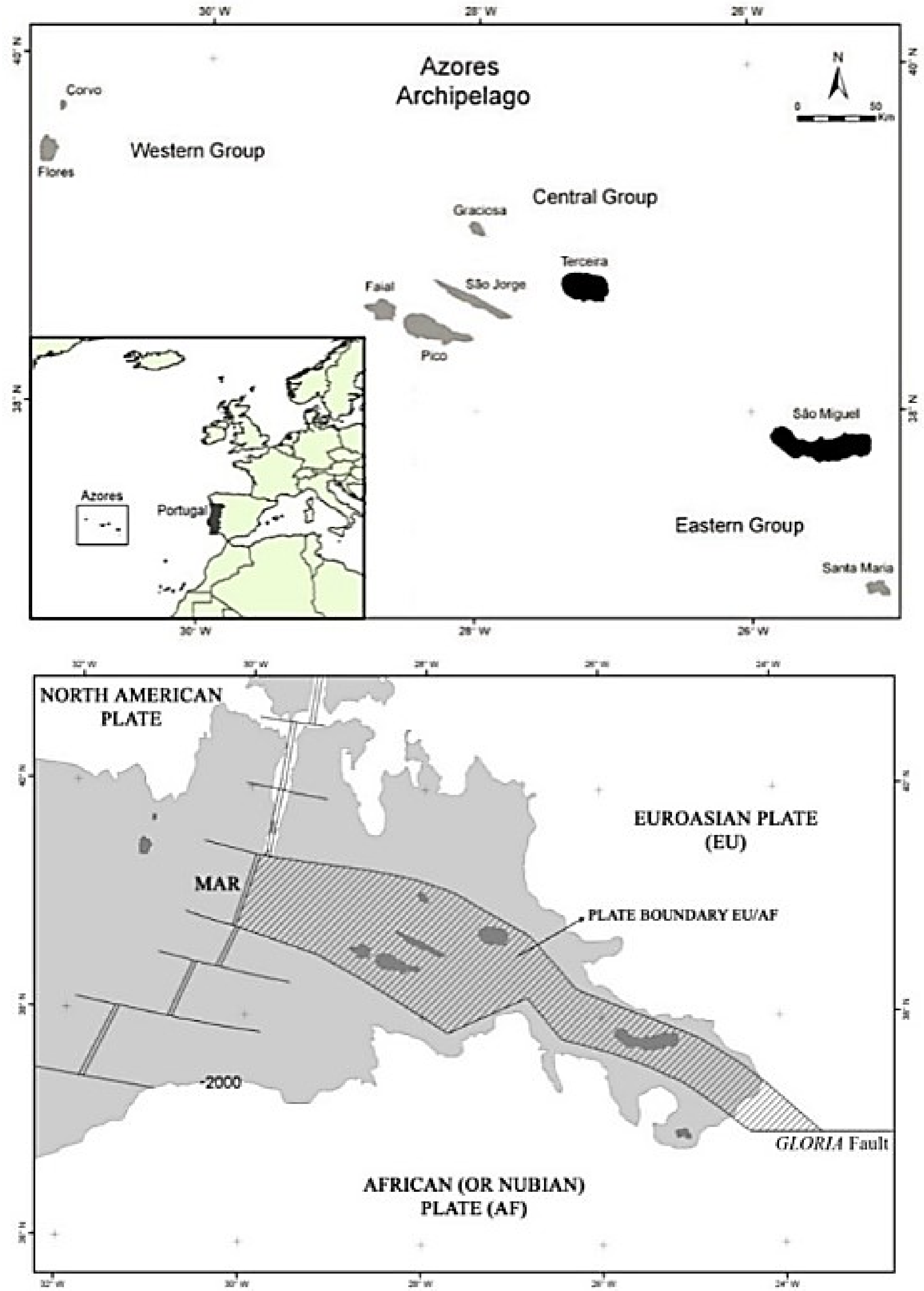


Figure 1: Location of Portugal Mainland, the Azores Archipelago and S. Miguel and Terceira islands (up) and the Azores Triple Junction area (low). MAR: Mid Atlantic Ridge. Shaded area represents the "Azores Plateau" (in: Nunes et al. 2016).

In the Azores islands, the low enthalpy resources are mostly directly related to the high enthalpy systems. A few thermal springs with temperatures up to 92ºC 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 favor 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, with a WNW-ESE trend, and emerge from the designated "Azores Plateau", which is defined by the bathymetric line of 2,000 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 polygenetic 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 245ºC in depth.

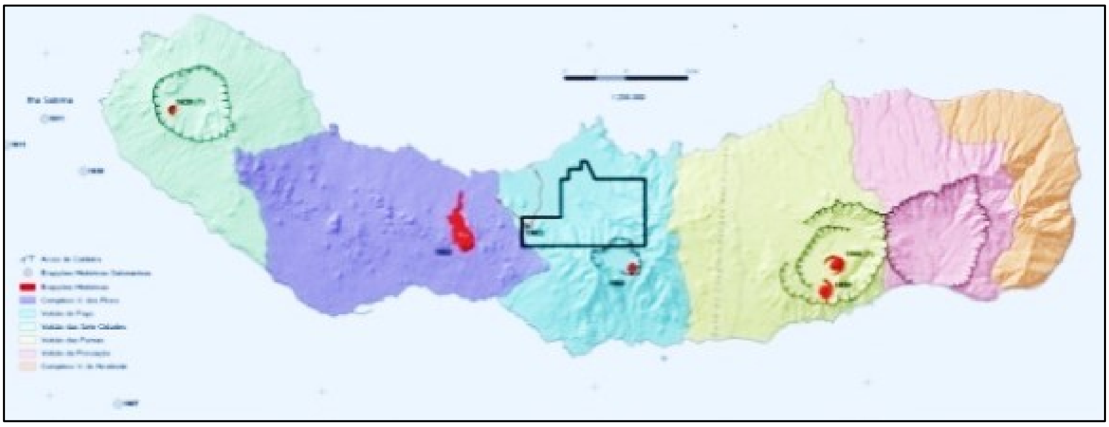


Figure 2: Volcanological map of S. Miguel Island (Nunes 2004). The Ribeira Grande geothermal field concession area is outlined.

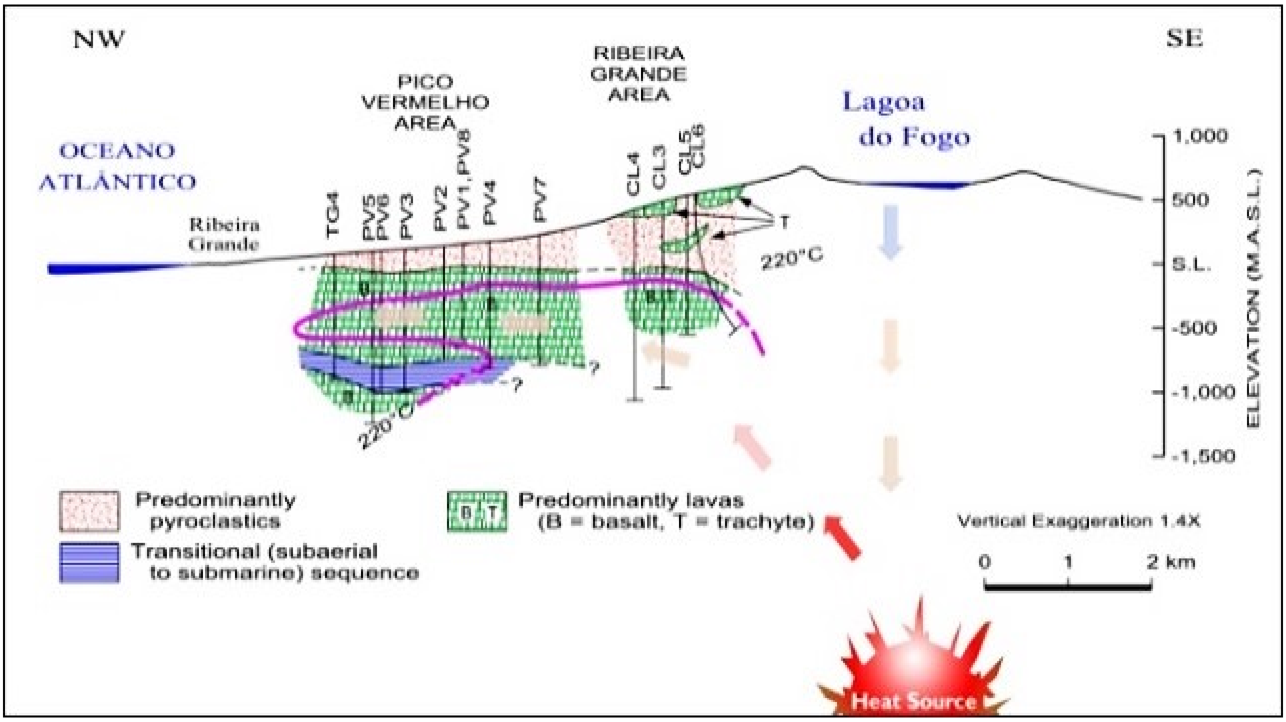


Figure 3: Generalized cross-section of the Ribeira Grande geothermal field (adapted from GeothermEx 2008).

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.

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 300ºC in depth.

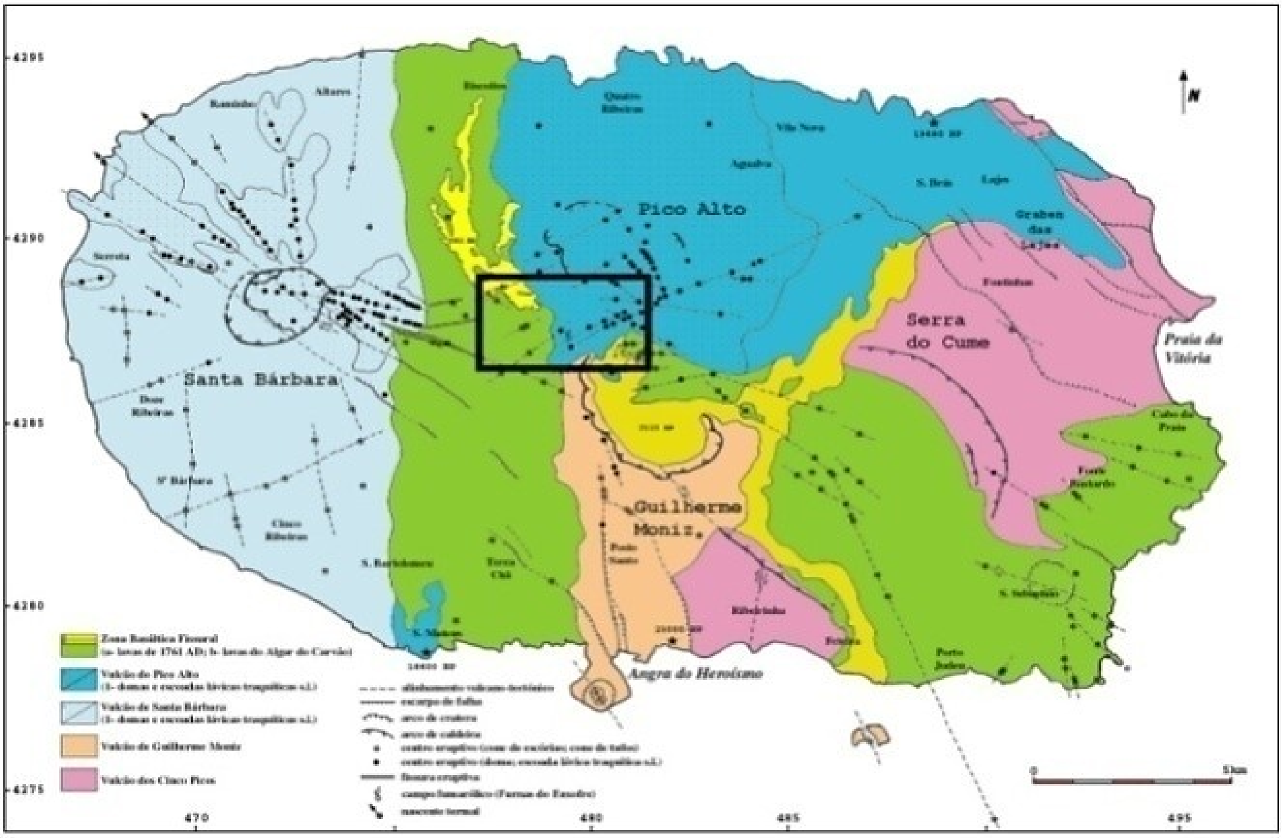


Figure 4: Volcanological map of Terceira Island (Nunes 2000). The Pico Alto geothermal field concession area is outlined.

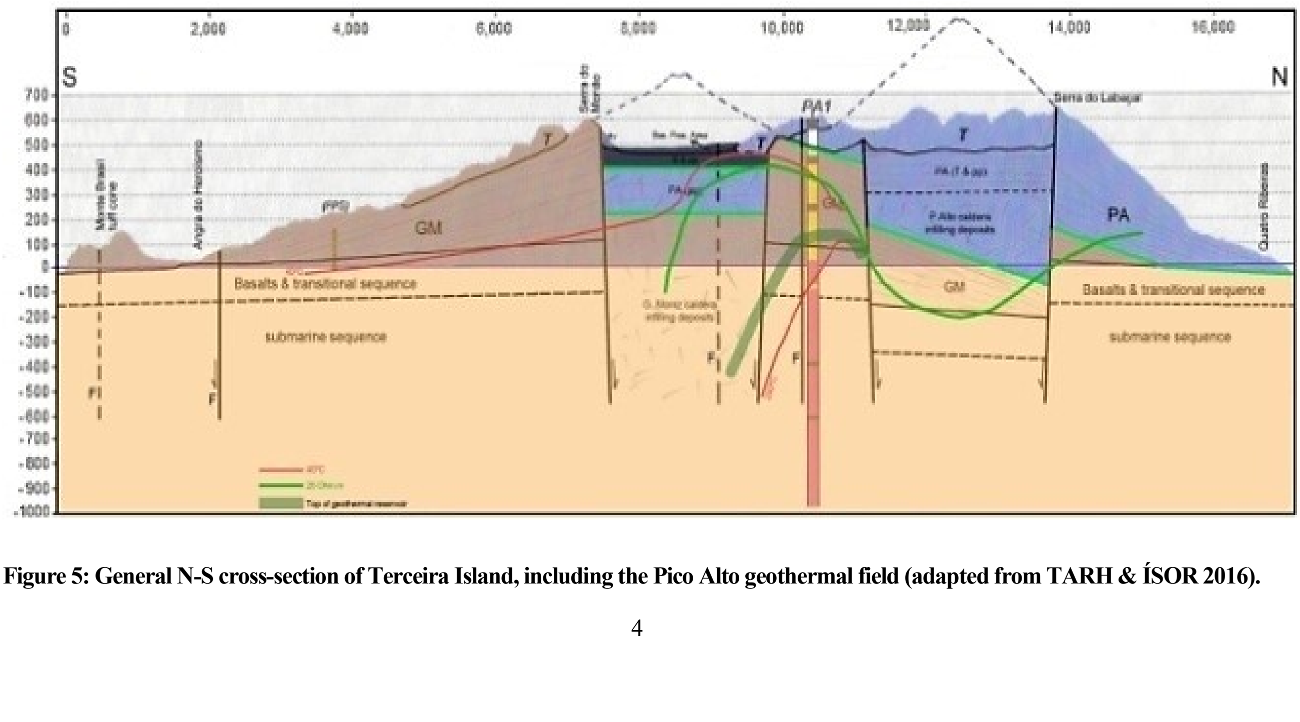


Figure 5: General N-S cross-section of Terceira Island, including the Pico Alto geothermal field (adapted from TARH & ÍSOR 2016).

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 Mainland, related to deep and active faults.

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 events) 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). In addition, Caldeira Velha, Poça da Dona Beija and Terra Nostra Garden thermal water swimming pools are used as public recreational infrastructures.

As represented in Figure 6 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.

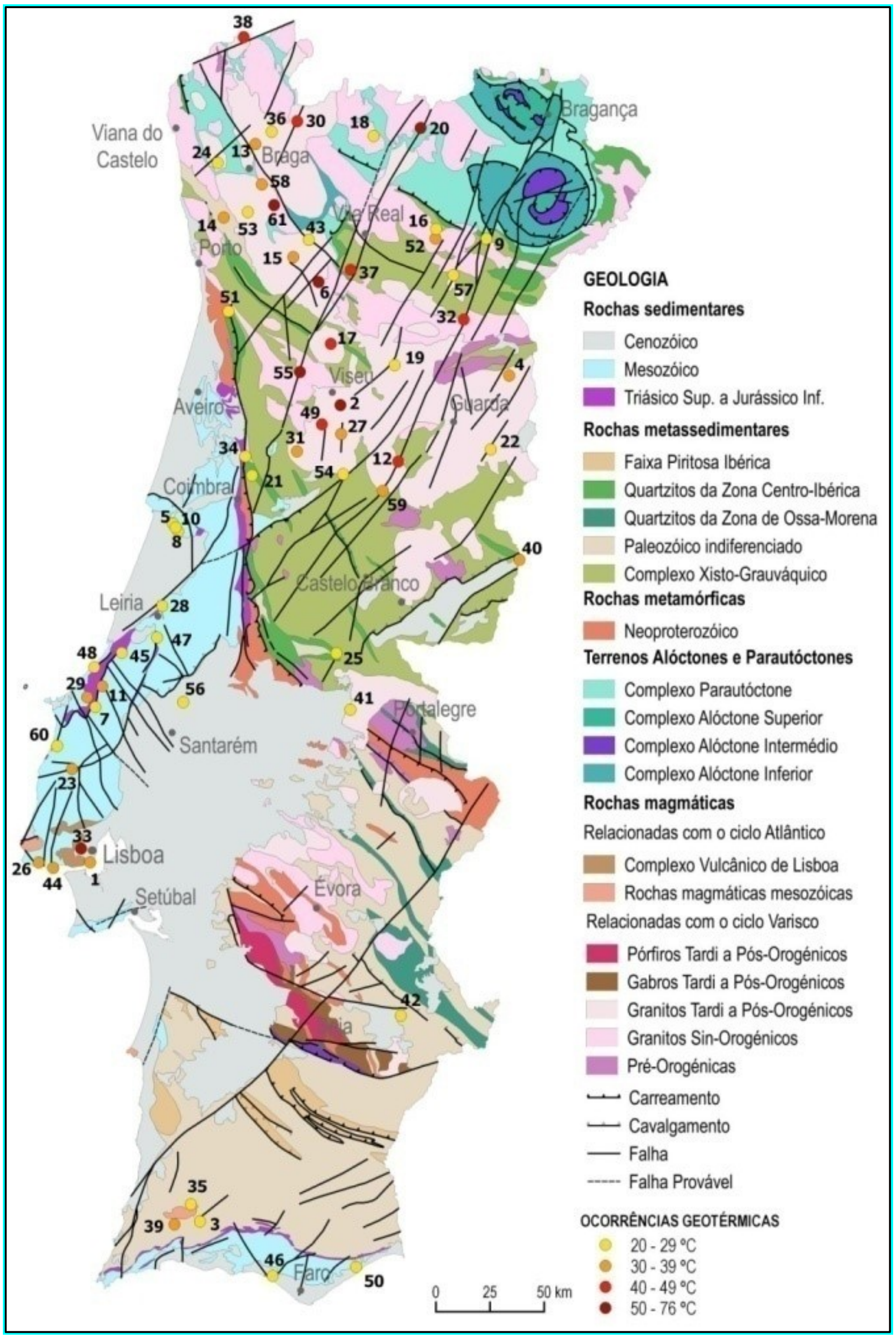


Figure 6: Geological map of Portugal Mainland and thermal occurrences (in: DGEG 2017).

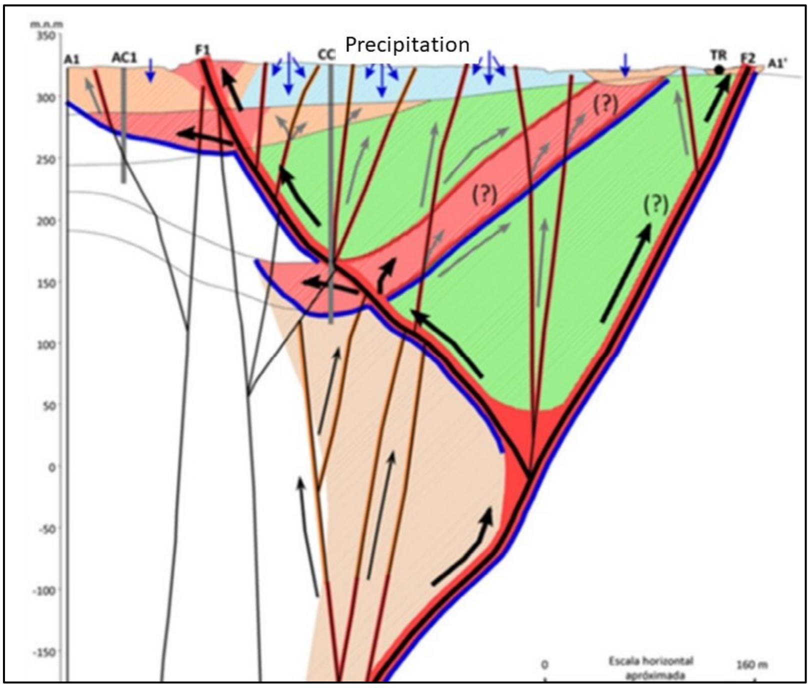
From the lithological point of view, the main rocks are granites of the Variscan orogeny and metasediments pre and post-orogenic. Weathering is quite irregular depending on tectonics and present and past climates: average reported depths to found rock massifs range from 0 to 60 m, but in the vicinity 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.

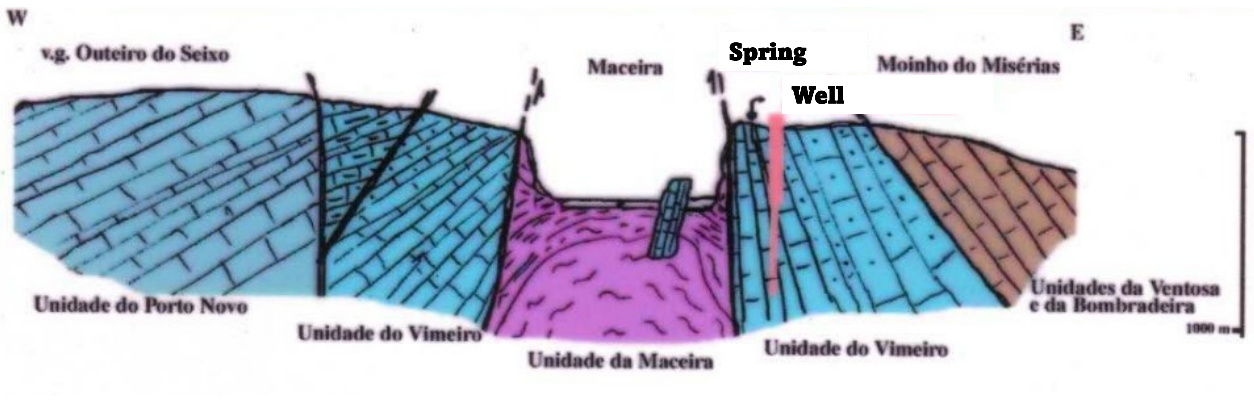
As expected, tectonics (and particularly active structures, for thermal waters, in a geological sense) is closely related to the occurrence of thermal springs. The distribution of Mainland users of geothermal energy (thermal baths) is superimposed in Figure 6 with tectonic data from Cabral (1995; in: 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 in tube wells and boreholes goes up to 77ºC. Among Portuguese mineral waters, twenty-eight discharges with temperatures higher than 25ºC are used for balneological purposes. Ten of those springs reach over 50ºC. 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 7 (Chaves) and 8 (Vimeiro), respectively.



<u>Figure 7:</u> Conceptual model of the Chaves thermal aquifer, close to the exploitation wells (Freitas 2015; in: DGEG 2021).



<u>Figure 8:</u> Conceptual model of the Vimeiro thermal aquifer (adapted from Chaminé et al. 2004).

The Portuguese government through the FAI – "Fundo de Apoio à Inovação", developed in 2021 (DGEG 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 '80s of the last century. Those resources were evaluated at about 184 GWh/year on Mainland and 9 GWh/year in the Azores mineral waters (DGEG 2021). Those figures are only indicative of the existing potential and has 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 1 to 4 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. 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.

The last decade was extremely relevant for high enthalpy geothermal resources in the Azores, as previously documented (e.g., Carvalho et al. 2015; Nunes et al. 2019; 2021; 2022). In the RGGF (S. Miguel Island) the development of geothermal resources has been well succeeded, 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 (S. Miguel Island) was only 133 GWh/year - 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 (Terceira Island) 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. Thus, in 2021 three deep wells were drilled with the main purpose to ensure the saturation of the existing power plant. In 2021 the production in the PAGF was about 26 GWh/year, 13,4% of the total production of electricity on the island (EDA, 2021).

3.2 Direct Heat Uses

Direct use application in Mainland and 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 (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 GSHP's are usually reversible, producing heat 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 Mainland and Azores (DGEG 2021).

3.2.1 District Heating

Two main operations are running normally in thermal baths:

- Chaves, Northern Portugal: a dedicated well, 150 m deep, 76ºC, 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, 74ºC, 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, 68ºC) is maintained as a backup well. Furthermore, in Chaves, an independent small operation (110 kW_{th}) was opened 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, 69ºC, 350 mg/L TDS, 10 L/s with the artesian flow, in fractured granite, supply 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 Vizela, Termas da Longroiva and Alcafache thermal baths on Mainland, and at Furnas hotels, in S. Miguel Island, Azores.

The two district heating and the three thermal bath direct uses in Mainland Portugal have a total energy use of about 15 GWh (DGEG/DSRHG 2021).

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

With the objectives defined by the European Community to cut greenhouse gas emissions by at least 55% by 2030 (EC, 2020), there has been increasing interest in surface geothermal projects in Mainland Portugal. Nevertheless, 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 project, especially concerning the residential sector.

Despite the lack of registration, there is some information about GSHP projects developed in Portugal (e.g., Edifícios e Energia, 2013, Cardoso & Lapa, 2015a; 2015b, Ferreira, 2019, Lapa, 2022), that was presented in more detail in previous reports (see also Carvalho et al. 2015; Nunes et al. 2016; 2021; 2022). After the implementation of the OMBRIA Project, other projects in the Algarve have followed. In addition to the installations mentioned in those previous reports (e.g., Brigantia Ecopark in Bragança, Aveiro University, Superior School of Technology of Setúbal (EST Setúbal), Sines Tecnopolo and Ombria Resort, Algarve installations), new projects are planned, namely an installation in a tourist resort in the south of Portugal where is estimated a total capacity of around 675 kW. Also, an installation is planned in a residential building in Lisbon, for heating and cooling with a total capacity of around 800 kW. Some installations are also foreseen for individual houses and for industry. Under construction are large new building projects in Lisbon city center (Tranquilidade and Fidelidade insurances company's buildings), where boreholes about 100 m depth, have been drilled to include simple "U" geothermal probes.

Despite the good climatic characteristics present in Portugal, some of the ground source heat pump projects need to be supported by other types of energy sources:

i) The Ombria Resort in Algarve has a surface geothermal system in a closed vertical circuit, composed of four distinct zones of boreholes. Each zone has a set of boreholes with lengths varying between 110 and 125 meters, in which geothermal probes are introduced (simple "U") through which water will circulate. However, to ensure sustained long-term exploitation, solar energy has been associated as a complement to geothermal energy. According to the designers' calculations, the geothermal heat pump system at the Ombria Resort allows a reduction of CO_2 production up to 373 ton/year, when compared to a "base" system of chillers and natural gas boilers;
ii) The CICFANO building of Aveiro University has the application of the geothermal solution on piles (10 m depth) and biothermal (urban effluent) for the air conditioning for acclimatization: the energy needs of the building were estimated to be 134 kWh when heating and 152 kWh when cooling (Lapa, 2022). The geothermal and biothermal solutions use 55 piles Ø600 mm, and 30 piles Ø400 mm, with 10 m of depth and serial connections, for an installed capacity of 100 kWh for heating and 90 kWh for cooling; Two thermal heat pumps, 2 storage tanks for DHW compensation, circulation pumps, and heat exchangers constitute the Thermo Activated Building System. The complementary heat source is the heat transfer of the urban effluents, composed of a steel heat exchanger of 320 mm 350 mm in emissary bypass, with a pressure drop of 84 L/s of effluent, and an average temperature between 21ºC and 25 ºC, 32 m long, with 3 tubes of stainless steel tubing for an installed power of 74,3 kWh for heating and 121,9 kWh for cooling (Lapa, 2022).

Costs associated with the implementation of geothermal heat pump projects are still very high, leading to very high payback periods for their application in private residential buildings.

Recently, the scientific project GeoSustained was funded by the Portuguese Science Foundation, with the aim to study the thermal behavior of Lisbon soils. The sustainability of different surface geothermal systems solutions operating under the climatic conditions prevailing in the city will be evaluated. It is also intended to study, through laboratory and mathematical modelling, the influence of temperature on the behavior of soils, with a view to the more efficient and safe use of this resource. The Consortium of the project is led by the Laboratório Nacional de Engenharia Civil (LNEC), and the following entities also participate in it: Lisbon City Council, Aveiro University, and Lisboa E-Nova.

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 last 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.

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, new three deep wells were drilled with the main goal to support the existing 4 MW Pico Alto power plant, that started operating in August 2017. In 2021 the energy production was about 26 GWhe, 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, with total energy used of 15 GWh (DGEG/DSRHG 2021).

In addition, in 2018 it was released a call 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. 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 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 35ºC, 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.

Concerning GSHP's 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. This new legislation was already prepared by the Directorate-General for Energy and Geology (DGEG) – the Portuguese authority for those geological resources – and 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.

Nevertheless, new installations were implemented in recent years and new projects are planned, namely an installation in a tourist resort in the south of Portugal and a residential building in Lisbon. Despite the good climatic characteristics present in Portugal, some of this ground source heat pump projects need to be supported by other types of energy sources.

The increased use of geothermal resources can be an attractive economic activity, especially in a context of economic crisis, as the energy can be applied under a regional framework of district heating or industrial networks, with positive effects on the development of the economy and job creation.

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Tables 1 – 4

Table 1. PRESENT PRODUCTION OF ELECTRICITY

Energy source	Geothermal		Hydro*		Nuclear		Fossil Fuels*		Other sources* (wind, photovoltaic & biomass)		Total	
	Installed Capacity (MWe)	Gross Electrical generation GWh/yr	Installed Capacity (MWe)	Gross Electrical generation GWh/yr	Installed Capacity (MWe)	Gross Electrical generation GWh/yr	Installed Capacity (MWe)	Gross Electrical generation GWh/yr	Installed Capacity (MWe)	Gross Electrical generation GWh/yr	Installed Capacity (MWe)	Gross Electrical generation GWh/yr
In operation in December 2021	32	159	7126	13 455	0	0	5634	21894	8023	18 845	**20815**	**54353**

(*) source: DGEG

Table 2. GEOTHERMAL POWER FIELDS, PLANTS AND UNITS IN THE COUNTRY

Geothermal Field

Name	Field operator	Wells in operation	Depth of deepest production well (m)	Reservoir type	System type
Ribeira Grande field - CL sector (S. Miguel Is.)	EDA Renováveis Company	4	2029	Hydrothermal	Two-phase, liquid-dominated: Medium enthalpy
Ribeira Grande field - PV sector (S. Miguel Is.)	EDA Renováveis Company	3	1135	Hydrothermal	Two-phase, liquid-dominated: Medium enthalpy
Pico Alto field (Terceira Is.)	EDA Renováveis Company	3	1230	Hydrothermal	Two-phase, liquid-dominated: High enthalpy

Power Plant

Name or number	(8) Plant operator	Combined Heat and Power (CHP)?	Co-production?	Hybrid energy system?	Percentage of energy produced from geothermal
Ribeira Grande	EDA Renováveis Company	No	No	No	
Pico Vermelho	EDA Renováveis Company	No	No	No	
Pico Alto	EDA Renováveis Company	No	No	No	

Power Unit

Name or number	Type of unit	Year of commission	Status	Turbine manufacturer	Installed Capacity (MW)	GEP (GWh/year)	NEP (GWh/year)
Ribeira Grande (Phase A)	B-ORC	1994	Operating	ORMAT	2.9		0
Ribeira Grande (Phase A)	B-ORC	1994	Operating	ORMAT	2.9		8.3
Ribeira Grande (Phase B)	B-ORC	1998	Operating	ORMAT	4.5		23.8
Ribeira Grande (Phase B)	B-ORC	1998	Operating	ORMAT	4.5		32.6
Pico Vermelho	B-ORC	2006	Operating	ORMAT	13		68.3
Pico Alto	B-ORC	2017	Operating	EXERGY	4		25.9

TABLE 3. SUMMARY OF GEOTHERMAL HEATING AND COOLING INSTALLATIONS IN THE COUNTRY

Geothermal Application	Total Installed Capacity (MWt)	Total Energy produced (TJ/year)	Total Energy used (TJ/year)	Number of Installations
Agriculture and food processing				
Industrial process heat				
Health, recreation and tourism	20.2		292.9	25
Heating and cooling for buildings	0.1		95.3	2
Other uses				

TABLE 4. HEATING AND COOLING PROJECTS IN THE COUNTRY AND RELATED GEOTHERMAL FIELDS

Geothermal Field						
Location	Name	Type of geothermal system	Wells in operation	Number of wells drilled over the last 3 years	Average TVD of wells under operation (m)	Max. temperature of the fluid (°C)
Mainland Portugal	Monção	Hot water system				49.0
Mainland Portugal	Chaves	Hot water system				74.0
Mainland Portugal	Caldelas	Hot water system				30.3
Mainland Portugal	Gerês	Hot water system				47.0
Mainland Portugal	Taipas	Hot water system				29.0
Mainland Portugal	Caldas da Saúde	Hot water system				30.0
Mainland Portugal	Carlão	Hot water system				27.5
Mainland Portugal	Aregos	Hot water system				63.0
Mainland Portugal	Carvalhal	Hot water system				60.0
Mainland Portugal	Cavaca	Hot water system				29.0
Mainland Portugal	São Pedro do Sul	Hot water system				67.0
Mainland Portugal	Alcafache	Hot water system				51.0
Mainland Portugal	Sangemil	Hot water system				40.0
Mainland Portugal	Felgueira	Hot water system				36.0
Mainland Portugal	Luso	Hot water system				24.9
Mainland Portugal	Manteigas	Hot water system				47.0
Mainland Portugal	Unhais da Serra	Hot water system				37.0
Mainland Portugal	Monfortinho	Hot water system				31.0
Mainland Portugal	Vimeiro	Hot water system				24.5
Mainland Portugal	Monchique	Hot water system				32.0
Mainland Portugal	Longroiva	Hot water system				47.0
Azores - S. Miguel Is.	Cald. R. Grande	Hot water system				70.5
Azores - S. Miguel Is.	Ferraria	Hot water system				62.1
Azores - S. Miguel Is.	Furnas	Hot water system				60.5
Azores - Graciosa Is.	Carapacho	Hot water system				37.6

Geothermal project (facility)												
Project name	Project operator	Geothermal application	Geothermal production technology	Nominal Capacity (MWt)	Energy used (net) (TJ/year)	Energy produced (gross) (TJ/year)	Hybrid energy system?	Percentage of energy produced from geothermal	Inlet temperature (°C)	Outlet temperature (°C)	No. of terminals
Monção		Heating and cooling for buildings	Heat Exchanger	1.52		30.6			49.0	20.0	
Chaves		Heating and cooling for buildings	District heating and cooling	3.39		71.2			74.0	20.0	
Caldelas		Health, recreation and tourism	Direct use of the fluid	0.32		6.1			30.3	20.0	
Gerês		Health, recreation and tourism	Direct use of the fluid	0.10		2.8			47.0	20.0	
Taipas		Health, recreation and tourism	Direct use of the fluid	0.17		2.4			29.0	20.0	
Caldas da Saúde		Health, recreation and tourism	Direct use of the fluid	0.17		4.0			30.0	20.0	
Carlão		Health, recreation and tourism	Direct use of the fluid	0.01		0.4			27.5	20.0	
Aregos		Health, recreation and tourism	Direct use of the fluid	0.72		22.7			63.0	20.0	
Carvalhal		Health, recreation and tourism	Direct use of the fluid	1.15		1.6			60.0	20.0	
Cavaca		Health, recreation and tourism	Direct use of the fluid	0.19		1.2			29.0	20.0	
São Pedro Sul		Heating and cooling for buildings	District heating and cooling	3.81		95.5			67.0	20.0	
Alcafache		Heating and cooling for buildings	Heat Exchanger	0.78		16.4			51.0	20.0	
Sangemil		Health, recreation and tourism	Direct use of the fluid	0.54		10.6			40.0	20.0	
Felgueira		Health, recreation and tourism	Direct use of the fluid	0.62		8.4			36.0	20.0	
Luso		Health, recreation and tourism	Direct use of the fluid	0.22		1.3			24.9	20.0	
Manteigas		Health, recreation and tourism	Direct use of the fluid	0.45		10.7			47.0	20.0	
Unhais da Serra		Health, recreation and tourism	Direct use of the fluid	0.51		11.2			37.0	20.0	
Monfortinho		Health, recreation and tourism	Direct use of the fluid	1.66		5.8			31.0	20.0	
Vimeiro		Health, recreation and tourism	Direct use of the fluid	0.55		1.2			24.5	20.0	
Monchique		Health, recreation and tourism	Direct use of the fluid	0.52		4.7			32.0	20.0	
Longroiva		Heating and cooling for buildings	Heat Exchanger	0.71		8.9			47.0	20.0	
Cald. R. Grande		Health, recreation and tourism	Direct use of the fluid	0.29		9.2			70.5	20.0	
Ferraria		Health, recreation and tourism	Direct use of the fluid	1.76		55.5			62.1	20.0	
Furnas		Heating and cooling for buildings	Heat Exchanger						60.5	20.0	
Carapacho		Health, recreation and tourism	Direct use of the fluid	0.18		5.8			37.6	20.0	