Geothermal Energy Use, Country Update for Portugal

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ABSTRACT

In Portugal, the presence of high temperature geothermal resources is restricted to the volcanic islands of Azores Archipelago, located in the North Atlantic Ocean and which are associated with the triple junction of the North American, Eurasian and African (or Nubian) plates.

Present investment projects at the Ribeira Grande Geothermal Field on the island of S. Miguel, implemented by EDA RENOVÁVEIS S.A. (former SOGEO – Sociedade Geotérmica dos Açores S.A.), led the installed generation capacity in Azores to a total of 23 MW net, with the contribution of the Pico Vermelho plant (10 MW net), which went into operation in November 2006. Thus, power production from geothermal resources in Azores presently meets about 44% of the electrical consumption of S. Miguel, and 23% of the total demand of the archipelago. Power production is stabilized since 2013.

On Terceira Island, evaluation tests of the existing wells were carried out during 2013/2014, and a 3.5 MW pilot power plant is now under construction at the Pico Alto Geothermal Field (PAGF), while deep exploratory drilling at the PAGF is scheduled to 2017.

Geothermal continue to be expected to assume an even more impressive role for electric power self-sufficiency of this Autonomous Region of Portugal, particularly in S. Miguel and Terceira Islands. However, its development is now considered in conjunction with other renewable energy sources, particularly wind energy.

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

In Portugal, ground source heat pump technology (GSHP) is gaining penetration in the heating and cooling of buildings market.

At Madeira Archipelago, in 2013, LNEG, the Portuguese National Laboratory for Energy and Geology carried out for EEM (Empresa Eléctrica da Madeira) a geothermal survey including geological, geochemical and geophysical investigations but the full results are not available so far.

1. INTRODUCTION

High temperature geothermal resources in Portugal are limited to the volcanic islands of Azores (Figures 1 and 2), where have been used for power production since 1980, at the Ribeira Grande Geothermal Field (RGGF).

In spite of some minor environmental impacts, the last years were extremely relevant for geothermal in the Azores (Cabeças et al., 2010, Carvalho et al., 2013, Carvalho et al., 2015), as:

- The generation capacity installed at the RGGF was expanded from the previous 13 MW, mainly concentrated at the Ribeira Grande plant, to a total capacity of 23 MW, including the Pico Vermelho plant;
- The development of geothermal generation projects on the island of S. Miguel has been well succeeded, with an annual average contribution of 42% of the electricity produced in the island since 2013.

Geothermal gained a renovated interest and assumes a leading position in the renewable energy portfolio of the island of S. Miguel. In the scope of renewable energies utilization expansion in Azores, the regional government considers geothermal as a main player for the development of new projects for electricity generation.

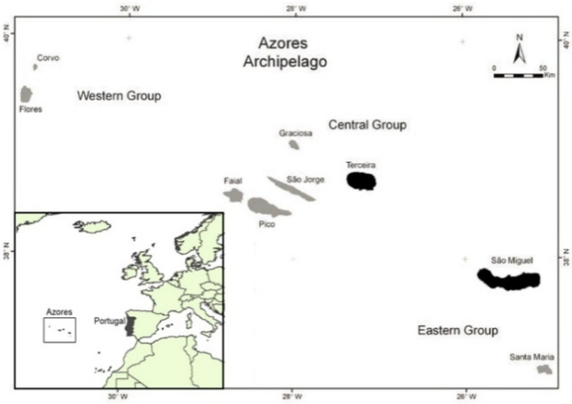

Figure 1: Location of Portugal Mainland, the Azores Archipelago and S. Miguel and Terceira Islands.

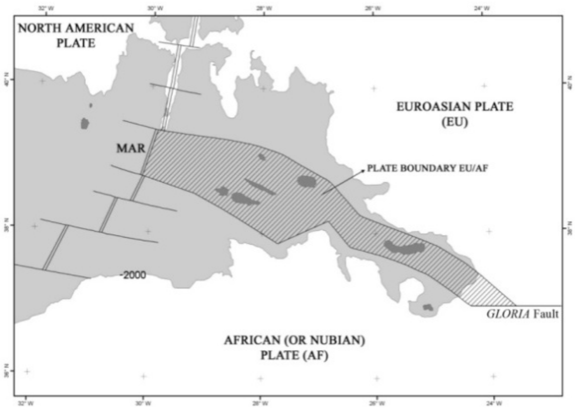

Figure 2: The Azores Triple Junction area. MAR: Mid Atlantic Ridge. Shaded area represents the "Azores Plateau" (adapted from Nunes et al., 2008).

The expansion of the installed capacity at the RGGF is under evaluation to increase the geothermal penetration on the market (more wells are to be drilled in 2017) to increase the available power up to 30 MW.

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).

Considering the high generation costs using fossil fuels, geothermal is a competitive source of energy, providing significant running savings to EDA S.A..

In Mainland, at present, there are no direct use projects running, outside a few existing Bath Spa's, and it is not envisaged the oncoming of new operations based in deep wells.

However, the municipality of Lisbon intends to develop at Alfama, an historic neighborhood, a brand new thermal spa including geothermal heating.

Portugal like the other Mediterranean countries has more leveled heating and cooling needs than Nordic countries. As a consequence, in Portugal GSHP's are usually reversible, producing heat and cooling. The equilibrium between heating and cooling in a dwelling is important in order to maintain the temperature stability of ground along the years.

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

2. GEOLOGY AND HYDROGEOLOGY BACKGROUND

Geology and hydrogeology controls the occurrence of geothermal resources, so a general description of these conditions is provided below, following a previous update report (e.g. Carvalho et al., 2015).

2.1 Mainland

In Mainland Portugal, classical geothermal resources are generally associated to the following origins: i) thermo-mineral waters related to active faulting and diapirism; and ii) deep circulation in some peculiar structures in the basement and particularly in the sedimentary borders trough permeable formations.

The existing temperatures restrain the utilization to direct uses. Twenty-four springs are officially used in balneotherapy having discharge temperatures between 25 ºC and 76 ºC (Figure 3).

From the lithological point of view, 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 sound rock ranges from 0 to 60 m but in the vicinity of main tectonic axis it is not infrequent to drill up to 300 m of weathered rock.

Naturally available discharging flows from former exploitation systems reached a maximum of 10 l/s. New wells up to 1,000 m depth, drilled after the seventies of the past century, allowed moderate improvements in sustainable production and in temperature (Carvalho, 2006).

Regarding chemistry, the following groups could be considered at the Variscan Massif: (i) hypo-saline waters with total dissolved solids (TDS) less than 150 ppm, frequently under 50 ppm. This less mineralized group corresponds mainly to water circulating in quartzite reservoirs, (ii) sulphurous waters with up to 1,000 ppm and temperatures up to 62 ºC, and (iii) carbonated sparkling waters with TDS up to 2500 ppm and temperatures up to 76 ºC.

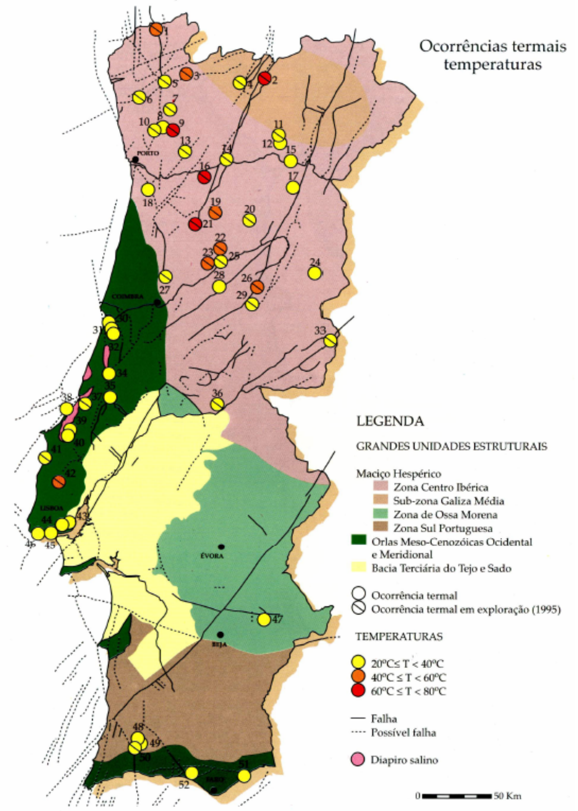

Figure 3: Geological sketch of Portugal Mainland, with thermal occurrences (adapted from IGM, 1998 - www.dgeg.pt).

The sedimentary borders composed of sequences of post Palaeozoic sediments with thickness up to 4,000 m also present several thermal waters related to deep faulting and diapiric tectonics. These waters are generally of the sodium chloride type and temperature from 20 to 40 ºC.

Synthesis of the Portuguese geological conditions related to mineral water and geothermal is available at the site (www.dgeg.pt) of Directorate General for Energy and Geology (DGEG), the Portuguese authority for those geological resources.

2.2 Azores Islands

The nine islands that form the archipelago of Azores are spread over 600 km in the Atlantic Ocean, along a WNW-ESE trend and emerge from the designated "Azores Plateau" (Figure 2), which is defined by the bathymetric line of 2,000 m. Being situated at the junction of the North American, Eurasian and African tectonic plates, the Azores display an intense seismic and volcanic activity. Since discovery and settlement of the islands, in early 15th century, 26 eruptions were recorded inland and onshore. Volcanic and seismotectonic activity are more concentrated in the Central Group and in the S. Miguel islands, those at the plate boundary between the Eurasian and African plates (cf. Figure 2).

Geochemically, the rocks in the Azores islands belong to the intraplate alkaline series and have a clearly distinct pattern from the toleiitic basalts from the Mid Atlantic Ridge.

On the island of S. Miguel, there are three active polygenetic volcanoes with caldera that produced explosive trachytic *s.l.* eruptions: Sete Cidades, Furnas and Fogo/Água de Pau. On the northern slopes of the Fogo volcano is located the Ribeira Grande Geothermal Field (Figure 4). The last event on that central volcano was a plinian eruption that took place in 1563 AD. Surface geothermal manifestations are spread in all those three central volcanoes, which are particularly impressive at Furnas with the presence of numerous thermal springs and fumaroles.

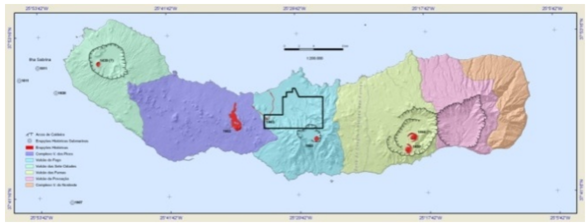

Figure 4: Volcanological map of S. Miguel Island (Nunes, 2004). The RGGF concession area is outlined.

On Terceira Island (Figure 5), 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 (Nunes, 2000). The Pico Alto volcano (the younger polygenetic volcano) is dominated by silicious formations, of pyroclasts and domes and *coulées* of trachytic and pantelleritic nature. At surface, the Pico Alto Geothermal Field (PAGF) encompasses the Pico Alto volcano and the Fissural Basaltic Zone formations (Figure 5).

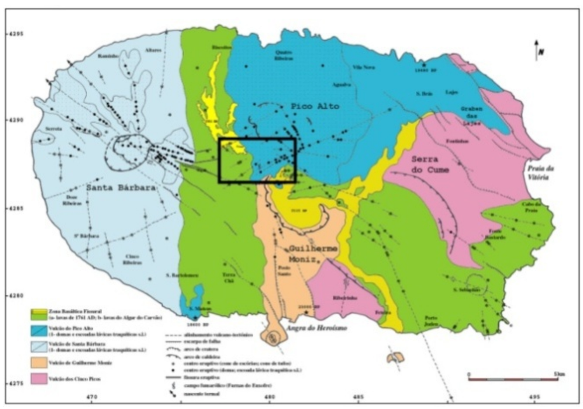

Figure 5: Volcanological map of Terceira Island (Nunes, 2000). The PAGF concession area is outlined.

Surface geothermal manifestations are reported in all islands but Corvo and Santa Maria islands. Presently four Thermal Baths/Spas using geothermal resources are installed in S. Miguel and Graciosa islands. In addition, the Caldeira Velha, Poça da Dona Beija and Parque Terra Nostra (S. Miguel Island) are also thermal attractions as well-being facilities.

3 GEOTHERMAL UTILISATION

Geothermal energy in Portugal is used for electricity production, for direct use in thermal baths/Spas and greenhouses, and in Ground Source Heat Pumps.

3.1 Electric Power Installation and Generation

At the Ribeira Grande Geothermal Field, S. Miguel Island, two geothermal power plants – Ribeira Grande and Pico Vermelho – are in operation with a net combined capacity of 23 MW (Table 1). Both plants are based on ORC binary systems.

The Ribeira Grande plant consists of four dual turbo-generators developed in two phases: Phase A (2 x 2,5 MW) installed in March 1994, and Phase B (2 x 4 MW) completed in November 1998.

The new Pico Vermelho plant started in November 2006 and replaced the former 3 MW pilot unit, in operation since 1980. This new phase at Pico Vermelho included the construction of a 10 MW power plant and an extensive drilling campaign, to increase the production and reinjection capacity in this sector of the RGGF.

All the geothermal brines resulting from the operation of the two geothermal power plants are re-injected.

The high productivity wells drilled in 2005 in the sector of Pico Vermelho allowed that the annual production attained 185 GWh in 2011 (Figure 6), representing approximately 44% of the electric consumption in the island of S. Miguel and 23% in the Azores archipelago.

The geothermal potential of Terceira Island has begun to receive some interest from researchers and politicians from the 70s of last century, but it was only in 2000 that an exploration license was granted in favor of GEOTERCEIRA (now EDA RENOVÁVEIS S.A.). The area of this license is located in the central part of the island in the Pico Alto volcano and close to the fumarolic field of Furnas do Enxofre.

In the licensed area, an AMT geophysical survey was carried out, and four thermogradient holes and five vertical evaluation production wells, those ones drilled in 2009/2010.

In 2013/2014 a campaign of short and long term tests was executed by GEOTERCEIRA with the support of the consultants GeothermEx, ÍSOR and TARH. Given the results it was decided by EDA REVOVÁVEIS S.A. to commission a 3.5 MW geothermal pilot power plant. This geothermal power plant is now under construction and is expected to start operation in the first semester of 2017.

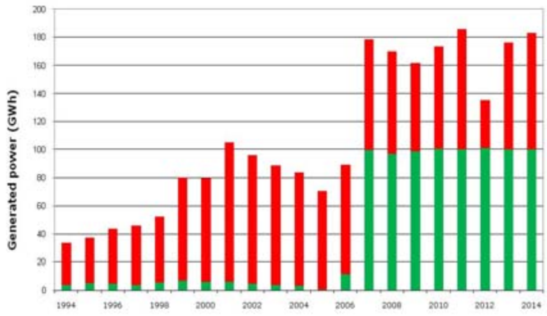

Figure 6: Annual geothermal power production in Azores for the period 1994-2014, including data for both the Pico Vermelho (in green) and Ribeira Grande (in red) plants (adapted from Ponte, 2012).

Simultaneously, extensive geological, hydrogeological, geochemical and geophysical exploration campaigns, under the coordination of TARH, Lda., were carried out in 2013/2014 aiming to improve the knowledge on the area and also to allow the delineation of a comprehensive conceptual model for the PAGF. This conceptual model was considered by EDA RENOVÁVEIS S.A. a management tool to reevaluate the geothermal resource and to design and locate new drillings (TARH & ISOR, 2016).

No direct uses related with the geothermal brines are in operation, as the former INOVA Institute greenhouse operation – financed by the THERMIE Program and running since 1997 (Rodrigues, 1998) – after 2005 was no longer nourished with geothermal effluent: that fact is related with the construction of the Pico Vermelho plant and subsequent re-injection of all effluent produced at the Pico Vermelho sector of the RGGF.

3.2 Direct Heat Uses

Direct use application in Mainland and Azores is restricted to small district heating operations, greenhouse heating and mainly balneological applications. The situation was reported recently, namely by Cabeças et al. (2010), Carvalho et al. (2013), Carvalho et al. (2015) and Lourenço (2016), and no significant changes are to be mentioned.

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). An independent well (100 m deep, 73 ºC, TDS of 2500 mg/l, 10 l/s capacity), taped hot water in metamorphic slates with quartz veins and feeds the Thermal Bath. A geothermal green

house, financed by the JOULE Project, is no more in operation;
- 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, 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 Vau greenhouse is no more in operation, since 2015.

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

3.2.2 Bathing and Swimming

Balneological activities using thermo-mineral waters are quite popular in Portugal for cure and touristic purposes. About 30 Thermal Baths are operating within a legal framework. Most are open only in summer, but some of them are operating normally 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 (e.g. Nunes et al., 2007; 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 last data recorded by EHPA, European Heat Pump Association, there were no new sales of GSHP in Portugal in 2014. The aggregated sales until 2014 was about 54 units with an installed capacity of 0.65 MW. Considering typical values, the installed capacity was 12 kW, with an operating hours value of 1,340 and a typical Seasonal Performance Factor (SPF) of 3.425. 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. 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 to 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, to promote the dialogue on geothermal community, to collaborate on new legislation, spread knowledge of technical standards and procedures, contributing to the training of the agents involved and to promote the development of new projects (http://www.ppgs.pt/ppgs).

As a consequence of PPGS work, new regulation is being prepared concerning shallow geothermal purposes and it is intended, among others, to establish the obligation to register all new GSHP's installations. So, it is expected to have statistical data of new installations in the near future.

In spite of the lack of registration, there is some information about GSHP projects developed in Portugal that are presented below (see also Carvalho et al., 2013, Edifícios e Energia, 2013, Cardoso & Lapa, 2015a; 2015b):

- Brigantia Ecopark in Bragança: it is equipped with three GSHP, one just for domestic hot water (DHW) heating and two for the 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 9,000 L. When the tanks are full, the excess of heated/cooled water is dissipated into the boreholes heat exchangers. Under this building there is a set of tubes to serve as an air inflow pre-heating to reduce energy consumption, thereby improving the system efficiency;

- Aveiro University (ECORR, ESAN, CCI, CICFANO and ESSUA buildings): Aveiro university has 5 buildings acclimatized with GSHP. Table 1 resumes the main properties of the installation;

- Superior School of Technology of Setúbal (EST Setúbal): the Polytechnic Institute of Setubal, that was a partner in GROUNDHIT European Project (6^{th} Framework Program), has a demonstration site for high energy efficiency GSHP's. Two GSHP's of 15 KWt for heating and 12 KWt for cooling, each, were installed in the thermodynamics laboratory, to acclimatize 7 office rooms with areas between 13 and 17 m^2 and 2 classrooms with 63 and 65 m^2. 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 GSHP's 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: the second example is another European project (7th Framework Program) called GROUNDMED, that aims at verifying sustainability of heat pump technology for heating and cooling of buildings in a Mediterranean climate. The Portuguese GROUNDMED installation is set on a regional authority administration building with offices and laboratories, located in Coimbra city. One GSHP with a heating capacity of 56 kWt and cooling capacity of 61 kWt (Eurovent conditions) serves the building 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 ceiling 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 kWt and the real heating capacity is 70.4 kWt, resulting in an increased performance. The results showed good results with a GSHP COP of 5.65 and an EER of 6.19;

- Sines Tecnopolo: this complex, that includes heating, cooling and domestic hot water production, has an existing renewed building with 251 m^2, a laboratory building with 534 m^2 and an office building with 1,286 m^2, all served by GSHP's. The existing renewed building is served by one GSHP with a heating capacity of 24.5 kWt and cooling capacity of 18.4 kWt, coupled to 2 simple U, 150 m vertical borehole heat exchangers;

- Aveiro University has been also collaborating with "Chama Energia" company in other projects as listed in Table 2.

Table 1: Main properties of the Aveiro University GSHP installation.

Designation	Year	Local	Building area (m^2)	Floors	Acclimatization area (m^2)	Annual heating needs (kWh)	Annual cooling needs (kWh)	Number of GSHP	GSHP COP	Thermo-active Foundations	BHE	Complement
ESSUA	2011	Campus de Crasto	3564	3	7660	612800	383000	4	4.3	147 thermal piles with 600mm and 8m deep, "U" vertical polyethylene heat exchangers with 32mm	22 BHE 150mm, double "U" vertical polyethylene heat exchangers with 32mm, 150m deep	
CICFANO	2012	Campus de Santiago	1600	3	3560	284800	178000	1	4.3	55 thermal piles with 600mm and 30 thermal piles with 400mm, 10m deep, "U" vertical polyethylene heat exchangers with 25mm		Thermal use of waste water effluents
ESAN	2013	Santiago de Riba-U1	4170	1	4088	327040	204400	4	4.3		34 BHE 150mm, "U" vertical polyethylene heat exchangers with 40mm, 150m deep	Solar painel
ECOCRR	2014	Campus de Santiago	2954	1	2240	179200	112000	1	4.3		22 BHE 150mm, "U" vertical polyethylene heat exchangers with 40mm, 120m deep	
CCCI	2015	Campus de Santiago	1600	3	3300	264000	165000	1	4.3		42 BHE 160mm, "U" vertical polyethylene heat exchangers with 40mm, 130m deep	Solar painel

4. CONCLUSIONS

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

Presently EDA RENOVÁVEIS S.A. has a total installed generation capacity in S. Miguel Island Azores of 23 MW net. That capacity ensures about 44% of the electrical consumption of S. Miguel, and 23% of the total demand of the archipelago. Power production is stabilized since 2013 and new wells are expected to be drilled in 2017 to increase the available power up to 30 MW.

On Terceira Island, EDA RENOVÁVEIS S.A. is building a 3.5 MW pilot power plant at the Pico Alto Geothermal Field (PAGF), to be running in the first semester of 2017.

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

At Madeira Archipelago, a general geothermal survey was performed by the LNEG, the Portuguese National Laboratory for Energy and Geology to the EEM–Empresa Eléctrica da Madeira company, but full results of that survey are not yet available.

Concerning GSHP's the potential is huge and is starting to be exploited, with new projects ongoing, new regulations being prepared and with the effort of PPGS in disseminating this technology. There are a few installations registered until 2014, but this tends to change due to the preparation of new legislation for regulating shallow geothermal operations. That will allow future statistical data to be more realistic and contribute to ameliorate the quality of the operations.

Table 2: GSHP projects of "Chama Energia" company, in cooperation with the Aveiro University.

Designation	Year	Local	Building area (m^2)	Floors	Acclimatization area (m^2)	Annul heating needs (kWh)	Annual cooling needs (kWh)	Number of GSHP	GSHP COP	BHE	Complement
EB23 Mortágua	2009	Mortágua	4300	3	4300	344000	215000	1	4.8	50 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
Hotel Aqua Village 5*	2015	Caldas São Paulo	6000	1	6000	480000	300000	1	6.2	33 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 150m deep	Solar painel
Hotel Stroganov 5*	2015	Fiais da Beira	320	3	960	76800	48000	1	4.3	10 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
CE Lorvão	2014	Lorvão	650	2	1300	104000	65000	1	4.3	10 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
CE Santa Comba Dão	2011	SCD	2200	1	2200	176000	110000	1	4.8	15 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
CE Santa Comba Dão	2011	SCD	1600	2	3200	256000	160000	2	4.8	18 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
CE Santa Comba Dão	2011	SCD	1400	3	4200	336000	210000	1	4.8	20 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
Centro Balmar	2007	Mortágua	1300	2	2600	208000	130000	1	5.0	14 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
APPC Viseu	2013	SC Dão	1250	1	1250	100000	62500	1	4.4	10 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
M. Coruche	2010	Coruche	2800	1	2800	224000	140000	2	4.1	18 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 100m deep	Solar painel
APPC Castelo Branco	2012	C. Branco	2200	1	2200	176000	110000	1	4.1	10 BHE 160mm "U" vertical polyethylene heat exchangers with 40mm, 130m deep	Solar painel

REFERENCES

Cabeças, R., Carvalho, J.M. and Nunes, J.C.: Portugal country geothermal update, *Proceedings of the World Geothermal Congress 2010*, Bali, Indonesia, (2010), paper #0165, 10 pp.

Cardoso, C. and Lapa, J.: A geotermia na sustentabilidade de campi universitários: os casos de estudo do edifício cicfano e da escola superior de saúde, *PPGS Newsletter* **3**, (2015a), 6-9.

Cardoso, C. and Lapa, J.: A geotermia na sustentabilidade de campi universitários: os casos de estudo dos edifícios de comunicações óticas, da escola superior Aveiro Norte comunicações rádio e robótica e do complexo do departamento de comunicação e arte, *PPGS Newsletter* **4**, (2015b), 8-10.

Carvalho, J.M.: *Prospecção e pesquisa de recursos hídricos subterrâneos no Maciço Antigo Português: linhas metodológicas*, Universidade de Aveiro, 292 pp, PhD Thesys, (2006), http://biblioteca.sinbad.ua.pt/teses/2007000122.

Carvalho, J.M., Coelho, L., Nunes, J.C. and Carvalho, M.R.: Geothermal Energy Use, Country update for Portugal, *Proceedings of the European Geothermal Congress 2013, Pisa, Italy*, (2013), paper CUR-24, 11 pp. (Cd-Rom Edition).

Carvalho, J.M., Coelho, L., Nunes, J.C., Carvalho, M.R., Garcia, J. and Cerdeira, R.: Portugal Country update 2015, *Proceedings of the World Geothermal Congress 2015*, Melbourne, Australia, (2015), paper #01065, 11 pp.

Edifícios e Energia Magazine, issue Nov./Dec., (2013).

IGM: Recursos geotérmicos em Portugal Continental: Baixa entalpia, *Instituto Geológico e Mineiro*, Lisboa, (1998), 23 pp.

Lourenço, C.: Geothermal resources, natural mineral and spring waters: an overview, *PIMBIS 2016– Portugal International Mining Business & Investment Summit*, Lisbon, April 12th-14th, (2016), pdf pps presentation.

Nunes, J.C.: Notas sobre a geologia da Ilha Terceira (Açores), *Açoreana*, **9 (2)**, Ponta Delgada, (2000), 205-215.

Nunes, J.C.: Geologia, in: Atlas Básico dos Açores, Forjaz, V.H. (Ed.), 60-62, *Observatório Vulcanológico e Geotérmico dos Açores*, Ponta Delgada, (2004).

Nunes, J.C., Lima, E.A. and Medeiros, S.: *Carta de geossítios da Ilha de Santa Maria*, 1/50,000 scale, Universidade dos Açores, Departamento de Geociências (Ed.). ISBN: 978-972-8612-47-4, (2008).

Nunes, J.C., Carvalho, J.M., Carvalho, M.R., Cruz, J.V., Freire, P. and Amaral, J.L.: Aproveitamento e valorização de águas termais no Arquipélago dos Açores, in: O Valor Acrescentado das Ciências da Terra no Termalismo e no Engarrafamento da Água. II Fórum Ibérico de Águas Engarrafadas e Termalismo, Chaminé, H.I. and Carvalho, J.M. (Eds.), 209-230, *Departamento de Engenharia Geotécnica/Laboratório de Cartografia e Geologia Aplicada (LABCARGA), Instituto Superior de Engenharia do Porto*, Porto, (2007), ISBN: 978-989-20-0892-9.

Nunes, J.C., Carvalho, J.M. and Olivera, L.C.: Águas termais dos Açores: passado, presente e futuro, *Balnea*, **10**, Madrid, (2015), 279-288. ISBN: 978-84-606-9368-0.

Ponte, C.B.: Aproveitamento de recursos geotérmicos para a produção de electricidade nos Açores, *Ingenium*, Set/Out, (2012), 64-67.

Rodrigues, A.C.: Geothermally heated greenhouses at Ribeira Grande (Azores) Portugal, in: Heating Greenhouses with Geothermal Energy. International Summer School on Direct Application of Geothermal Energy, Popovski, K. and Rodrigues, A.C. (Eds.), 433-441, *INOVA Institute*, Ponta Delgada, Azores, (1998).

TARH & ISOR: Conceptual model of the Pico Alto Geothermal Field, Terceira Island, Azores, Final Report. *EDA RENOVÁVEIS S.A. Internal Report*, (2016), 73pp.

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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 2015 *	23	182	17830	52000*	0.13	0.4
Under construction end of 2015	3.5	not available	not available	not available	not available	not available
Total projected by 2018	36	285	not available	not available	not available	not available
Total expected by 2020	36	285	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 2015 (indicate exploration/exploitation, if applicable):						

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)	2015 pro-duction * (GWh_e/y)
Ribeira Grande (S. Miguel Island, Azores)	Pico Vermelho	2006	1 (RI)	O	B-ORC	13.0	13	100.6
Ribeira Grande (S. Miguel Island, Azores)	Ribeira Grande	1994/ 1998	4 (RI)	O	B-ORC	14.8	10	81.4
total						27.8	23	182.0

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

** 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 geothermal district heating (DH) plants and other direct uses, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for individual 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 2015 *	2.1	53700	0	0	1.0	25570	17.1	309000
Under constru-ction end 2015	not available	not available	not available	not available	not available	not available	not available	not available
Total projected by 2018	not available	not available	not available	not available	not available	not available	not available	not available
Total expected by 2020	not available	not available	not available	not available	not available	not available	not available	not available

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})	2015 produc-tion * (GW_{th}/y)	Geoth. share in total prod. (%)
Chaves	Chaves	1982/ 2015	N	N	0.8	not available	23600	
S. Pedro do Sul	S. Pedro do Sul	2000/ 2015	N	N	1.2	not available	30100	
total					2.0	-	53700	

Table D2: Existing geothermal direct use other than DH, individual sites

Locality	Plant Name	Year commis-sioned	Cooling **	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 production * (GWh_{th}/y)	Geoth. share in total prod. (%)
Monção			N	not available	not available	not available	
Alcafache			N	not available	not available	not available	
Longroiva			N	not available	not available	not available	
Furnas (Azores)		2016	N	not available	not available	not available	
total				1,0	-	25570	

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

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2015 *		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2015 *	54*	0.65*	0.871*	not available	not available	not available
Projected total by 2018	not available	not available	not available			

Table F: Investment and Employment in geothermal energy

	in 2015 *		Expected in 2018	
	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				

Table G: Incentives, Information, Education

	Geothermal el. power	Geothermal direct uses	Shallow geothermal
Financial Incentives – R&D	Portugal 2020 and Horizon 2020 (EU)	Portugal 2020 and Horizon 2020 (EU)	Portugal 2020 and Horizon 2020 (EU)
Financial Incentives – Investment	no	no	no
Financial Incentives – Operation/Production	no	no	no
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	A few academic courses	A few academic courses
Education/Training – Vocational	A few academic courses	A few academic courses	A few academic 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)