Proceedings World Geothermal Congress 2010
Bali, Indonesia, 25-29 April 2010

Portugal Country Geothermal Update 2010

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Keywords: Portugal, Azores, power generation, self-sufficiency, EGS.

ABSTRACT

In Portugal, the presence of high temperature geothermal resources is restricted to the volcanic islands of the Azores, which are associated with the triple junction of the North American, Eurasian and African plates. New investment projects at the Ribeira Grande geothermal field on the island of São Miguel, implemented by SOGEO (Sociedade Geotérmica dos Açores, S.A.), have more than doubled the installed generation capacity in the Azores to a total of 23 MW net, with the contribution of the new Pico Vermelho plant (10 MW net), which went into production in November 2006. Thus, power production from geothermal resources in the Azores presently meets 39% of the needs of São Miguel, and over 20% of the total demand of the archipelago. On Terceira island, where the installation of a 12 MW net plant is planned, deep exploratory drilling conducted at the Pico Alto field has found a maximum temperature of 312ºC. An extensive drilling campaign at the Ribeira Grande and Pico Alto fields is underway, to provide additional production and injection capacity for new investments that are intended to increase the geothermal contribution to power generation in the Azores to 75% by 2018. Therefore, geothermal is expected to assume an even more impressive role for the power self-sufficiency of this region.

Low-temperature geothermal resources in mainland Portugal are exploited for direct uses in balneotherapy, small heating systems and heat pumps. In 2008, private investors obtained concession rights for exploration of geothermal resources for a total area of 2655 km^2, aiming the future development of small scale generation projects. These EGS projects are expected by the government to achieve up to 12 MW net of generation capacity.

1. INTRODUCTION

High temperature geothermal resources in Portugal are limited to the volcanic islands of the Azores, where have been used for power production since 1980, at the Ribeira Grande geothermal field (Figure 1).

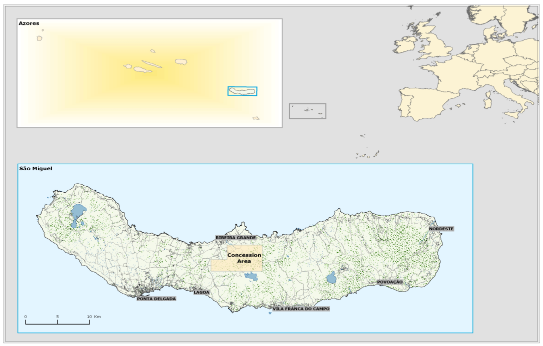

Figure 1: Location of the Azores, São Miguel island and Ribeira Grande concession area.

The last five years were extremely relevant for geothermal in the Azores:

- The generation capacity installed at the Ribeira Grande field was expanded from the previous 16 MW, mainly concentrated at the Ribeira Grande plant, to a total capacity of 23 MW.

- The recent development of the geothermal generation projects on the island of São Miguel has been very well succeeded, with an annual average contribution of approximately 39% of the electricity produced in the island.

Based on this successful scenario, geothermal gained a renovated interest and assumes clearly a leading position in the renewable energy portfolio. In the scope of the expansion of the utilization of renewable energies in the Azores, the regional government considered geothermal as the main source for the development of new projects for electricity generation.The expansion of the installed capacity at the Ribeira Grande field and the development of other projects in new areas where exploration has been carried out recently is expected to increase the penetration of geothermal to 75% by 2018.

These objectives were assumed by the regional electric utility EDA – Electricidade dos Açores, S.A., through its affiliated companies SOGEO - Sociedade Geotérmica dos Açores, S.A. and GeoTerceira - Sociedade Geoeléctrica da Terceira, S.A., which concentrate the local effort in the development of the generation projects in the region. Considering the high generation costs using fossil fuel, geothermal is a very competitive source of energy, providing significant savings to EDA. Therefore, has not been considered by the government a special funding program for geothermal, aside giving priority to this energy source.

2. GEOLOGY AND HYDROGEOLOGY BACKGROUND

2.1 Mainland

In the mainland, where crystalline rocks outcrop over 60% of the area, thermal waters are related with active faulting. Twenty-four springs used in balneotherapy have discharge temperatures between 25ºC and 76ºC.

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 range from a few m^3/d to 10 l/s. In general, with new-drilled wells up to 1000 m, it has been possible to increase former production.

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 group corresponds mainly to water circulating in depth in quartzite reservoirs, (ii) sulphurous waters with up to 1000 ppm and temperatures up to 62ºC, and (iii) carbonated waters with TDS up to 2500 ppm and temperatures up to 76ºC.

The sedimentary borders composed of sequences of post Palaeozoic sediments with thickness up to 4000 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 20ºC to 40ºC. Synthesis of the Portuguese geological conditions related to geothermal conditions is available in Aires-Barros and Marques (2000), Costa and Cruz (2000), Carvalho (1995, 1996; 1998), and Carvalho and Carvalho (2004).

2.2 Azores Islands

The nine islands that form the archipelago of Azores are spread over 600 km in the Atlantic ocean following a WNW-ESE trend, emerging from the designated “Azores Plateau”, which is defined by the bathymetric line of 2000 m. Being situated at the junction of the American, Eurasian and African tectonic plates (Figure 2), the Azores are obviously a region with intense seismic and volcanic activity. Since discovery and settlement of the islands, in early 15th century, 26 eruptions were recorded inland and onshore.

That dynamics is particularly concentrated in the vicinity of the Mid Atlantic Ridge and a tectonic structure that delineates the so called Terceira Rift, which corresponds to a branch of the Azores Triple Junction (Gaspar, 1996).

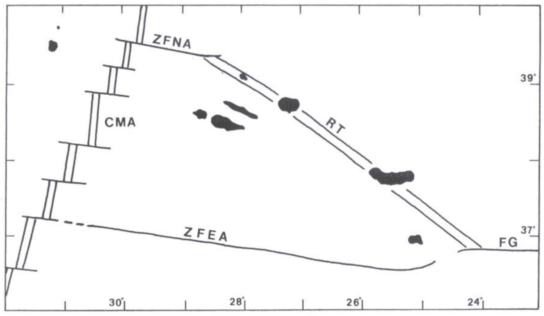

Figure 2: Main tectonic structures in the region of the Azores. CMA – Mid Atlantic Ridge; ZFNA – North Azores fracture zone; ZFEA – East Azores fracture zone; RT – Terceira rift; FG – GLORIA fault (Gaspar, 1996).

Geochemically, the rocks in the Azores islands are part of the intraplate alkaline series, clearly distinct from the toleiitic basalts from the Mid Atlantic Ridge.

On the island of São Miguel, there are three active central volcanoes that produced explosive trachytic 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 3). The last event was a plinian eruption that occurred in 1563 A.D. Surface geothermal manifestations are spread in all these volcanoes, which are particularly impressive at Furnas with the presence of numerous thermal springs and fumaroles.

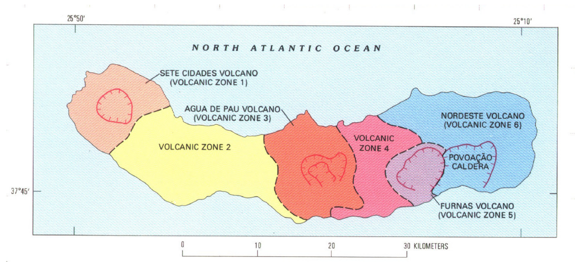

Figure 3: Volcanologic map of São Miguel (Moore, 1991).

On the island of Terceira (Figure 4), which has a complex tectonic setting, five volcanic complexes are considered (in chronologic order): Cinco Picos, Guilherme Moniz, Santa Bárbara, Pico Alto and the so called Fissural Basaltic Zone (Nunes, 2000). The Pico Alto volcano is dominated by pyroclastic formations alternated with lava flows, and domes of trachytic and pantelleritic nature.

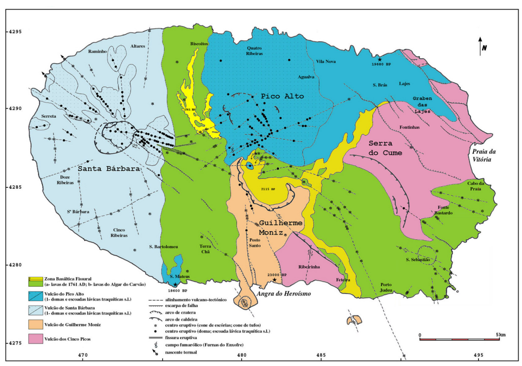

Figure 4: Vulcanologic map of the island of Terceira (Nunes, 2000).

Surface geothermal manifestations are reported in all but Corvo and Santa Maria islands and five spas using the geothermal resource are installed in São Miguel, Faial and Graciosa Islands.

3. GEOTHERMAL RESOURCES AND POTENTIAL

3.1 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 (quartzite strata) and particularly in the sedimentary borders trough permeable formations. The existing temperatures restrain the utilization to direct uses.

Main geothermal resources - thermo-mineral springs - related to faulting in the Variscan basement and diapirism in the sedimentary borders presents a total available capacity is of the order of 27,8 MW(t), if considering only the Variscan Massif. These capacities refer to an outlet temperature of 20ºC.

In the sedimentary borders deep aquifers are known as in the Lisbon area where a 1500 m deep well taped Cretaceous sandstones with 53ºC-bottom hole temperature (BHT). This well supplied the Air Force Hospital geothermal project in operation since 1992 till 2002 with 500 mg/l TDS water and temperature of 49ºC.

Oil wells in the Tejo and Sado basins (Carvalho et al 1990) suggest temperatures of 75ºC at 2500 m in Jurassic limestone with 5 000 ppm TDS water.

The higher geothermal gradient is about 3.5ºC/100 m (Anon, 1998a). Normal gradients are in the range of 2.1 ºC/100m (Ribeiro and Almeida 1981). That means average BHT of ca 50ºC at 1500 m depth.

Anon (1998b) suggests the equation

$$T(^{o}C) = 0.021\, x\ Depth\ (m) + 17.66 \qquad (1)$$

for the estimation of the temperature in a given depth in the Portuguese Sedimentary Borders: this linear regression model confirms an average geothermal gradient of 2.1ºC/100 m with an average shallow groundwater temperature of 17.7ºC.

According to Correia et al (2002) the regional heat flow density (HFD) is about 60-90 mW/m^2 in the Variscan Massif and 40-90 mW/m^2 in the sedimentary basins.

Potential for EGS projects is not yet scientifically assessed but the government agency (DGEG) expected to achieve up to 12 MW net of generation capacity.

3.2 Azores Islands

In the Azores, the presence of geothermal resources is associated to the active volcanism of the archipelago. Although extensive developments have been made at the Pico Alto field, the Ribeira Grande field continues to be the only high-temperature field under exploitation in the region. The conceptual model of this field has been described by GeothermEx (1996), Cabeças and Henneberger (2001) and recently updated by SOGEO and GeothermEx (2008). The Ribeira Grande field is an extensive liquid dominated system located on the northern flank of the Fogo stratovolcano elongated in a northwestern direction, which is likely to be related to a NW-trending pattern of faulting originated by the regional tectonic stress regime. However, the boundaries are not sufficiently delineated considering that drilling has been concentrated mainly in two sectors of the field and a geoelectric survey suggests that the field might extend to northeast further than considered previously.

The model of the reservoir considers that an upflow of geothermal water in excess of 250ºC enters in the reservoir in the proximity of the sector of Cachaços-Lombadas and moves laterally to northwest in an extensive zone of at least several hundred meters thick, in which temperatures exceed 220ºC. The geothermal water is sodium-chloride type, with TDS of about 6-7 g/l.

Exploratory drilling in the sector of Caldeiras of the Ribeira Grande field is planned for 2009 for confirmation of the extension of the reservoir towards this area and delineation of the additional generation capacity to be installed in this field.

On the island of Terceira, following the previous exploration studies that included a geoelectric survey and a temperature gradient drilling campaign, deep exploratory drilling and testing is in progress at the Pico Alto field. The preliminary results indicate the presence of a geothermal reservoir with temperatures in the range of 250 – 300ºC. Further drilling and long-term testing is required to determine the total extent of the reservoir and for characterization of the resource.

Reconnaissance studies and an AMT/MT survey were developed on selected areas of the Fogo and Sete Cidades volcanic complexes and in the island of Faial in 2006/2007 and temperature gradient drilling is planned to evaluate the most promising anomalies.

4. GEOTHERMAL UTILIZATION

4.1 Electric Power Installation and Generation

At the Ribeira Grande field 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 3 MW pilot unit, in operation since 1980. This project included the construction of a new 10 MW power plant and an extensive drilling campaign, to increase the production and injection capacity in this sector of the field. The high productivity wells drilled in 2005 in the sector of Pico Vermelho allowed that the annual power average of this unit is remarkably higher than the contracted power with the manufacturer. The annual production has been exceeding 170 GWh (Figure 5), representing approximately 39% in the island of São Miguel and about 20% in the Azores region.

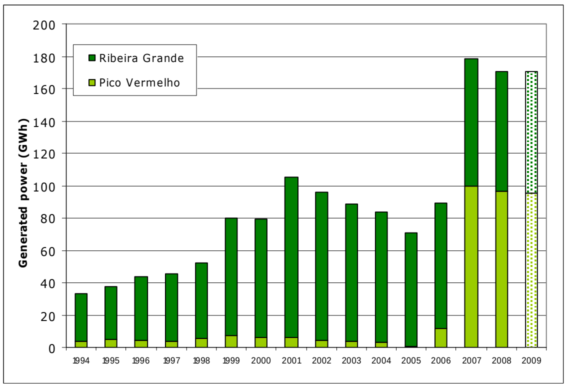

Figure 5: Annual geothermal power production in the Azores islands (Source: SOGEO, 2009).

On the island of Terceira, deep exploratory drilling is in course in the first semester of 2009 at the Pico Alto field for resource characterization for the purpose of installation a 12 MW power plant that is expected to be online in 2012.

4.2 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 by Carvalho et al (2005) and no significant changes were reported so far.

4.2.1 District Heating

Two main operations are running normally:

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

S. Pedro do Sul, central Portugal, the main Portuguese Spa: one inclined well, 500 m deep, 350 mg/l TDS, 10 l/s artesian flow, 69ºC in fractured granite, supply the Bath and is in use in a small heating operation in two hotels and inside the spa.

4.2.2 Greenhouse Heating

One single operation is running:

S. Pedro do Sul (Vau): two km south of São Pedro do Sul Spa two wells up to 216 m in granitic rocks (10 l/s at 68ºC, 350 mg/l TDS) are used in a 2 ha greenhouse producing tropical fruits (mainly pineapple).

The São Miguel, Azores: 6 x 200 m^2 demonstration greenhouses from INOVA Institute formerly heated with the geothermal effluent of Pico Vermelho geothermal power plant is no more in operation.

4.2.3 Bathing and Swimming

Balneological activities using termo-mineral waters are quite popular in Portugal for cure and tourist purposes. About 30 spas 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 spas is carried out under strict medical control.

Since 2004 the Azores Government decided to undertake the study on the possible utilization of the geothermal effluents of São Miguel Island and other low temperature resources for direct use including touristic activities and balneology. Resulting from these activities (Nunes et al 2006) new shallow wells were carried out in Ferraria (S. Miguel), Varadouro (Faial) and Carapacho (Graciosa)

4.3 Geothermal Heat Pumps

The last four years saw a crescent enthusiasm towards the utilization of geothermal heat pumps in mainland Portugal.

Two installers are operating regularly. There are no statistical data as these applications are not recognized as geothermal resource by the Portuguese administration.

Probably several dozen of single small installations are operating all over mainland Portugal, particularly in touristic areas and main towns.

5. ENHANCED GEOTHERMAL SYSTEMS (EGS)

At the end of 2008 two private Portuguese companies (Geovita S.A. and Gesto-Energia S.A.) applied for concessions for exploring geothermal energy resources aiming to develop EGS projects in mailand Portugal.

Geovita S.A. signed a 3 years contract of € 300,000 for an area of 530 km^2 in central Portugal over Variscan Granites where significant temperature anomalies could be related with radioactive activity.

Gesto S.A. signed equivalent contracts for three areas in the sedimentary borders between Leiria and Setúbal (627 + 672 + 826 km^2).

The level of investment suggests that no deep drilling is foreseen at this stage. Final target assumed by the Government is to attain 12 MW$_e$.

6. DISCUSSION

In the Azores islands, close to 30 years after the beginning of the exploitation of geothermal resources for power generation at the Ribeira Grande field, the contribution of this energy source assumes an extremely relevant role. The most outstanding features from the last five years include:

- The installed capacity was expanded from 16 MW net to 23 MW net, with the new 10 MW net Pico Vermelho plant.
- The annual production more than doubled in this period, increasing from approximately 80 GWh to 170 GWh, due to the high productivity wells drilled in the sector of Pico Vermelho.
- The contribution of the geothermal source represents today 22% of the power generated in the Azores region.
- Deep drilling in the new high temperature field of Pico Alto was developed and confirmed the presence of a productive reservoir.
- Approximately 60 M€ were invested on drilling of new wells, generation equipment and exploratory activities.

Finally, it should be emphasized that the generation costs are extremely competitive in the Azores due to its remote location, and allowed significant savings particularly during the price peak of the oil in 2008.

In the mainland, the geothermal exploration and exploitation has been quite stable during the period 2005-2010. Only three "deep" wells were drilled in that period over existing spa (Carvalhal, 600 m; Unhais da Serra, 750 m, and Fonte Santa de Almeida, 1000 m, in due course at 750 m). The results were: (i) a spectacular increase of temperature and flow rate at Carvalhal (from 3 l/s at 44.4 ºC to 6 l/s at 60ºC - Ferreira Gomes 2007), (ii) unsuccessful at Unhais da Serra and, (iii) appreciable temperature increase (19ºC to 35ºC) at Fonte Santa de Almeida (Personal communication J.Guedes, AQUALIS, 2009).

7. FUTURE DEVELOPMENT AND INSTALLATIONS

The very well succeeded production results of the Ribeira Grande project and the energy policy of the government of the Azores, favouring the development of renewable energies projects, conducted to the elaboration of plan for maximizing the contribution of the geothermal with the objective of providing 75% of the power generated by 2018.

In the scope of this ambitious plan is expected to be developed a total of 60 MW: i) development of the Pico Alto project with the installation of 12 MW power plant, which is expected to be online by 2012; ii) expansion of the generation capacity installed at the Ribeira Grande field; iii) development of other projects in promising areas of São Miguel and Faial. The total investment is expected to be approximately 200 M€.

Unfortunately, within the next years the electricity demand of the other smaller islands will be still insufficient to support the development of economically viable geothermal generation projects.

Given the increasing demand and (economic) interest regarding the Azores thermal resources and potential touristic products on that area, besides the ongoing tasks regarding the Bath and spas facilities, INOVA Institute (with the support of SOGEO S.A.) intents to carry out several studies on the use of effluents of the Pico Vermelho power plant (including its silica thermal mud's) for recreational and cosmetic purposes.

In mainland it is not expected significant activity, except regarding progress in geothermal heat pump technology and exploration for EGS operations.

8. ACKNOWLEDGMENTS

The authors would like to thank: SOGEO - Sociedade Geotérmica dos Açores, S.A. and GeoTerceira - Sociedade Geoeléctrica da Terceira, S.A. for authorizing and providing valuable data regarding the projects in the Azores; Roger Henneberger for his availability and review of the paper.

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APPENDIX

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr	Capac-ity MWe	Gross Prod. GWh/yr
In operation in December 2009	23	175		32542	4883	7797	0	0	3937	8251	8843	48765
Under construction in December 2009												
Funds committed, but not yet under construction in December 2009	32											
Total projected use by 2015	55											

Capacity is net capacity

Other renewables: Solar, biomass, waste and wind

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2009

1) N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

2) 1F = Single Flash B = Binary (Rankine Cycle)
2F = Double Flash H = Hybrid (explain)
3F = Triple Flash O = Other (please specify)
D = Dry Steam

3) Data for 2009 if available, otherwise for 2008. Please specify which.

Locality	Power Plan Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe*	Total Running Capacity MWe*	Annual Energy Produced 2009[3)] GWh/yr	Total under Constr. or Planned MWe
Ribeira Grande	Phase A	1994	2		B	6		77	
Ribeira Grande	Phase B	1998	2		B	9			
Ribeira Grande	Pico Verme	2006	1		B	13,5		98	
Total			5			28,5		175	

* Installed capacity is maximum gross output of the plant; running capacity is the actual gross being produced.

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2008 (other than heat pumps)

[1)] I = Industrial process heat
C = Air conditioning (cooling)
A = Agricultural drying (grain, fruit, vegetables)
F = Fish farming
K = Animal farming
S = Snow melting

H = Individual space heating (other than heat pumps)
D = District heating (other than heat pumps)
B = Bathing and swimming (including balneology)
G = Greenhouse and soil heating
O = Other (please specify by footnote)

Locality	Type	Maximum Utilization					Capacity	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy (kJ/kg)			Ave. Flow	Energy	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor
Monção	B	10,0	50	20			1,26	4,0	15,8	0,40
Chaves	B+D	15,0	76	20			3,52	11,0	81,3	0,73
Caldelas	B	9,3	33	20			0,51	4,5	7,7	0,48
Gerês	B	0,9	47	20			0,10	0,8	2,8	0,89
Taipas	B	7,3	32	20			0,37	2,0	3,2	0,27
Caldas da Saúde	B	4	30	20			0,17	3,0	4,0	0,75
Vizela	B+D	3,8	62	20			0,67	2,5	13,8	0,66
Carlão	B+G	0,5	29	20			0,02	0,5	0,6	0,99
Moledo	B	19,1	45	20			2,00	4,0	13,2	0,21
Aregos	B	7,5	62	20			1,32	4,0	22,2	0,53
Carvalhal	B	6,0	60	20			1,00	0,3	1,6	0,05
Cavaca	B	1,3	29	20			0,05	0,0	0,0	0,00
São Pedro do Sul	B+D+G	19,4	69	20			3,97	9,0	58,2	0,46
Alcafache	B	5,9	51	20			0,77	4,0	16,4	0,68
Sangemil	B	6,5	50	20			0,82	4,0	15,8	0,61
Felgueira	B	5,7	36	20			0,38	4,0	8,4	0,71
Luso	B	5,4	27	20			0,16	2,0	1,8	0,37
Manteigas	B	5,5	48	20			0,65	3,0	11,1	0,54
Unhais da Serra	B	10,2	37	20			0,72	5,0	11,2	0,49
Monfortinho	B	36,0	31	20			1,66	4,0	5,8	0,11
Caldas da Rainha	B	15,0	34	20			0,88	13,0	24,0	0,87
Vimeiro	B	15,0	26	20			0,38	2,0	1,6	0,13
Monchique	B	7,0	31	20			0,32	3,0	4,4	0,43
Longroiva	B	8,3	44	20			0,83	2,5	7,9	0,30
Azores Islands										
Caldeiras RGrande	B	1	90	20			0,29	1,0	9,2	1,00
Carapacho (Graciosa)	B	3,0	42	20			0,28	0,2	0,6	0,07
Ferraria (S. Miguel)	B	20,0	55	20			2,93	0,0	0,0	0,00
Furnas (S. Miguel)	B	5,0	92	20			1,51	2,5	23,8	0,50
Varadouro (Faial)	B	3,0	40	20			0,25	0	0,0	0,00
TOTAL							**27,8**		**366,35**	**0,42**

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2009

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (^oC) - outlet temp. (^oC)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W)
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% capacity all year

Note: please report all numbers to three significant figures.

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]			
District Heating [4]	1,5	12,9	0,3
Air Conditioning (Cooling)			
Greenhouse Heating	1,0	13,8	0,4
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	25,3	358,6	0,4
Other Uses (specify)			
Subtotal	27,8	385,3	0,4
Geothermal Heat Pumps			
TOTAL	27,8	385,3	0,4

4) Other than heat pumps
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2005 TO DECEMBER 31, 2009 (excluding heat pump wells)

1) Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)	2				3,4
Production	>150^o C	10				10,9
	150-100^o C					
	<100^o C		3			2,4
Injection	(all)	4				4,4
Total		16	3			21,1

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2005	2	14	9	5		1
2006	2	14	9	4		1
2007	2	14	9	3		1
2008	2	16	9	3		1
2009	2	19	9	5		1
Total	10	77	45	20		5

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2009) US$

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999						
2000-2004	2,5	6,4	0,25	8,5	50	50
2005-2009	8,5	71,4			90	10