Geothermal Exploration in Chile: Country Update

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ABSTRACT

During the last five years geothermal exploration in Chile has been very active for energy security reasons. The country depends on imports to meet more than 75% of its energy needs. At present, detailed exploration studies are being carried out by 14 private companies in 76 geothermal concession areas. Currently, Chile's installed electrical generation capacity is 19,127 MWe; 31% supplied by hydropower, 67% by conventional thermal power, 1% by wind, and 1% by biomass. Nearly 85% of fossil fuels must be imported for electricity generation.

The Chilean Government is trying to promote the development of non-conventional renewable energy sources (wind, solar and geothermal). There is now some growth in research funding for geothermal energy. The University of Chile has received a major grant to create the Andean Geothermal Centre of Excellence (CEGA), while the National Service of Geology and Mines is developing a basic geothermal research program. In spite of the country's great geothermal potential, this clean and renewable energy source has yet to be exploited for electricity generation; currently, it is used only for recreational and touristic purposes.

Over 70 geothermal exploration concessions have been awarded by the Chilean government to private companies, and exploration drilling has been conducted in at least 9 of these areas. Based on the results of these studies, eight exploitation concessions have been awarded. At two of these geothermal systems, Apacheta and Tolhuaca, the results of environmental impact studies have been submitted in advance of possible plans to develop these fields for geothermal power production.

1. INTRODUCTION

The Chilean Andes host one of the largest undeveloped geothermal provinces of the world. Geothermal resources could provide a clean source for electricity generation, since the country needs to import nearly 85% of fossil fuels for electricity production and more than 75% of all its energy requirements.

Geothermal resources in the Chilean Andes occur in close spatial relationship with active volcanism, which is primarily controlled by the convergence of the Nazca and South American Plates. The distribution of Quaternary volcanism is controlled by the dip and morphology of the Benioff zone (Figure 1). North of 28ºS and south of 33ºS the down-going slab dips easterly about 30º. In between (28ºS – 33ºS), the Benioff zone dips at only 5º - 10º and Quaternary volcanism is absent (Barazangi and Isacks, 1976). Two main geothermal volcanic zones can be distinguished within the Chilean Andes, the Northern Zone (17ºS – 28ºS) and the Central-Southern Zone (33ºS – 46ºS), both parallel to the Coastal Range. High-temperature spring areas are associated with the active volcanic zones; in regions where Quaternary volcanism is absent and along Coastal Range, thermal springs are scarce and their temperatures are usually below 30ºC (Hauser, 1997; Lahsen, 1976, 1988; Lahsen et al., 2005).

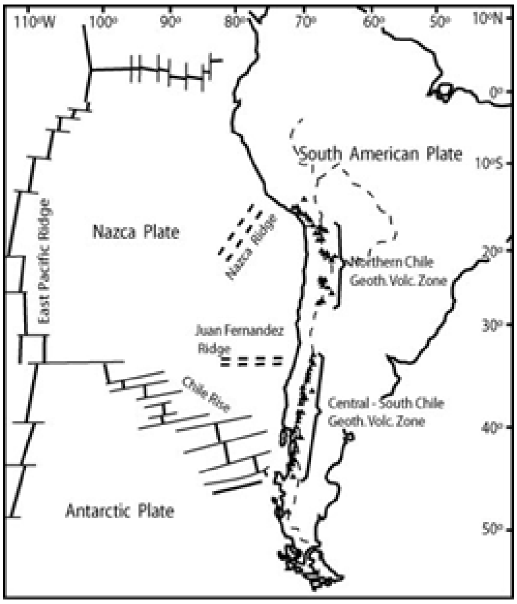

Figure 1: Active volcanic-geothermal zones of Northern and Central-Southern Chile

2. GEOTHERMAL EXPLORATION AND POTENTIAL.

Geothermal exploration in Chile is currently very active and is driven by the need for energy security. In the country there are more than 300 geothermal areas associated with Quaternary volcanism; preliminary assessment of the two geothermal volcanic-zones estimates a potential in the order of 16,000 MWe for at least 50 years from geothermal fluids with temperatures above 150ºC, located at a depth less than 3000 m (Lahsen , 1986). Due to the increasing demand for new sources of energy, during the last five years there has been a renewed interest for developing Chile's geothermal resources.

Currently in Chile there are fourteen private companies exploring 76 geothermal concession areas with the objective to narrow the focus and identify areas of highest technical and commercial potential. In all of these areas current exploration activities involves geological and tectonic surveys, volcanological studies, and geophysical and geochemical studies to find areas with high geothermal potential where exploratory drilling will be conducted (Figures 2 and 3).

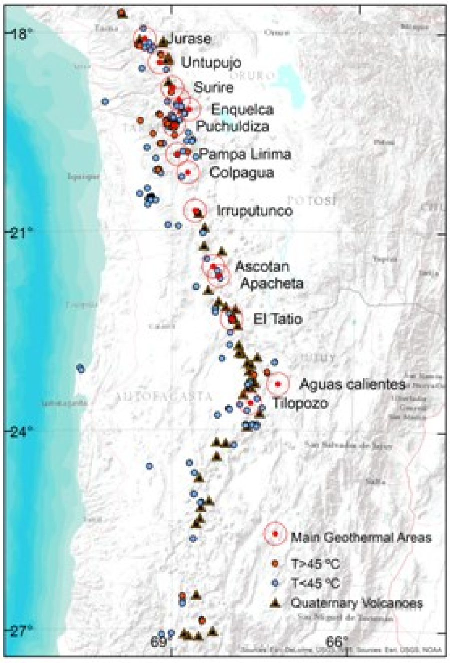

Figure 2: Geothermal prospects of Northern Chile.

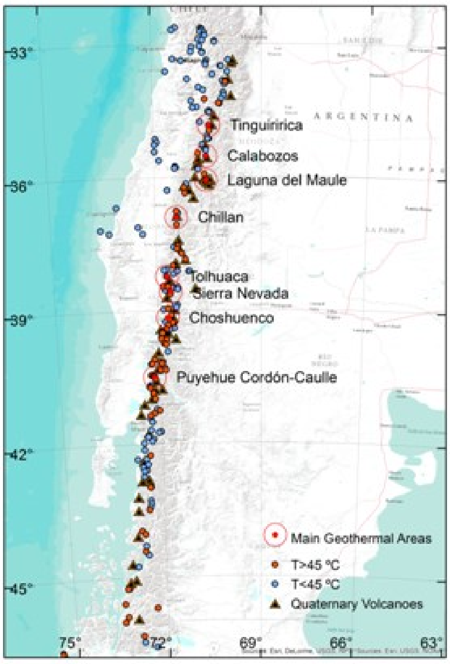

Figure 2: Geothermal prospects of Central-Southern Chile.

The Northern Chile geothermal zone has about 90 identified hot-spring areas (Hauser, 1997), and 45 exploration concessions are being surveyed. In this region, the most advanced exploration programs have been carried out in the Colpitas, Apacheta, Pampa Lirima and El Tatio-La Torta geothermal prospects (e.g., Urzua et al., 2002; Aguirre et al., 2011; Sofia and Clavero, 2010). Exploratory wells have been drilled in all of these four prospects. Their estimated combined power potential of exploitable geothermal energy is between 400 and 1,000 MWe. Exploitation concessions have been granted for the Apacheta and El Tatio geothermal fields, and the environmental assessment for the installation of a 50 MWe power plant has been approved for Apacheta. The El Tatio project is the most advanced, but, recently has been canceled due to the company failing to comply with environmental and safety requirements. The company Geotérmica del Norte, a joint venture of CODELCO, the State Copper Company, ENAP, the State Oil Company and ENEL, has indefinitely suspended geothermal development at the site (from Think Geoenergy website).

In the Central-Southern Chile geothermal zone there are more than 200 geothermal areas (Hauser, 1997) and 31 explorations concessions are underway. The most advanced exploration surveys have been completed at the Tinguiririca, Calabozos, Laguna del Maule, Chillán and Tolhuaca geothermal areas (e.g., Clavero et al., 2011; Sofia and Clavero, 2010; Melosh et al., 2010, 2012; Hickson et al.,2011). Exploratory wells have been drilled in all these prospects and the estimated combined power potential for the five areas ranges from 650 to 950 MWe. Exploration concessions were granted for the Laguna del Maule area (Mariposa sector) and Tolhuaca (San Gregorio) prospects, where production-size wells have been drilled. An environmental impact assessment was submitted to the authorities for the approval of the installation of a 70 MWe power plant at Tolhuaca where well Tol-4 has an output of 12 MWe based on flow testing data.

3. ELECTRICITY MARKET

In Chile, the electricity market is private and the State has only a regulatory role; the total installed capacity according to the CNE and CDEC (website data accessed December 2013) is 19,127 MWe with a gross production of 65,469 GWh/yr (Table 1). Most electricity in the country is generated by fossil fueled power plants (CDEC and CNE, website data accessed December 2013). The electricity distribution system consists of two major separated grids; the Northern Interconnected System (SING) and the Central Interconnected System (SIC). The SING has an installed capacity of 4,852 MWe, with a gross production of 14,101GWh/yr. Due to the extreme aridity of northern Chile, hydropower resources are virtually absent, and almost all the electricity is generated by burning fossil fuels (oil, natural gas and coal). In 2014, three solar electricity plants were installed with a capacity of 144 MWe. The major clients of the SING are the large copper mines, representing nearly 90% of the total power demand.

The SIC has an installed capacity of 14,130 MWe and a gross production of 50,941 GWh/yr, supplying electricity to 90% of Chile's population. The installed capacity of this system includes 26% large hydropower plants, 54% fossil-fueled plants (oil, natural gas, and coal), 2% biomass, 2% wind and 16% small hydropower.

There are two other small electrical distributions systems in Chile; the Aysen and Magallanes Systems in the southern extreme of the country. The first one has an installed capacity of 44 MWe (hydropower 47%, thermal power 49% and wind power 4%), while the Magallanes System has an installed capacity of 102 MWe supplied by conventional thermal power plants.

In Chile, electricity demand increases by about 5% a year; for this reason it is necessary to increase electricity capacity by approximately 1,000 MWe annually (Table 1).

4. DIRECT USE OF GEOTHERMAL RESOURCES

In Chile, geothermal resources have been traditionally used for recreational and touristic purposes. Direct use in spas and swimming pools accounts for an installed capacity of 11.31 MWt, which equals an annual energy use of 152.12 TJ/yr (assuming a 46% capacity factor). These values do not include about seven additional private thermal baths and hotels from which quantitative information is not available; for them one could roughly estimate a capacity of 2.20 MWt and an annual energy use of 27.30 TJ/yr (Tables 3 and 5). In most cases the thermal waters are collected from natural hot springs and piped to buildings and pools; only at four spas have shallow wells been drilled to extract geothermal waters. Generally, information on private investment for direct utilization projects is not easy to obtain.

The use of heat pumps in Chile began in 1996; 51 units were installed in the southern part of the country. Approximately 70% of them are closed-loop (ground-coupled) and the rest are open-loop (water-source) systems. The total installed heat pump capacity is 8.6 MWt with an energy use of 34 TJ/yr. Approximately 83% of the units are installed in commercial, industrial and institutional buildings; only 17% in houses and apartments (Table 5).

5. PERSONNEL

Estimates of personnel involved in geothermal activities in Chile consider only geoscientists and engineers, as administrative personnel are not included (Table 7). There are indications that the number of geothermal professionals has increased from 10 in 2001, to 45 in 2009 (Lahsen et al. 2005, 2010), reaching up to 96 professionals across the various sectors in 2014.

During the last few years there has been a significant growth in research funding; the National Geological and Mining Survey (SERNAGEOMIN), in collaboration with the German KfW, is developing basic geothermal studies in southern Chile. The Department of Geology of the University of Chile received a grant from the National Commission of Scientific and Technological Research (CONICYT) to create the Andean Geothermal Centre of Excellence (CEGA) with an annual US$1.5 million budget. Currently, the geothermal course at the Department of Geology has nearly 140 undergraduate engineering and geology students, as well as some PhD and MSc students.

6. INVESTMENT

Table 8 shows Chile's increase in geothermal investment from the previous half decades. During the last five years it has risen to around US$350 million from previous levels of around US$26 millon.

The public (Government) investment has decreased from 44% to 21%, coming through research funds and public institutions.

The main indicator of investment activity has been the well drilling program undertaken by some of the private companies exploring for geothermal resources. Table 6 shows that the number of drilled wells has also increased with respect to the previous half decade (Lahsen et. al., 2010).

7. CONCLUSIONS

Geothermal exploration in Chile has been very active during the last five years. This is driven by the country's continuing economic growth and by the need for energy security and fuels diversity:

- There has been an outstanding growth in the public funds for geothermal research,
- A significant increase in investment by companies that are exploring geothermal resources, and
- A significant increase in the number of geothermal concession areas.

However, none of the geothermal projects that have reached the exploitation concession phase have been developed into a producing field. The high cost of drilling and lack of spur transmission lines to connect with the existing power distribution system are some of the hurdles that need to be overcome before successful development of geothermal power in Chile can occur.

8. ACKNOWLEDGMENTS

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STANDARD COUNTRY UPDATE TABLES

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2014			12823	45208	6003	19648			302	562	19128	65469
Under construction in December 2014			340		425				700		1465	
Funds committed, but not yet under construction in December 2014			1200		1560				2383		5143	
Estimated total projected use by 2020	120		14363		7988				3385		25856	88428

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2014 (other than heat pumps)

Locality	Type[1)]	Maximum Utilization					Capacity[3)]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2)] (kJ/kg)			Ave. Flow	Energy[4)]	Capacity Factor[5)]
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	
Mamiña	B	2.7	51	28			0.26	1.9	5.76	0.7
Pica	B	2.3	34	26			0.08	1.6	1.69	0.66
Socos	B	3.2	30	22			0.17	2.56	2.7	0.5
Colina	B	7.3	50	24			0.79	5.62	19.27	0.77
Cauquenes	B	2.8	45	30			0.18	1.8	3.56	0.63
El Flaco	B	7	76	45			0.91	3.6	14.72	0.51
Panimavida	B	1.8	32	25			0.05	1.4	1.29	0.82
Chillán	B	15.2	65	45			1.27	7.8	20.57	0.51
Tolhuaca	B	4.6	61	45			0.31	2.7	5.7	0.58
Manzanar	B	6.9	48	35			0.38	1.9	3.26	0.27
Huife	B	8.2	52	40			0.41	2.1	3.32	0.26
Minetué	B	2.6	41	30			0.52	1.3	3.25	0.2
San Luis	B	0.8	40	28			0.04	0.6	0.95	0.75
Palguín	B	2.9	39	28			0.12	1.8	2.61	0.69
Coñaripe	B	6.5	64	45			0.52	1.3	3.25	0.2
Liquiñe	B	13.6	46	35			0.63	3.2	4.64	0.23
Puyehue	B	5	70	45			0.52	3.4	11.21	0.68
Aguas Calientes	B	4.5	65	45			0.38	2.8	7.38	0.62
El Amarillo	B	4.2	55	40			0.26	2	3.95	0.48
Puyuhuapi	B	13.6	68	45			1.31	4.2	12.74	0.31
Others 7	B						2.2		27.3	
TOTAL							11,30		152,12	0,46

B = Bathing and swimming (including balneology)

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2014

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]			
Air Conditioning (Cooling)			
Greenhouse Heating			
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	11.3	152.12	0.46
Other Uses (specify)			
Subtotal			
Geothermal Heat Pumps	8.60	34.00	
TOTAL	19.90	186.12	

[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, 2010 TO DECEMBER 31, 2014 (excluding heat pump wells)

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1]	(all)	12				10,47
Production	>150° C	6				9,85
	150-100° C					
	<100° C					
Injection	(all)					
Total		18				20,32

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

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

Year	Professional Person-Years of Effort					
	1	2	3	4	5	6
2010	5	9	8	9	3	42
2011	5	9	10	12	4	40
2012	6	9	10	12	8	48
2013	6	10	12	14	8	42
2014	6	10	14	15	8	44
Total	28	47	54	62	31	216

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

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2014) 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	2.00					100
2000-2004	5.20				10	90
2005-2009	13.42	12.25			56	44
2010-2014	241.40	103.00			79	21