Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geothermal Country Update of Argentina: 2015-2020

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Keywords: Geothermal exploration, magmatic-hydrothermal system, deep-seated hydrothermal system

ABSTRACT

During the last years, there has been a renewed interest in developing new energy sources in Argentina, resulting in a significant change in the power generation matrix. Through the Program of Electricity Supply from Renewable Sources (RenovAr), the national government awarded 147 projects equivalent to 4466.5 MW of installed capacity in different technologies (wind, solar, biomass, biogas and small-scale hydroelectric plants). However, geothermal energy had not been included in the technologies to be tendered. Within this framework, the government is working to tender the first Power Purchase Agreement (PPA) of geothermal Energy for the Copahue Geothermal Project, the only one at the feasibility stage at the national level. In this way, it is intended to encourage the development of other geothermal projects at the pre-feasibility stage and promote the development of the geothermal energy in Argentina. It is estimated that Argentina has a potential of more than 1000 MW for electric power generation from its geothermal resources. In this sense, the most interesting high-temperature geothermal systems in Argentina are located in the western sector (Central and Southern Volcanic Zones of the Andes), associated with the Neogene-Holocene volcanic arc. In this context, there are five projects oriented to electric power generation which are the most developed: Copahue (Neuquén), Domuyo (Neuquén), Tuzgle (Jujuy), Tocomar (Salta) and Los Despoblados (San Juan) and others that are in the initial exploration stage: Volcán Socompa (Salta), Cuenca Tucumán-Santiago del Estero, Caldera del Cerro Blanco (Catamarca), Volcán Peteroa (Mendoza) and Laguna del Maule (Mendoza).

Regarding direct uses, it is continuously working on the construction of balneology projects associated with deep-seated hydrothermal systems in sedimentary basins. These projects are located mainly in the central and eastern regions of Argentina. On the other hand, the geothermal heats pumps (GHP) projects have been a remarkable development in the last years.

Finally, The National Council for Scientific and Technological Research (CONICET) and the Geological and Mining Survey of Argentina (SEGEMAR) are the main organizations that promotes the R + D + I of geothermal resources in Argentina, through the financing of research projects oriented to produce the necessary base of knowledge for further accurate assessment of the geothermal potential and ultimately the implementation of the geothermal resource as a viable energy alternative. In this sense, recent investigations have provided new information that has allowed to improve the state of knowledge of the geothermal resource at the national level.

1. INTRODUCTION

Andean South American countries constitute promising sites for geothermal exploration due to their position upon the Pacific Ring of Fire, where magmatic and tectonic features favour the development of geothermal systems. Vieira and Hamza (2019) estimate that the entire South American continent hosts at about of 5.226 x 10^{12} GJ as geothermal resource base (at depths not exceeding three kilometres), where the Andean region represents more than >294 GJ/m^2 (resource base per unit area). Despite the proven existence of this resource in South America, only one geothermal plant is currently producing electrical energy across the continent. Inc is the recently inaugurated (September 2017) Cerro Pabellón 48 MWe installed geothermal power plant, in Chile (Aravena et al., 2016). Prior to this, a 0.67 MWe binary prototype unit was in operation for a short period of time until 1996 (Bertani, 2010) in the Copahue geothermal field (Neuquén Province, Argentina). Particularly, Argentina has an estimated geothermal potential of 490 - 2010 MWe (Bona and Coviello, 2016); however, this resource is currently only used for direct use (Fig. 1) such as balneology (52.7 %), domestic use (24.6 %), home heating (4.6 %), greenhouses (4.5 %), aquaculture (1.5 %), industrial uses (6.7 %) and snowmelt (5.4 %). During the last years, there has been a renewed interest in developing new energy sources in Argentina, resulting in a significant change in the power generation matrix. Through the Act 27.191 and the Program of Electricity Supply from Renewable Sources (RenovAr), the national government awarded 147 projects equivalent to 4466.5 MW of installed capacity in different technologies (wind, solar, biomass, biogas and small-scale hydroelectric plants). However, geothermal energy had not been included in the technologies to be tendered. Within this framework, the government is working to tender the first Power Purchase Agreement (PPA) of geothermal Energy for the Copahue Geothermal Project, the only one at the feasibility stage throughout the country. In this way, it is intended to encourage the development of other geothermal projects at the pre-feasibility stage and promote the development of the geothermal energy in Argentina. The National Council for Scientific and Technological Research (CONICET) and the Geological and Mining Survey of Argentina (SEGEMAR) are the main organizations that promotes the R + D + I of geothermal resources in Argentina, through the financing of research projects oriented to contribute and extend the necessary base of knowledge for further accurate assessment of the geothermal potential and ultimately the implementation of the

geothermal resource as a viable energy alternative. In this sense, recent investigations have provided new information that has allowed to improve the state of knowledge of the geothermal resource at the national level.

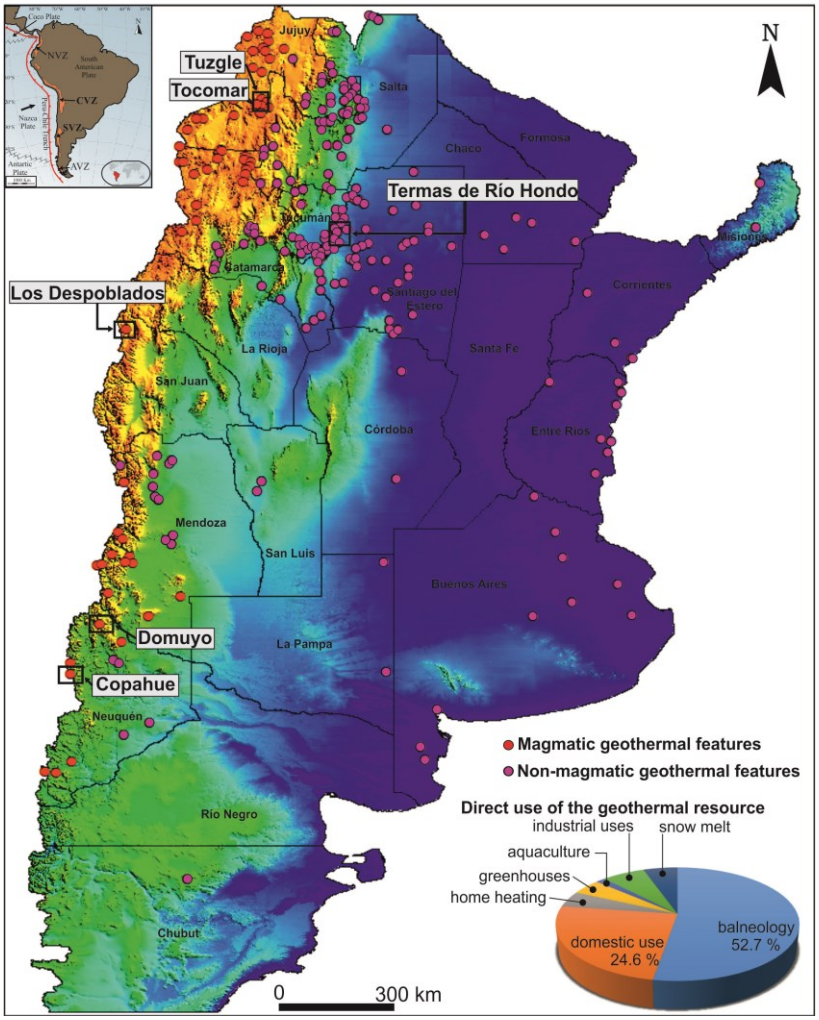

Fig. 1. Distribution of geothermal systems in Argentina. Western sector: magmatic geothermal systems likely related to the Neogene-Quaternary volcanic arc (red circles), Center and East: non-magmatic geothermal systems (purple circles). Projects oriented to electric power generation: Copahue, Domuyo, Tuzgle, Tocomar, Los Despoblados and Termas de Río Hondo. The distribution of the direct use of the geothermal resource is also shown.

2. GEOTHERMAL RESOURCES AND POTENTIAL

From the point of view of electric power generation, the most interesting high-temperature geothermal systems in Argentina are located in the western sector (Central and Southern Volcanic Zones of the Andes), likely associated with the Neogene-Quaternary volcanic arc (Fig. 1). While toward the east (extra-Andean region), medium to low-temperature geothermal systems associated with the deep circulation of meteoric waters is developed (Fig. 1). In this context, there are six projects oriented to electric power generation which are the most developed (Fig. 1): Copahue (Neuquén Province), Domuyo (Neuquén Province), Tuzgle (Jujuy Province), Tocomar (Salta Province), Los Despoblados (San Juan Province) and Termas de Río Hondo (Santiago del Estero Province) and others that are in the initial exploration stage: Socompa volcano (Salta Province), Cerro Blanco caldera and Cerro Galán caldera (Catamarca Province), Peteroa and Los Molles projects (Mendoza Province) and Laguna del Maule (Mendoza Province). Regarding direct uses, work continues on the construction of balneology projects associated with deep-seated hydrothermal systems in sedimentary basins. These projects are located mainly in the central and eastern regions of Argentina (Fig. 1). In addition, geothermal heats pumps (GHP) projects have been a remarkable development in the last years.

2.1 Magmatic Geothermal Systems: Projects Oriented to Electric Power Generation

Barcelona et al. 2017, suggest that the region with the highest geothermal potential in Argentina is located in the Southern Volcanic Zone (SVZ) of the Andes due to its tectonic and volcanic features. Within this region, the geothermal systems with the highest degree of progress (Fig. 1) are those associated with the Copahue volcano (e.g. Melnick et al., 2006; Mas y Mas, 2011, 2015; Chiodini et al., 2015; Roulleau et al., 2017; Barcelona et al., 2019a,b; Lamberti et al., 2019) and the Domuyo volcano (e.g. Mas y Mas, 2011; Chiodini et al., 2014; Tassi et al., 2016; Galetto et al., 2018). Toward the North within the Central Volcanic Zone (Fig. 1, CVZ; in Central Puna), the most advanced geothermal project in the development stage is the Tuzgle-Tocomar geothermal system (e.g. Coira, 1995; Sainato and Pomposiello, 1997; Giordano et al., 2013, Norini et al., 2014). Recently investigations (Filipovich et al., 2016, 2017a, 2017b, 2018; Giordano et al., 2016; Ahumada et al. 2017, 2019; Chiodi et al., 2019a), reveal the

existence of two independent geothermal systems for the previously defined Tuzgle-Tocomar geothermal system, significantly advancing in the knowledge of the Tocomar system and estimating a minimum power capacity of ~ 6 MWe (Filipovich et al., 2017a,b). On the other hand, in the Northern Puna, Coira (2008) reports numerous hydrothermal manifestations of high enthalpy (e.g. Vilama, Coranzulí, Turi-Lari). Although, Peralta Arnold et al. (2017) suggest high temperatures for the deep hydrothermal reservoirs (up to 200 ºC) based on fluid geochemistry data, the great depth of the geothermal resource in this region (possible > 5,000 m b.g.l.) likely constitutes a barrier for further studies aimed to evaluate possible exploitation. Regarding the Southern Puna, recent investigations (Viramonte et al., 2005; Chiodi, 2015; Chiodi et al., 2019b) unveiled a promising geothermal target, calculating a preliminary geothermal potential up to E = 11.4*1018 J. This is the Cerro Blanco geothermal system hosted in the youngest collapse caldera system in the Southern sector of the Central Andes (Middle Pleistocene-Holocene; Báez et al., 2015 and references therein; Fernández-Turiel et al., 2019). In addition, the Cerro Galán geothermal system is likely another interesting geothermal target due to its association with the largest caldera system (2.1 Ma in age, Key et al., 2011; Folkes et al., 2011) in this sector of the Andes (Chiodi, 2015 and references therein). Moreover, there are numerous magmatic-related geothermal manifestations throughout the Puna region with scarce or null investigations (Pesce and Miranda, 2003 and references therein).

2.1.1 Copahue Geothermal Field

The Copahue volcano is located at a latitude of 37.8º S at the Argentina-Chile border, a region with a complex tectonic setting (Barcelona et al., 2019a and references therein). The volcano has shown intense activity for the last 250 years (e.g. Petrinovic et al., 2014; Caselli et al., 2016; Folguera et al., 2016). The Copahue geothermal field, located in the northeastern flank of the volcano, is the most advanced Argentinian geothermal project thus far (e.g. JICA, 1992; Agusto et al., 2013; Chiodini et al., 2015; Tassi et al., 2017; Lamberti et al., 2019; Barcelona et al., 2019b). The deep-drilling exploration stage was carried out during several on and off stages between 1976 and 1991 and leads to perform production tests over a total of three exploratory wells (Barcelona et al., 2019b). The evaluation of the geothermal potential indicates that the field could generate electricity for 30 years with a capacity of 30 MW as the generation size of the plant (JICA, 1992; Pesce, 2010, 2015; Pesce et al., 2014). In this sense, a 0.67 MWe binary prototype unit was in operation for a short period of time until 1996 (Bertani, 2010). After that, the government of the Neuquén Province, through the Agency for the promotion and the Development of Investments of the Neuquén (ADI-NQN), was calling a public bid for private investors interested in building and operating a future plant for the generation of electrical power of 30 MW. In 2010, the Canadian company Geothermal One was awarded the tender, which was succeeded by the Australian company Heat Heat Resources, but in August of 2013, the company decided to withdraw for various reasons. Currently, Neuquén province throughout the ADI-NQN and the Under-Secretariat of Renewable Energy are working in tender documents in order to include the geothermal technology in the next round of RenovAr. At the same time, it's carrying out an initial assessment of public perception and acceptance of geothermal energy in local communities around the most advanced projects.

The degree of knowledge about the geothermal field is in constant progress through new investigations. The most recent research (Barcelona et al., 2019b) in the geothermal field proposes a layered model based on available multiproxy data including a shallow vapour zone at about 200-215 ºC above a pressurised fluid reservoir. The deep liquid-dominated reservoir has a temperature of ~ 280 ºC, developed below 1,500 m depth (Barcelona et al., 2019b). A natural thermal energy release of 107.5 MW was computed by using CO_2 as a tracer of the original vapour phase (Chiodini et al., 2015).

2.1.2 Domuyo Geothermal Field

The Domuyo Volcanic Complex (36º 340 S, 70º 250 W, 4,709 m high), is Middle Miocene to Early Pliocene in age and is located in the northwestern sector of Neuquén Province, in the Southern Volcanic Zone. The Domuyo volcano, with an estimated volume of ~ 200 km^3 and a base area of 138 km^2 (Volker et al., 2011), is a broad structural dome and forms, together with three other tectonic domes, a major anticline, the "La Cruzada" high (Folguera et al., 2007). The younger volcanic products were dated between 0.55 ± 0.10 and 0.11 ± 0.02 Ma (JICA, 1992), suggesting that Domuyo volcanism has been active through the Late Pleistocene. The western flank of the Domuyo volcano hosts one of the world's largest high-enthalpy geothermal field (Chiodini et al., 2014; Tassi et al., 2016). From this area, several boiling thermal springs discharge into roughly ENE-WSW-oriented creeks (Chiodini et al., 2014). Two hydrothermal explosions occurred in 2003, producing a vapour plume with a maximum height of about 300 m (Mas et al., 2009). This explosive event took place in a fumarolic area that characterises the SW part of the Domuyo volcanic complex and was attributed to local sealing of near-surface channels from where the hydrothermal fluids are discharges (Mas et al., 2009).

Chiodini et al. (2014) proposed a surprisingly high-energy release of 1.1 ± 0.2 GW, being the second-largest advective heat flux ever measured from a single on-land volcanic center (other than Yellowstone), suggesting that the high heat flux may originate from a magma intrusion at shallow depth, possible related to a recent reactivation of the Domuyo volcanic system. Based on geochemical analyses of gas and water samples, Tassi et al. (2016) proposed two possible reservoir levels: a relatively shallow hydrothermal reservoir (400-600 m) characterized by medium-enthalpy conditions and hosted by Cenozoic volcanic and Mesozoic sedimentary rock; and a deeper (2-3 km), high-enthalpy reservoir embedded in older units, which has been hypothesized by JICA as well (1992, 1984). Galetto et al. (2018) propose the high potential zone for geothermal energy production denominated "Domuyo Triangle Zone" (JICA, 1992). Equilibrium temperatures up to 220-240ºC likely referred to the shallow hydrothermal reservoir (Tassi et al., 2016). Tassi et al. (2016) show that their results confirm the promising indications of the preliminary surveys carried out in the 1980s, providing useful information for a reliable estimation of the geothermal potential and highlight the need to detailed geophysical measurements for a correct estimation of depth and dimensions of the fluid reservoir(s).

In 2015, the Federal Government, through the Secretariat of Energy, and within the framework of a "Program of studies in the energy sector of the Argentine Republic" financed through the Development Bank of Latin America (CAF), issued an international public tender to deepen studies in the Domuyo area. The bidding process ended with the award of the contract to the consortium between the Mexican geothermal company ENAL and the Argentinian engineering consultancy PROINSA. The main results of this study determined that geothermal reservoir is hosted in poly-deformed rocks of Choiyoi Group, Plutonitas Varvarco and part of the Sedimentary sequence of Neuquen basin. The secondary type permeability was produced by faulting and fracturing in two

deformation phases (late Cretaceous and late Miocene). The impermeable layers of Domuyo pyroclastic flows constitute the caprock of this geothermal system. According to geophysical surveys, there is a high resistivity between El Humazo and Los Tachos hot springs assumed as the core of the Domuyo geothermal system. Finally presents a potential of 100 MW according to the volumetric model coupled to Montecarlo probabilistic method, while an electrical potential was obtained using the gradual decompression model.

2.1.3 Los Despoblados Field

The El Cura valley develops within an N-S thrust system in the high Andes of San Juan Province, shows several geothermal manifestations, among which are those of hypothermal water surges of Los Despoblados (Barcelona et al., 2013). Magnetotelluric surveys carried out by Barcelona et al. (2014) defined two conductive anomalies, one directly linked with the hot springs and the other one without superficial manifestation. Both anomalies show structural control and deep circulation of geothermal fluids. The Despoblados geothermal system has plumes like upwelling zones channelled by faults that surround the valley and downwelling zones linked to the main thrusts, where the meteoric water leaks. Although there is no evidence of a shallow reservoir, is not discarded the existence of one bellow 4,000 m depth. The geothermal fluid circulation could be by normal geothermal gradient convection or favoured by a remnant thermal anomaly from the Cerro Vidrio volcanic event (1.5 Ma).

In addition, between 2010 and 2013 a Joint Venture formed by the Empresa de Energía Provincial de San Juan (EPSE), Geotermia Andina S.A. (GASA) and Barrick Gold Corp. have evaluated their potential, arriving at similar conclusions as were suggested by Barcelona et al. (2014): a normal geothermal gradient, the uncertainty about the existence of a main geothermal reservoir and the low temperature of the system. The project was announced to advance with deep exploratory drilling and a feasibility study for a 20 MWe geothermal plant (Energy News, 2013); however the activities stalled and there were no reports of further advances in the project to date (Bona and Coviello, 2016).

2.1.4 Tocomar Geothermal Field

The Tocomar geothermal area is located in the Central Puna in the vicinity of the NW–SE Calama–Olacapato–El Toro (COT) lineament (Norini et al., 2013 and references therein), one of the major active tectonic lineaments in the Central Andes. The area shows pieces of evidence of geothermal activity, including numerous hot springs and sinters-travertine deposits, along with profuse Quaternary volcanism (0.5 Ma; Petrinovic et al., 2006). A high voltage power line (345 kV) connecting Chile and Argentina runs parallel to the COT aside the main Salta-Antofagasta road, securing and easy connection for electric power generation from middle to high enthalpy fluid. Furthermore, the many mining prospects existing in the area would also provide for future local customers along with the nearby towns of San Antonio de Los Cobres and Olacapato (Giordano et al., 2013).

Numerous companies and researchers surveyed the area during the 1970s and 1980s (Aquater, 1980; Hidroproyectos et al., 1984; CREGEN, 1988; Coira and Kay, 1993; Ferreti and Alonso, 1993; Coira, 1995; Sainato and Pomposiello, 1997).

Recent investigations (Giordano et al., 2016) proposed a conceptual model based on a multidisciplinary study including new: stratigraphic, structural, hydrogeological, geochemical and magnetotelluric data. The main geothermal reservoir is located within the fractured Pre-Paleozoic-Ordovician units (~0.8-1.5 km; Ahumada et al., 2017), reaching temperatures up to 235 ºC (based on geothermometric calculations; Chiodi et al., 2019a). The sedimentary-pyroclastic cover would act as a seal of the system. The location of the hot springs above the intersection of the NW-SE main regional structures with secondary structures associated with the development of the Tocomar basin suggests that hot fluid upwelling occurs in areas intensely fractured. The coeval evolution of the Tocomar basin with bimodal magmatism in a narrow area is responsible for generating the local geothermal gradient of~ ~130ºC/km (Giordano et al., 2016). Filipovich et al. (2017a,b) present the first preliminary estimation of the geothermal potential of the Tocomar geothermal field for electricity production, carried out using the reformulated USGS heat in place volumetric method together with Monte Carlo simulations, suggesting a power production capacity between ~6 MWe to ~56 MWe.

2.1.5 Cerro Tuzgle Geothermal Field

The area surrounding the Quaternary Cerro Tuzgle volcanic field is located in the Puna plateau (NW Argentina, Riller et al., 2001 and references therein) and across the NW–SE Calama–Olacapato–Toro (COT) lineament (Viramonte et al., 1984; Salfity, 1985), one of the major active tectonic lineaments in Central Andes; it cuts through the entire Andean mountain belt from the Chilean forearc to the Argentinean foreland (Schurr et al., 1999). The area shows pieces of evidence of recent active tectonics (Petrinovic et al., 2006, 2010; Mazzuoli et al., 2008; Acocella et al., 2011) and several geothermal manifestations (Giordano et al., 2013). The same investigations carried out in the Tocomar geothermal field were made in this area due to previously to 2016 both Tocomar and Tuzgle were considered as unique geothermal system (Aquater, 1980; Hidroproyectos et al., 1984; CREGEN, 1988; Coira and Kay, 1993; Sainato and Pomposiello, 1997; Giordano et al., 2013).

The Cerro Tuzgle geothermal field is associated with Miocene-Quaternary volcanic complexes, which overlie a polydeformed Pre-Cambrian-Ordovician basement and Cretaceous-Oligocene sedimentary successions.

Coira (1995) investigated the local magmatic source using geothermometers and geobarometers minerals from the 0.5 Ma Tuzgle ignimbrite unit, estimating a pressure of 2.5 to 3 kbar for the magma chamber; therefore the existence of a middle crustal magma chamber was assumed to be adequate for explaining the geothermal anomaly of the area (Giordano et al., 2013). The magnetotelluric and gravimetric surveys supported the presence of the Cerro Tuzgle magma chamber, with its top below 8 km depth (Coira, 1995). According to later magnetotelluric and gravimetric surveys held by Sainato and Pomposiello (1997), the top of the magma chamber is located at 8 km depth and extends down to 22 km depth (Sainato and Pomposiello, 1997). According to CREGEN (1988), Tuzgle springs are of the alkaline-chloride type, with conductivities of 1920 to 6710 µS/m and temperatures between 39 °C and 56 °C. K-Mg and silica (chalcedony) geothermometers indicate reservoir temperatures of 134 and 143 °C, respectively (Coira, 1995).

Giordano et al. (2013) present a reinterpretation of the Vertical Electric Soundings (VES) performed by HIDROPROYECTOS S.A. (unpublished data, courtesy of Dr Giorgio Stangalino, Senior geophysicist at AREA GEOFISICA ENG. S.A.-Buenos Aires, Argentina) showing that the Cerro Tuzgle field is characterised by two main geoelectrical units. The low resistivity cover, on average 200–600 m thick with values >8–10 Ωm overlies a resistive basement characterised by values >500 Ωm (800 Ωm on average). The basement shows 1.2 Ωm low values confined in a vertical geometry, whereas in the cover, resistivity values are higher (3.2–4.4 Ωm) and increase up to 9 Ωm away from the main anomaly area pertaining (=permeating) to the entire cover geometry. The upwelling of hydrothermal fluids can only be associated with areas where the resistivity drops below 5 Ωm. The observed geometries suggest that fluids upwell through the basement along with vertical fractures, and then spread laterally into the shallow aquifer hosted by the poorly porous rocks which form the cover (Giordano et al., 2013).

Based on existing information Carrizo (2016) presents a preliminary estimation of the geothermal potential of the Cerro Tuzgle geothermal field for electricity production, carried out using the reformulated USGS heat in place volumetric method together with Monte Carlo simulations, suggesting a power production capacity between ~28 MWe to ~34 MWe.

No significant progress was made in the development of this geothermal area in recent years.

2.2 Non-magmatic Geothermal Plays: Direct-Use Oriented Projects

Towards the centre and the east of Northern Argentina, there are numerous hydrothermal manifestations related with both the Subandean foreland fold-and-thrust belt and sedimentary basins. Recent research (e.g. Barcelona et al., 2013, 2014; Invernizzi et al., 2014; Chiodi et al., 2015, 2016; Maffucci et al., 2015, 2016; Seggiaro et al., 2015) reveals the significant potential of the geothermal resources in this region.

The exploitation of geothermal resources at low temperatures, corresponding to the conductive hydrothermal systems, has allowed the generation of sustainable development in this region. Since several years these geothermal systems are being used for direct uses (e.g. Rosario de la Frontera thermal spa in Salta Province; Termas de Río Hondo in Santiago del Estero Province). In the last decade, significant progress was made in the knowledge and direct-use of the geothermal resource, mainly related with the construction of Thermal Complexes, among which the following projects stand out (Pesce, 2015): Wanda and 2 de Mayo (Misiones Province); San Roque, Curuzú Cuatiá and Monte Caseros (Corrientes Province); Chazón, Miramar and Mar Chiquita (Córdoba Province); Tigre, Ramallo, Navarro, Las Flores, Chascomus, Pehuajó, Tapalqué and Dolores (Buenos Aires Province).

The Termas de Río Hondo Project (central Argentina) stands out on this scene as the possibility of electricity generation is presently being evaluated.

2.2.1 Termas de Río Hondo Project:

The Termas de Río Hondo Project is located on the border of centre-west of the Santiago del Estero Province (central Argentina), where a strong anomaly of heat is found (Martin and Palazzo, 2007). In the period 1920-1950, the SEGEMAR investigated the area by exploration wells up to 910 m deep. At this depth, they obtained outflow water at 80°C with a flow rate of about 27 l/s. Later geothermal explorations allowed the estimation of a fractured saturated sedimentary basin, at a depth of more than 6,000 m, which most probably hosts an important hydrothermal reservoir of which just a surface outcropping spot is known.

A program conducted by the SEGEMAR with the aim to assess the future possibilities of electricity generation is currently under development. So far it has been interpreted that the continental lithosphere has a thinning of ~8-12 km (Febrer et al., 1982) and is fractured, generating an ascent of the asthenosphere and a regional geothermal gradient between 1.5 and 2 times higher than normal. An area of low resistivity was defined, which deepens up to 9.5 km, between two resistive areas that reflect the rise of thermal heat flow coming from the asthenosphere (Pesce, 2014). This information made it possible to delimit a more reduced zone, which has an area of 36 km^2, where the development of the next stage is planned. This area is located in a depression of tectonic origin, limited by the blocks of the Pampeanas Hills, the Aconquija Hills to the west and the Guasayán Hills to the east, where the sedimentary thickness of the entire column can reach values of more than 6,000 m (Febrer et al., 1982). Currently, it is intended to measure variations in the heat flow through gradient wells, to define the location for a deep exploratory well, which is expected to reach a depth of 2,000 m. In addition, temperature variations in 25 to 100 m-deep wells within the selected area were being measured (Pesce, 2015).

Farina Zeno (2018) conducted an evaluation of the possibility of generating electricity in different scenarios making use of the medium-temperature geothermal resource. Considering an optimistic scenario, it could be generated by using an Organic Rankine Cycle technology (ORC) a gross power output of 300 kWe and net power output of 275 kWe.

3. CONCLUSIONS AND FINAL REMARKS

The Act. 27191, published in 2015, establishes that renewable energies should reach 20% of the energy matrix by the year 2025, which constitute a great challenge, due to currently 95 % of Argentina's energy matrix is composed mainly of non-renewable energy sources: 63 % thermal, 28 % hydraulic and 5 % nuclear (CAMMESA, April 2019).

To achieve this goal, the national government through the Program of Electricity Supply from Renewable Sources (RenovAr), includes regular public bidding processes in which different companies present their investment projects and the price at which they are willing to sell their capacity.

So far, two tenders have been launched, with respective names RenovAr 1 and RenovAr 2, where a specific power amount was allowed divided according to the production source and the geographic location. In RenovAr 2, held in November 2017, 66 projects were awarded, for wind, solar, biomass, biogas, landfill biogas and small-scale hydroelectric plants. With respect to the prices with which energy is sold, these have fallen in each auction, with averages in Round 1, held in July 2016, of $59.70 per MWh, while prices in Round 2 averaged $40.40 per MWh (Farina Zeno, 2018).

The implementation of programs and promotion policies (e.g., RenovAr) has allowed increasing the participation of renewable energies in the energy demand of 1.8% in 2016 (installed power 0.8 GW) to > 5% with peaks of > 8% in the year 2018 (CAMMESA, May 2019).

Although the promotion regime considers the geothermal energy among renewable energy sources for electricity generation, none of the rounds of the RenovAr (1, 1.5, 2 and 3) has been included for bidding. This could be explained due to the initial uncertainty and risk involved in the exploration and development of the geothermal resource. Table 1 shows the Present and Planned Production of Electricity until 2019, where is possible to see an estimated Geothermal capacity of 30 MWe; however, this projection seems very unlikely due to the fact that only projects related to Hydro and Other Renewables are currently under construction. Table 2 shows that nowadays, there are no geothermal projects under construction or planned.

Finally, despite the potential of geothermal resources that Argentina has, it has a historically weak development of geothermal energy-oriented to electric power generation because it has encountered several problems. The main issues are the availability of geothermal resource information to developers and investors; the strength of institutions and government organisation with respect to geothermal energy development; an adequate policy and legal framework to attracting private investor and access to the project developer to suitable financing.

On the other hand, the direct-use projects have generated a significant impact on the local economies of some sectors of Argentina, favouring tourism ventures and productive developments (Table 3 and 5).

Table 1. Present and planned production of electricity.

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (specify)		Total	
	C	GP	C	GP	C	GP	C	GP	C	GP	C	GP
In operation in December 2019	0	0	24.583	87.727	10.790	37.420	1.755	6.453	1.193	3.354	39.042	137.482
Under construction in December 2019					1.310				912			
Funds committed, but not yet under construction in December 2019												
Estimated total projected use by 2020	30	237										

C: Capacity [MWe], GP: Gross Production [GWh/y].

Table 2. The utilisation of geothermal energy for electric power generation as of 31 December 2019.

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status1)	Type of Unit2)	Total Installed Capacity MWe3)	Total Running Capacity MWe4)	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
Copahue (NQN)	Copahue	1988	1	R	B	0.67	0	-	0
Total			1			0.67	-	-	0

(1) R: Retired, (2) B: Binary (Rankine Cycle), (3) Electrical installed capacity in 2019, (4) Electrical capacity up and running in 2019.

Table 3. The utilisation of geothermal energy for direct heat as of 31 December 2019 (other than heat pumps).

Locality	Type1)	Maximum Utilization					Capacity3)	Annual Utilization		
		Flow Rate	Temp (oC)		Enthalpy2) (kJ/kg)			Ave. Flow	Energy4)	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor5)
Federación (ER)	B-H	125	41	30			5.75	62.5	90.6	0.5
Concordia (ER)	B	73.3	41	32			2.76	36.6	43.4	0.5

Villa Elisa (ER)	B	33	38	28			1.38	16.5	21.7	0.5
Colón (ER)	B	41.6	36	25			1.9	20.8	30.1	0.5
La Paz (ER)	B	33.3	41	30			1.53	16.6	24	0.5
Villaguay (ER)	B	8.3	40	28			0.42	4.15	6.6	0.5
Maria Garande (ER)	B	9.7	43	28			0.6	4.85	9.5	0.5
Gualeguaychu (ER)	B	5.5	35	28			0.16	2.75	2.5	0.5
Basavilbaso (ER)	B	19.5	42	32			0.8	9.75	12.8	0.5
Victoria (ER)	B	12.5	37	29			0.41	6.25	6.6	0.51
Diamante (ER)	B	4.72	47	35			0.24	2.36	3.7	0.49
San Jose (ER)	B	12.2	38	31			0.35	6.1	5.6	0.5
Chajarí (ER)	B	101.2	39	31			3.4	50.8	53.6	0.5
Campo Timbo (SFE)	B	18.06	36	28			0.6	11.73	12.4	0.65
Obera (MIS)	B-H	44.4	51.3	33			3.4	40	96.5	0.9
Cerro Azul (MIS)	H	10.58	32.3	20			0.54	10.03	16.3	0.9
Posadas (MIS)	H	17.22	35	25			0.72	14.63	19.3	0.8
Uritorco (CBA)	B	20	38	28			0.84	8	12	0.45
La Carrindanga (BA)	G	6.94	55	32			0.66	3.12	9.4	0.45
San Clemente (BA)	B	8.9	41	29			0.44	5.8	9.2	0.66
Necochea (BA)	B	4.4	37	26			0.2	2.86	4.1	0.65
Medanos (BA)	B	33.3	54	33			3.01	20	55.3	0.58
Dolores (1) (BA)	B	16.6	42	25			1.18	10	22.4	0.6
Dolores (2) (BA)	B	8.5	37	32			0.17	5.1	3.4	0.63
Ramallo (BA)	B	6.2	36	30			0.15	2.48	2	0.42
Geral Belgrano (BA)	B	5.8	38	31			0.17	3	2.8	0.5
Bahía Blanca (BA)	B-H-F	244	55	32			23.5	73.2	222	0.3
Los Gauchos (BA)	B	22.2	44	34			0.92	10	13.2	0.45
Tapalque (BA)	B	10.5	31	25			0.26	3.15	2.5	0.3
Telsen (CHU)	B	5.1	23	18			0.1	1.53	1	0.31
Gan CHU)	F	5.5	22.8	14			0.2	3.85	4.5	0.7
Caimancito (JY)	B	7.8	38	32			0.2	3.51	2.7	0.4
Aguas Caliente (JY)	B	1	45	32			0.5	0.45	0.7	0.04
Termas de Inti (SAL)	B	0.5	45	30			0.03	0.15	0.5	0.5
Rosario de la Frontera (SAL)	B	8.9	45	32			0.5	5.8	9.9	0.62
Incachule (SAL)	B	4.2	45	32			0.22	0.84	1.44	0.2
Tocomar (SAL)	B	2.2	55	35			0.18	0.44	1.2	0.2

Fiambala (CAT)	B	2.5	53	33			0.2	1.25	3.3	0.5
Aguadita CAT)	B	2.7	38	25			0.15	0.81	1.4	0.3
Villavis (CAT)	B	1	45	30			0.06	0.3	0.6	0.3
Los Nacimientos (CAT)	B	1.5	36	30			0.04	0.45	0.35	0.27
Ojo de Villa vis (CAT)	B	6	24	22			0.05	1.2	0.3	0.2
La Colpia (CAT)	B	1	25	22			0.01	0.2	0.08	0.25
La Cienaga (CAT)	B	2.5	24	22			0.02	0.75	0.2	0.3
Vis (CAT)	B	7	31	25			0.17	1.75	1.4	0.26
La Soledad (SGO)	B	6.1	41	35			0.15	1.52	1.2	0.25
Rio Hondo (SGO)	B-H	1000	45	30			62.76	700	1.385	0.7
Santa Teresita (LR)	B	4.9	42	33			0.18	2.45	3	0.5
Suriyaco (LR)	B	2	40	30			0.08	0.6	0.8	0.3
Las Lajas (SJ)	B	4	36	22			0.23	1.8	3.3	0.45
Despoblados (SJ)	B	1	32	22			0.04	0.2	0.26	0.2
Rosales (SJ)	B	4	40	30			0.16	1.2	1.6	0.3
Pismanta (SJ)	B	7	43	30			0.38	4.55	7.8	0.65
Talacasto (SJ)	B	12.5	26	22			0.2	5.6	3	0.47
Rio Valvez (TdF)	B	9.7	37	32			0.2	4.85	3.2	0.5
Los Molles (MZ)	B	4.2	41	35			0.1	1.9	1.5	0.47
Cacheuta (MZ)	B	8.8	44	30			0.51	7.04	13	0.8
Carrillo (MZ)	B	0.5	38	33			0.01	0.2	0.13	0.4
Copahue (NQ)	B-H	79	43	30			4.3	15.8	27	0.2
Aguas Calientes(NQ)	B	5	43	30			0.27	1.5	2.6	0.3
Domuyo (NQ)	H	12.5	65	35			1.57	3.75	15	0.3
Epulaufque (NQ)	B	5	55	33			0.46	2	5.8	0.4
Larrude (LP)	B	5.1	29	25			0.08	2.55	1.34	0.5
Guatrache (LP)	B	3.4	31	25			0.08	1.7	1.34	0.5
Monte Casero (CO)	B	97.2	38	28			4.06	43.74	57.7	0.4
Curuzu Cuatia (CO)	B	41.6	42	29			2.3	20.8	35.6	0.5
TOTAL		**2330.32**					**137.21**		**1029.625**	

(1) **B: Bathing and swimming (including balneology), H: Individual space heating (other than heat pumps), G: Greenhouse and soil heating, F: Fish farming; (3) Capacity (MWt) = Max. flow rate (Kg/s)[inlet temp. (ºC) – outlet temp. (ºC)] x 0.004184; (4) Energy use (TJ/yr) Ave. flow rate (KJ/s) x [inlet temp. (ºC) – outlet temp. (ºC)] x 0.1319; (5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171.**

Table 5. Summary table of direct geothermal heat uses as of 31 December 2019.

Use	Installed Capacity1)	Annual Energy Use2)	Capacity Factor3)

	(MWt)	(TJ/yr = 1012 J/yr)	
Individual Space Heating4)	22.40	50.00	0.07070000
District Heating 4)			
Air Conditioning (Cooling)			
Greenhouse Heating	21.48	40.10	
Fish Farming	7.03	13.10	
Animal Farming			
Agricultural Drying5)			
Industrial Process Heat6)			
Snow Melting	1.36	31.60	0.73
Bathing and Swimming7)	137.21	1029.63	0.24
Other Uses (specify)	15.30	44.64	0.09
Subtotal	204.78	1209.07	
Geothermal Heat Pumps			
TOTAL	204.78	1209.07	

(1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (ºC) - outlet temp. (ºC)] x 0.004184; (2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (ºC) - outlet temp. (ºC)] x 0.1319; (3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171; (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 the electrical, direct and combined use of geothermal resources from January 1, 2015, to December 31, 2019 (excluding heat pump wells).

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration1)	(all)	3				3.5
Production	>150o C					
	150-100o C			15		12
	<100o C					
Injection	(all)					
Total		3		15		15.5

(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)
2015	11		7			5
2016	12		10	7	1	7
2017	16		12	3	1	7
2018	16		11		1	10
2019	16		17			12
Total	71		57	10	3	41

(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 2019 US$.

Period	Research & Development Inc. Surface Exploration & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilisation		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	4.8	1.2			70	30
2000-2004	1.5	3.5			85	15
2005-2009	5.3	6.5			80	20

2010-2014	6.5	15			80	20
2015-2019	7.1	?			75	25

ACKNOWLEDGEMENTS

A. Chiodi and R. Filipovich thank for financial and lodging assistance to University of Salta (UNSa) and National Scientific and Technical Research Council (CONICET), Argentina.

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