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Geothermal Country update of Argentina: 2020-2023

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ABSTRACT

Following the global trend of energy transition, during the las years Argentina has been incorporating more and more renewable energies into its energy matrix (11.6 %: mainly solar and wind, without any contribution from geothermal energy); however, it is still far from reaching the proposed goal of covering 20 % of the demand by 2025. Through the Act 27.191 and the Program of Electricity Supply from Renewable Sources (RenovAr), the national government awarded during the 2019, 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 continues to date without being included in the tenders. The latter being possibly linked to the state of progress of geothermal projects in Argentina, which in most cases are in the exploration stage. 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. 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 use of geothermal heat pumps (GHP) has experienced a marked increase in recent years, mainly in those areas where there is no access to the natural gas network. 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

The Andean convergent margin encompasses promising sites for geothermal exploration marked by high heat flow (>110 mW/m^2) related to the Central and Southern volcanic zones (Springer and Forster, 1998; Lucazeau, 2019), hosting around 294 GJ/m^2 as geothermal resource base (Viera and Hamza, 2019). Argentina has an estimated geothermal potential of 490 - 2010 MWe (Bona and Coviello, 2016), which is currently used for health, recreation and tourism (62.3 %), heating and cooling for buildings (37.3 %) and agriculture and food processing (0.4 %). Between 1988 and 1996, a 0.67 MWe B-ORC unit was in operation in the Copahue geothermal field (Neuquén Province), however actually it is decommissioned (Bertani, 2010). Although Argentina follows the global trend of energy transition, incorporating more and more renewable energies into its energy matrix (11.6 %: mainly solar and wind, without any contribution from geothermal energy; CAMMESA, 2021), it is still far from reaching the proposed goal of covering 20 % of the demand by 2025. Through the Act 27.191 and the Program of Electricity Supply from Renewable Sources (RenovAr), the national government awarded during the 2019, 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 continues to date without being included in the tenders. The latter is possibly linked to the state of progress of geothermal projects in Argentina, which in most cases are in the exploration stage. In this sense, Barcelona et al. (2021) conducted an analysis of the current state of the most advanced geothermal project in Argentina (Copahue Geothermal Project) concluding "that more work is needed before advancing towards the development stage of the project. That is mandatory to improve the estimates of the steam supply, enhance the success rate of wells by a new drilling exploration stage, resize the projected power plant and perform a more accurate feasibility report". Following this reasoning, it is essential to continue advancing in the knowledge of the geothermal resources of the country to achieve a successful evaluation of the geothermal potential in order to reach successful projects. On the other hand, significant progress has been made in the use of heat pumps, expanding the area of coverage in the last few years (Fig. 1).

2. GEOTHERMAL RESOURCES AND POTENTIAL

High-temperature geothermal systems (>230 °C; Sanyal, 2005) in Argentina are located in the western sector associated with the Neogene-Quaternary magmatic arc (Fig. 1A), whereas low-temperature geothermal systems (<150 °C; Sanyal, 2005) associated with deep circulation of meteoric waters occur toward the east (extra-Andean region, Fig. 1A) (Filipovich et al. 2022). In this framework, there are six projects oriented to electric power generation which are the most developed: 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. 1A). Besides, geothermal heat pumps (GHP) projects have been a remarkable development in the last years (Fig. 1B).

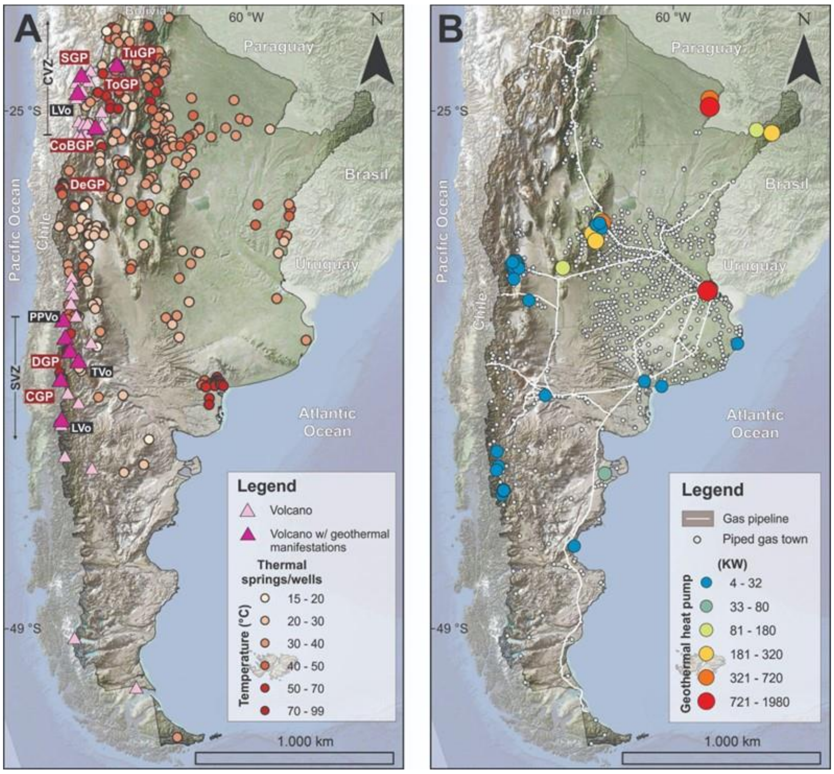

Figure 1: A) Hot springs and well discharges classified by temperature in Argentina. The location of the geothermal projects for the generation of geothermoelectric energy (red rectangles) and volcanoes with proven thermal manifestations (black rectangles) are also shown. TuGP= Tuzgle geothermal project; SGP; Socompa geothermal project; ToGP= Tocomar geothermal project; CoBGP= Cerro Blanco geothermal project; DeGP= Los Despoblados geothermal project; DGP= Domuyo geothermal project; CGP= Copahue geothermal project; LVo= Lastarrea volcano; PPVo= Planchón-Peteroa volcanic complex; TVo= Tromen volcano; LVo= Lanín volcano. B) Approximate location of geothermal heat pumps and nominal installed geothermal capacity. The location of pipelines and towns supplied by piped gas is included (data from https://www.enargas.gob.ar/).

2.1 Geothermal projects oriented to electric power generation

Barcelona et al. (2017) suggested that the region with the highest geothermal potential in Argentina is located in the Andean Southern Volcanic Zone (SVZ, 33–46° S) due to its tectonic and volcanic features. Within this region, the Copahue geothermal system is the project most developed. Toward the North, within the Central Volcanic Zone (CVZ, 16–28° S), there are numerous geothermal projects with varying degrees of knowledge (e.g. Chiodi et al., 2019; Guevara et al., 2021; Ahumada et al., 2022; Filipovich et al., 2022), from advanced stages of exploration (e.g. Tuzgle, Tocomar) to very incipient research (e.g. Botijuela, Aguas Calientes de Pastos Grandes, etc).

2.1.1 Copahue geothermal field

The Copahue volcano is located at a latitude of 37.8° 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). The Copahue geothermal field, hosted on 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 project reached a deep-drilling exploration stage during several on-and-off phases between 1976 and 1998. Its milestones are three production-diameter exploration boreholes, one slim hole, a low-scale district-heating project and a 0.64 MWe binary prototype unit that was in operation for only a few months (Mas, 2005; Mas and Mas, 2016; Barcelona et al., 2019b, 2021). Recent researches propose a layered reservoir comprising a shallow vapor zone at 200 - 215 ºC above a deep liquid-dominated reservoir at ~280 ºC that develops below 1,500 m depth (Barcelona et al., 2019a,b). Preliminary calculations achieved a power potential of 30 MWe (JICA, 1992; Nakanishi et al., 1995), but production tests yield that the current proved resource is below 10 MWe (Barcelona et al., 2021). Conservative volumetric heat in place estimations rise to ~15 MWe and ~35 MWe at 90 % and 50 % confidence, respectively, when a wider – probable – reservoir definition is considered. Despite this uncertainty, a direct measure of 255 °C at 1,200 m below surface (JICA, 1992), 100 MW_t release calculated using CO_2 as a tracer (Chiodini et al., 2015), extended hydrothermal activity illuminated by seismic events (Lundgren et al., 2017) among other evidence puts its enormous heat storage beyond doubt. In 2008, the government of the Neuquén Province, through the Agency for the Promotion and the Development of Investments of Neuquén (ADI-NQN), acquired the mining rights over the geothermal resources and is looking for funding to develop the project. After several attempts to put the project out to tender and encountering some social resistance in the project's area of influence, it was decided to put it on hold and focus on resolving the social issue.

2.1.2. Domuyo geothermal field

The Domuyo Volcanic Center (36º 34' S, 70º 25' W, 4,709 m a.s.l.) is part of the Southern Volcanic Zone in the northwestern sector of Neuquén Province. It is made up of a prominent anticline forced by a late Pliocene granitic stock (Groeber, 1947; Miranda et al., 2006) and a set of three north-to-south trend dacitic lava domes dated between 0.55 ± 0.10 and 0.11 ± 0.02 Ma (JICA, 1992; Miranda et al., 2006). The western flank of the volcano hosts a vigorous geothermal system expressed on the surface by numerous fumaroles, hydrothermally altered soils and hot springs. The Domuyo geothermal system is triggered by extensional and transtensional structures (Galetto et al., 2018), and preliminary calculations suggest that release 1.1 ± 0.2 GW, 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. The first conceptual models were proposed by JICA (1983, 1984) and Pesce (2013) and upgraded by Tassi et al. (2016), Galetto et al. (2018) and, recently, Fragoso et al. (2021). No substantial geological, structural or geothermometrical modifications were proposed in the most recent models; this observation highlights the excellent progress of the research carried out so far. The first conceptual model was based on: a) a first 600 m thick clay cap illuminated by electrical (JICA, 1983, 1984) and magnetotelluric survey (Fragoso et al., 2021); b) an 800 m depth liquid-dominated reservoir; c) a deep reservoir, around 2,000 m and 3,000 m depth (JICA 1983, 1984; Pesce 2013). While gas geothermometers suggest that the shallow reservoir is at 220-240 °C, the inferred deep reservoir has no geothermometric estimation available (JICA, 1983, 1984; Tassi et al., 2016; Esteban, 2020). Further chemical and isotopic analysis from La Bramadora fumaroles, the eastward manifestation of the geothermal field, is needed to assess the deepest levels of the geothermal reservoir. Recently, InSAR interferometry dataset demonstrated that the Domuyo is currently subjected to an inflation-deflation process suggesting a system driven by magmatic activity (Astor et al., 2019; Lundgren et al., 2020; Godoy et al., 2021). These fluctuations are consistent with several documented hydrothermal explosions (Mas et al., 2009), slope instabilities that trigger mass-wasting deposits (Hurley et al., 2020) and the recorded surficial heat flow subordinated oscillating degassing process (Lundgren et al., 2020). The Domuyo geothermal project reached pre-feasibility status during the 80s. The report included petrophysical, seismic, electrical, gravimetric and geochemical surveys and gradient boreholes (JICA, 1983, 1984). After a long period without significant advances, 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. A new pre-feasibility report was performed, reviewing the previous dataset and adding new gravimetric, 3D magnetotelluric, and geochemical surveys (see Esteban, 2020). The report presents a potential estimation of 100 MW by volumetric method and gradual decompression model (Hiriat and Sanchez, 1985), more than twice the previously estimated (JICA, 1984). Currently, social and environmental studies with the financial support of the IDB are being carried out for the following stages, as well as engineering studies to define the drilling targets.

2.1.3. Los Despoblados field

The El Cura valley develops within a N-S thrust system in the high Andes of San Juan Province, shows several geothermal manifestations, among which are those of hipothermal 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 plume like upwelling zones channeled 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 favored 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 (~24° S, NW Argentina) related to the <0.57 Ma Tocomar volcanic center (Petrinovic et al., 1999; Petrinovic and Colombo Piñol, 2006) linked to 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. A high voltage power line (345 kV) connecting Chile and Argentina runs parallel to the COT aside the main Salta-Antofagasta road, securing an easy connection for electric power generation from middle to high enthalpy fluid. In addition, this HV power transmission line integrates 300 MW into the grid, from a photovoltaic project (Puna Solar) 20 km west (Filipovich et al., 2022). 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; Filipovich et al., 2022; Ahumada et al., 2022) proposed a conceptual model based on a multidisciplinary study including new: stratigraphic, structural, hydrogeological, geochemical and magnetotelluric data. The Tocomar geothermal field is a fault-controlled geothermal system hosted by, to a minimum extent, at depths of 1,000–1,500 m below surface and lies within fractured Ordovician basement rocks. The main geothermal reservoir (Na^+-$Cl^-(HCO_3)^-$ in composition) is located within the fractured Pre-Paleozoic-Ordovician units (~0.8-1.5 km; Ahumada et al., 2017, 2022), reaching temperatures up to 235 ºC (based on geothermometric calculations; Chiodi et al., 2019a; Filipovich et al., 2022). 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 ~130 ºC/km (Giordano et al., 2016). The volumetric heat in place resource estimation method together with Monte Carlo simulations results predict a probable electric potential capacity above 1.23 MWe, 6.18 MWe, 11.67 MWe at the 90 %, 50 %, and 10 % confidence level, respectively (Filipovich et al., 2022). The inferred resources are less than a third of the previously calculated power capacity (Filipovich et al., 2017a,b).

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 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 cristal 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 characterized by two main geoelectrical units. The low resistivity cover, on average 200–600 m thick with values >8–10 Ωm overlies a resistive basement characterized 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 vertical fractures, and then spread laterally into the shallow aquifer hosted by the poorly porous rocks which form the cover (Giordano et al., 2013). In 2015, the private company Andean Geothermal Power Inc. completed a prefeasibility study at Tuzgle field. The company reported geothermometry values of 180 °C to 200 °C (type of geothermometer not reported) and suggested a minimum capacity of 16 MWe to 34 MWe with 50 % probability via Monte Carlo simulation modeling, and higher values ranging from 35 MWe (90 % probability) to 70 MWe (50 % probability) based on geophysical studies (Lindsey et al., 2021). Similar calculations (between ~28 MWe to ~34 MWe) were presented by Carrizo (2016).

2.1.6. Volcan Socompa

The Socompa Geothermal Prospect (SGP, Guevara et al., 2021) is related to the Socompa Volcano, a Quaternary stratovolcano located at 24.4° S in the southern segment of the Central Volcanic Zone at the Argentina-Chile border. The first schematic conceptual model was proposed by Galliski et al. (1987); however, in the last years the Argentinean Geological Survey (SEGEMAR) has carried out an exploration program that includes geological mapping, structural and hydrothermal alteration analysis, hidrogeochemistry, geophysical surveys and CO_2 flux data aimed to understand the hydrothermal system (Conde Serra et al., 2020). The SGP has been interpreted as a blind geothermal system hosted on the southern flank of the Socompa volcano beneath the Socompa lagoon (Conde Serra et al., 2020) with the reservoir at a minimum depth of 700 m (Guevara et al. 2021). While both results geothermometric estimations (Lelli, 2018) and CO_2 flux data (Raco, 2018) were discouraging, the SEGEMAR is considering to enlarge the exploration program (Conde Serra et al., 2022), a decision based mainly on the geological framework and the young age of the local magmatism (5.91 ± 0.43 ka, Grosse et al., 2022).

2.1.7. Termas de Río Hondo Project

The Termas de Río Hondo Project is located on the border of center-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) with a gross power output of 300 kWe and net power output of 275 kWe.

2.2. Direct-use oriented projects

Towards the center and the east of Northern Argentina there are numerous hydrothermal manifestations (Fig. 1A) related with both the Subandean foreland fold-and-thrust belt and sedimentary basins (e.g. Barcelona et al., 2013; Invernizzi et al., 2014; Chiodi et al., 2015, 2016; Maffucci et al., 2015, 2016; Peralta Arnold et al., 2020; Guevara et al., 2020; Barry et al., 2022). The exploitation of geothermal resources of low temperatures has allowed the generation of sustainable development in these regions. 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 decades, the Geological Mining Service of Argentina (SEGEMAR) has advanced in the knowledge and direct use of the geothermal resource, together with the authorities of the towns, developing numerous Thermal Complexes. The following projects are the latest developed (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.

2.3. Geothermal heat pumps (GHP)

The use of geothermal heat pumps (GHP) has experienced a marked increase in Argentina in recent years, mainly in those areas where there is no access to the natural gas network (Fig. 1B). Although there have been no governmental policies to promote the use of shallow geothermal energy, private companies have emerged in the last decades that have motivated its knowledge and use, as well as research groups that have been studying the thermal properties of the subsoil and have quantified the benefits of its application. In the private sector, several commercial Ground Source Heat Pumps (GSHP) service providers have emerged in the market, some of the main ones CIATEMA and Küme Newen, who have been working in the market since 1998 and 2015, respectively. CIATEMA company is a leader in South America concerning the development of integral geothermal systems and has the highest installed geothermal power for heating and cooling spaces since they develop and manufacture the entire system. According to the installed capacity, geothermal systems with heat pumps are mainly used for heating and cooling residential buildings (41 %). The remainder is distributed among gyms and swimming pools (31 %), hotels (11 %), commercial and office buildings (7 %), public buildings (6 %), and 4 % with no data (Fig. 2). These systems are generally installed in buildings under construction (new buildings). The most common used geothermal systems, also based on installed capacity, are geothermal piles (46 %), followed by different types of collectors combined in a single system (26 %), vertical collectors (15 %), slinky pipes (5 %), horizontal collectors (4 %), and 4% with no data (Fig. 2). All reported projects are developed in closed-loop systems. The installed systems are highly efficient, with a mean value of Coefficient of Performance (COP) of around 5.92 (data from CIATEMA). Unfortunately, energy use by GHP in Argentina is not adequately reported, as the data are not collected and collated by any central government organization. The values expressed here are derived from a small compiled data set. These values were assumed to be representative; however, most of the individual projects remain unmeasured and/or unrecorded in a single database.

On the other hand, several institutions and researchers have worked to determine different factors that influence the use of geothermal energy, as well as the thermal properties of soils (Ianelli y Gil, 2012; Bidarmaghz et al., 2015; Alcaraz et al., 2016, 2019; Alcaraz and Vives, 2021; Pleitavino et al., 2022).

Despite the favorable global scenario for the development of renewable energies, in Argentina exists a particular situation that hinders the growth of shallow geothermal energy. As mentioned above, there is a lack of government policies to promote the use of shallow geothermal energy. On the contrary, there are partial subsidies for conventional energy sources historically used in the country, the main one being natural gas. This source constitutes 54 % of Argentina's primary energy matrix (Balance Energético Nacional, 2021), followed by petroleum (32 %). As stated by Gil (2022), 40 % of the entire energy consumption corresponds to residential and building consumption, from which 62.8 % is provided by natural gas, 27.3 % by electricity, and 8.6 % by Liquefied Petroleum Gas (LPG). Of all energy sources used for residential consumption, natural gas is the least expensive one, up to 4 to 5 times lower than other sources (Gil et al., 2022). However, its price varies greatly across the country, depending on the distributor and the consumer category (currently ranges from 0.044 USD/m^3 to 0.18 USD/m^3). In accord with this information, Gil (2020) performed a cost analysis for a GHP system installed in a 60 m^2 house (traditional construction system), concluding that the investment in a GHP system is not recoverable until 20 years.

According to the different investigations, it seems that the system becomes economically attractive in areas where there is no natural gas connection (Fig. 1B) and/or in areas where the soils -for example, loess soils that, as reported by Terzariol (2009), cover approximately 35 % of the country- or the building dimensions require pile foundations, which implies the reduction of drilling costs during the installation of the geothermal system.

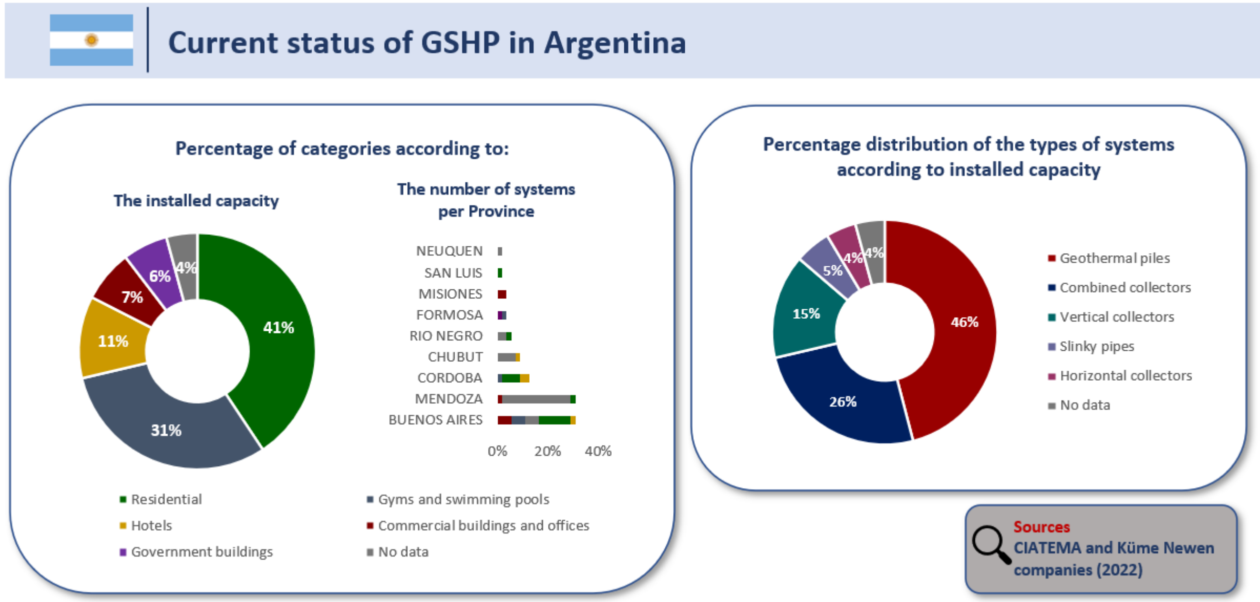

Figure 2: Summary of the development of GSHP in Argentina.

3. CONCLUSIONS AND FINAL REMARKS

The Act. 27191, published in 2015, establishes that renewable energies should reach 20% of the total national consumption of electric power by December 31st 2025, which constitute a great challenge, due to currently 87 % of Argentina's electric generation matrix is composed mainly of non-renewable energy sources: 63 % thermal, 17 % hydraulic and 7 % nuclear (CAMMESA, May 2022). To achieve this goal, the national government through the Program of Electricity Supply from Renewable Sources (RenovAr), includes regular public bidding process. The implementation of programs and promotion policies (e.g., RenovAr) has allowed to increase the participation of renewable energies in the demand for electrical energy of 1.8% in 2016 (installed power capacity 0.8 GW) to 13 % avg with peaks of 16,1 % in the year 2021 (Table 1; CAMMESA, May 2022). 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 2 shows that nowadays there are no geothermal projects under construction or planned. Despite the potential of geothermal resources that Argentina has, it has an 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 organization 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, favoring tourism ventures and productive developments (Table 3 and 4). Finally, the use of geothermal heat pumps (GHP) has experienced a marked increase in Argentina in recent years, mainly in those areas where there is no access to the natural gas network.

4. REFERENCES

Acocella, V., Gioncada, A., Omarini, R., Riller, U., Mazzuoli, R., and Vezzoli, L. Tectonomagmatic characteristics of the back-arc portion of the Calama–Olacapato–El Toro Fault Zone, Central Andes. *Tectonics*, (2011), *30*(3).

Agusto, M., Tassi, F., Caselli, A. T., Vaselli, O., Rouwet, D., Capaccioni, B. and Darrah, T. Gas geochemistry of the magmatic-hydrothermal fluid reservoir in the Copahue–Caviahue Volcanic Complex (Argentina). *Journal of volcanology and geothermal research*, (2013), 257, 44-56.

Ahumada Ma. F., Favetto A., Filipovich R., Chiodi A., Báez W., Viramonte J. G. and Guevara L. Aplicación del método magnetotelúrico en la exploración del sistema geotermal Tocomar (Puna, NO Argentina). Proceedings, XX Congreso Geológico Argentino, S13, 3-8, San Miguel de Tucumán, Argentina (2017).

Ahumada Ma F., Favetto A., Filipovich R., Chiodi A., Báez W. and Viramonte J.G. Análisis e Interpretación 3-D de datos magnetotelúricos de corto periodo del Sistema Geotérmico Tocomar (Puna, NO argentino). Proceedings, *1º Congreso de la Asociación Latinoamericana de Volcanología,* Antofagasta, Chile (2019).

Alcaraz, M. and Vives, L. GIS-Mapping of Shallow Geothermal Resources of Buenos Aires, Argentina. *Proceedings First EAGE Workshop on Geothermal Energy in Latin America* European Association of Geoscientists & Engineers, (2021), 1: 1-5.

Alcaraz, M., García-Gil, A., Vázquez-Suñé, E. and Velasco, V. Advection and dispersion heat transport mechanisms in the quantification of shallow geothermal resources and associated environmental impacts. *Science of The Total Environment*, (2016), 543: 536–546.

Alcaraz, M., Vázquez-Suñé, E., Pleitavino, M., Sheiber, L., González, O. D. R., Villacreses, G., Aravena D., Moreno D., Pedro A., Samaniego L., Ramos A., Pérez M., Morrillón D., Blessent D., Daniele, L. Ramos J. and Macías, J. Ibero-American Atlas of Shallow Geothermal Energy by RIGS-CYTED. *Proceedings AGU Fall Meeting,* (2019).

Aquater, S. A. Exploración geotérmica del área del Cerro Tuzgle. *Provincia de Jujuy, República Argentina: Argentina, Secretaría de Estado de Minería, Open-File Report*. (1980).

Astort, A., Walter, T. R., Ruiz, F., Sagripanti, L., Nacif, A., Acosta, G. and Folguera, A. Unrest at Domuyo volcano, Argentina, detected by geophysical and geodetic data and morphometric analysis. *Remote Sensing*, (2019), 11(18), 2175.

Barcelona, H., Favetto, A., Peri, V. G., Pomposiello, C. and Ungarelli, C. The potential of audiomagnetotellurics in the study of geothermal fields: a case study from the northern segment of the La Candelaria Range, Northwestern Argentina. *Journal of Applied Geophysics*, (2013), 88: 83-93.

Barcelona, H., Peri, G., Tobal, J., Sagripanti, L. and Favetto, A. Tectonic activity revealed by morphostructural analysis: Development of the Sierra de la Candelaria range, northwestern Argentina. *Journal of South American Earth Sciences*, (2014), 56: 376-395.

Barcelona, H., Yagupsky, D. L., Wincour, D., Caselli, A. and Cristallini, E. O. Modelo geológico estructural 3D del sistema geotérmico Copahue. Proceedings, XX Congreso Geológico Argentino, Argentina, (2017), 26-31.

Barcelona, H., Yagupsky, D. and Agusto, M. The layered model of the Copahue geothermal reservoir, Argentina. *Geothermal Energy*, (2019a).

Barcelona, H., Yagupsky, D., Vigide, N. and Senger, M. Structural model and slip-dilation tendency analysis at the Copahue geothermal system: Inferences on the reservoir geometry. *Journal of Volcanology and Geothermal Research*, (2019b), (375), 18-31.

Barcelona, H., Senger, M. and Yagupsky, D. Resource assessment of the Copahue geothermal field. *Geothermics*, (2021). 90, 101987.

Barry P., de Moor M., Chiodi A., Barraza F., Hudak M., Bekaert D., Turner S., Curtice J., Seltzer A., Jessen G. Osses E., Blamey J., Amenábar M., Selci M., Cascone M., Bastianoni A., Nakagawa M., Filipovich R., Bustos E., Schrenk M., Buongiorno J., Ramírez C., Rogers T., Lloyd K., Giovannelli D. The helium and carbon isotope characteristics of the Andean Convergent Margin. *Frontiers Earth Sciences*, (2022), 10,3389. DOI=10.3389/feart.2022.897267

Bertani, R. Geothermal power generation in the world, 2005-2010 Update Report. *Proceedings World Geothermal Congress,* (2010), Indonesia, Bali, p. 41.

Bidarmaghz, A., Makasis, N., Narsilio, G. A., Francisca, F. M. and Carro Perez, M. E. Geothermal energy in loess. *Environmental Geotechnics,* (2015), 3(4), 225-236.

Bona, P. and Coviello, M. Valoración y gobernanza de los proyectos geotérmicos en América del Sur. *Comisión Económica para América Latina y el Caribe (CEPAL)*, (2016).

CAMMESA. Compañía Administradora del Mercado Mayorista Eléctrico S.A., 59. (2021), (2022). https://cammesaweb.cammesa.com/

Carrizo, N. Aplicación del método volumétrico USGS Heat in Pleace y probabilístico (Monte Carlo) para la estimación del potencial eléctrico del campo Geotérmico Tuzgle, Jujuy. *Asociación Argentina de Geólogos Economistas*, (2016), 1-17p.

Caselli, A., Agusto, M., Vélez, M.L., Forte, P., Bengoa, C., Daga, R., Albite, J.M. and Capaccioni, B. The 2012 eruption. En Tassi, F., Vaselli, O. y Caselli, A. (eds.) *Copahue Volcano. Active volcanoes of the world, Book Series,* (2016), Springer-Verlag – Heidelberg, 61-77.

Chiodi A., Tassi F., Báez W., Maffucci R., Invernizzi C., Giordano G., Corrado S., Bicocchi G., Vaselli O, Viramonte J.G. and Pierantoni P.P. New geochemical and isotopic insights to evaluate the geothermal resource of the hydrothermal system of Rosario de la Frontera (Salta, northern Argentina). *Journal of Volcanology and Geothermal Research,* (2015), 25: 16-25.

Chiodi, A., Báez, W., Filipovich, R., Ahumada, F. and Viramonte, J.G. Modelo conceptual preliminar del sistema geotermal El Sauce (Salta) a partir de estudios de geoquímica de fluidos. *Revista de la Asociación Geológica Argentina*, (2016), 73 (1): 94-104.

Chiodi, A. Filipovich, R., Báez, W., Giordano, G., Tassi, F. and Viramonte, J.G. Modelo conceptual preliminar del sistema geotermal Tocomar (Puna Central, Argentina) a partir de estudios de geoquímica de fluidos. *Proceedings 1º Congreso de la Asociación Latinoamericana de Volcanología, Antofagasta,* (2019a), Chile.

Chiodi, A., Tassi, F., Báez, W., Filipovich, R., Bustos, E., Glok Galli, M., Suzaño, N., Ahumada, Ma.F., Viramonte, J.G., Giordano, G., Pecoraino, G. and Vaselli, O. Preliminary conceptual model of the Cerro Blanco caldera-hosted geothermal system (Southern Puna, Argentina): inferences from geochemical investigations. *Journal of South American Earth Sciences*, (2019b), 94, 102213.

Chiodini, G., Cardellini, C., Lamberti, M. C., Agusto, M., Caselli, A., Liccioli, C. and Caliro, S. Carbon dioxide diffuse emission and thermal energy release from hydrothermal systems at Copahue–Caviahue Volcanic Complex (Argentina). *Journal of Volcanology and Geothermal Research*, (2015), *304*, 294-303.

CREGEN. Estudio geotérmico del área Tuzgle-Tocomar-Pompeya, Centro Regional de Energía Geotérmica del Neuquén (inédito), Neuquén, (1988), 16p.

Coira, B. Cerro Tuzgle Geothermal Prospect, Jujuy, Argentina. *Proceedings of the World Geothermal Congress*, (1995), 1161-1165.

Coira, B. and Kay, S. M. Implications of Quaternary volcanism at Cerro Tuzgle for crustal and mantle evolution of the Puna Plateau, Central Andes, Argentina. *Contributions to Mineralogy and Petrology*, (1993), 113(1), 40-58.

Energy News. First Geothermal Power Plant in Argentina to be Built in the Andes. Newsletter September 13, (2013), http://www.energynwes.es/english/first-geothermal-power-plant-in-argentina-to-be-built-in-los-andes/.

Esteban C. Geothermal Exploration Survey of Domuyo Geothermal Field. *Proceedings World Geothermal Congress2020+1*, (2021), Reykjavik, Iceland.

Farina, Z. Geothermal energy in Santiago del Estero, Argentina: a flesibility study of power generation from medium enthalpy thermal sources. *Thesis Work, (inedito*), Instituto Tecnológico de Buenos Aires, Argentina and Karlsruhe Institute of Technology, Alemania, (2018), 76p.

Febrer, J. M., Baldis, B., Gasco, J. C., Mamani, M. and Pomposieilo, C. La anomalia geot6rmica Calchaqui en el noroeste argentino: un nuevo proceso geodinamico asociado a la subducci6n de la placa de Nazca. *Quinto Congr. Latino Americano de Geologia, Argentina*, (1982), 3: 691-703.

Ferretti, J. and Alonso, R. Geoquímica del campo geotérmico Tocomar (Salta). *XII Congreso Geológico Argentino. II Congreso de Exploración de Hidrocarburos,* (1993), Buenos Aires.

Filipovich, R., Barrios, A., Ahumada, M.F., Chiodi, A., Báez, W., Giordano, G. and Viramonte, J.G.. Probabilistic assessment of electrical potential of Tocomar Geothermal Field (Central Puna - NW Argentina) using volumetric method. Proceedings 39th New Zealand Geothermal Workshop, (2017a), University of Auckland, Rotorua, p. 84.

Filipovich, R., Barrios, A., Ahumada, M.F., Chiodi, A., Báez, W., Giordano, G. & Viramonte, J.G. Evaluación probabilística del potencial eléctrico del campo geotérmico Tocomar (Puna Central), mediante el método volumétrico, *Proceedings XX Congreso Geológico Argentino,* (2017b), Asociación Geológica Argentina, San Miguel de Tucumán, Argentina, pp. 46–52.

Filipovich R., Chiodi A., Báez W., Ahumada F., Invernizzi C., Taviani S., Aldega L., Tassi F., Barrios A., Corrado S., Groppelli G., Norini G., Bigi S., Caricchi C., De Benedetti A., De Astis G., Becchio R., Viramonte J.G. and Giordano G. Structural analysis and fluid geochemistry as tools to assess the potential of the Tocomar geothermal system, Central Puna (Argentina). Geothermics, (2022), 98, 10227.

Fragoso, A., Ferrari, L., Norini, G., Orozco-Esquivel, T., Corbo-Camargo, F., Bernal, J. P., Castro C. and Arrubarrena-Moreno, M. Geology and conceptual model of the Domuyo geothermal area, northern Patagonia, Argentina. *Journal of Volcanology and Geothermal Research*, (2021), 420, 107396.

Galetto, A., García, V. and Caselli, A. Structural controls of the Domuyo geothermal field, Southern Andes (36°38′ S), Argentina. *Journal of Structural Geology*, (2018), 114, 76-94.

Galliski, M., Arias, J. E., Coira, B. and Fuertes, A. Reconocimiento geotérmico del área de Socompa, Provincia de Salta, República Argentina, (1987), 37-53.

Gil, S. Viabilidad Económica de la Geotermia en Argentina, Panorama Actual. AGEOCOL - *Asociación Geotérmica Colombiana*, (2022), https://www.youtube.com/watch?v=XZRBnhZNH-w

Gil, S., Prieto, R. and Codeseira, L. El gas natural, una herramienta útil para una transición justa y sostenible. *Petrotecnia,* (2022), *1,* 14-23.

Giordano, G., Pinton, A., Cianfarra, P., Baez, W., Chiodi, A., Viramonte, J., Norini, G. and Groppelli, G. Structural control on geothermal circulation in the Cerro Tuzgle-Tocomar geothermal volcanic area (Puna plateau, Argentina). *Journal of Volcanology and Geothermal Research*, (2013), 249, 77-94.

Giordano, G., Ahumada, F., Aldega, L., Báez, W., Becchio, R., Bigi, S., Caricchi, C., Chiodi, A., Corrado, S., De Benedetti, A.A., Favetto., A., Filipovich, R., Fusari, A., Gropelli., G., Invernizzi, C., Mafucci., R., Norini, G., Pinton, A., Pomposiello, C., Tassi., F., Taviani, S. and Viramonte, J.G. Preliminary data on the structure and potential of the Tocomar geotermal field (Puna plateau, Argentina). *Energy Procedia,* (2016), 97, 202-209.

Godoy, L. B., Nacif, S., Lupari, M., García, H. P., Correa-Otto, S., Melchor, I., Pechuan S., Ariza J., Gimenez M. and Caselli, A. T. Geophysical evidence of first stages of inflation in Domuyo volcanic center in northwestern Neuquén province, Argentina. *Journal of South American Earth Sciences*, (2021), 107, 102694.

Groeber, P. Observaciones geologicas a lo largo del meridiano 70. 3. Hojas Domuyo, Mari Mahuida, Huarhuar Co y parte de Epu Lauken. *Revista de la Sociedad Geológica Argentina,* (1947), 2(4), 347-433.

Grosse, P., Danišík, M., Apaza, F. D., Guzmán, S. R., Lahitte, P., Quidelleur, X., Self S., Slebe C., van Wyk de Vries B., Ureta G., Guillong M., De Rosa R., Le Roux P., Wotzlaw J and Bachmann, O. Holocene collapse of Socompa volcano and pre-and post-collapse growth rates constrained by multi-system geochronology. *Bulletin of Volcanology*, (2022), 84(9), 1-18.

Guevara, L., Pomposiello, C. and Favetto, A. Three-dimensional audio-magnetotelluric characterization of the geothermal area in Tucumán basin, Argentina. *Journal of South American Earth Sciences*, (2020), 97, 102415.

Guevara, L., Apaza, F. D., Favetto, A., Seggiaro, R., Pomposiello, C. and Serra, A. C. Geoelectrical characterization of Socompa lagoon area in the Andean Central Volcanic Zone from 3-D audiomagnetotelluric inversion. *Journal of Volcanology and Geothermal Research*, (2021), 415, 107246.

Hirart, G., and Sanchez, E. Thermodynamic behavior of simplified geothermal reservoirs, *Proceedings X Workshop on Geothermal Reservoir Engineering*, (1985), Stanford University, Stanford, California.

Hurley, M., Colavitto, B., Astort, A., Sagripanti, L., Rosselot, E. A. and Folguera, A. Mass-wasting deposits in the Domuyo Volcanic Center, northern Neuquén Andes (Argentina): An analysis of the controlling factors. *Journal of South American Earth Sciences*, (2020), 103, 102760.

Hydroproyectos, S.A., Stec, S.R.L. Sepic, S.C. Estudio de la segunda fase de prefactibilidad geotérmica del área denominada Tuzgle. Departamento de Susques, Provincia de Jujuy, (1984), Ministerio de Economía, Jujuy.

Iannelli, L. and Gil, S. Acondicionamiento térmico de aire usando energía geotérmica-ondas de calor. *Latin-American Journal of Physics Education*, (2012), 6(1): 100.

Invernizzi, C., Pierantoni, P. P., Chiodi, A., Maffucci, R., Corrado, S., Baez, W., Tassi, F., Giordano, G. and Viramonte, J. Preliminary assessment of the geothermal potential of Rosario de la Frontera area (Salta, NW Argentina): Insight from hydro-geological, hydro-geochemical and structural investigations. *Journal of South American Earth Sciences*, (2014), 54: 20-36.

JICA. Argentine Republic. Final Report on the Northern Neuquén Geothermal Development Project. First-Second Phase Survey, No 25, (1983).

JICA. Argentine Republic. Final Report on the Northern Neuquén Geothermal Development Project. Third Phase Survey, No 25, (1984).

JICA. Feasibility study on the northern Neuquén geothermal development project, (1992), Japan.

Lamberti, M. C., Vigide, N., Venturi, S., Agusto, M., Yagupsky, D., Winocur, D. and Tassi, F. Structural architecture releasing deep-sourced carbon dioxide diffuse degassing at the Caviahue–Copahue Volcanic Complex. *Journal of Volcanology and Geothermal Research*, (2019), 374, 131-141.

Lelli, M. Socompa Geothermal Prospect. Report on Water Geochemistry, SEGEMAR, (2018).

Lindsey, C. R., Ayling, B. F., Asato, G., Seggiaro, R., Carrizo, N., Larcher, N., Marquetti C., Naón V., Conde Serra A., Faulds J., and Coolbaugh, M. F. Play fairway analysis for geothermal exploration in north-western Argentina. *Geothermics*, (2021), 95, 102128.

Lucazeau, F. Analysis and mapping of an updated terrestrial heat flow data set. *Geochemistry, Geophysics, Geosystems*, (2019), 20(8), 4001-4024.

Lundgren, P., Girona, T., Bato, M. G., Realmuto, V. J., Samsonov, S., Cardona, C., Franco L., Gurrola E. and Aivazis, M. The dynamics of large silicic systems from satellite remote sensing observations: the intriguing case of Domuyo volcano, Argentina. *Scientific reports*, (2020), 10(1), 1-15.

Maffucci, R., Bigi, S., Corrado, S., Chiodi, A., Di Paolo, L., Giordano, G. and Invernizzi, C. Quality assessment of reservoirs by means of outcrop data and «discrete fracture network» models: The case history of Rosario de La Frontera (NW Argentina) geothermal system. *Tectonophysics*, (2015), 647. 112-131.

Maffucci, R., Corrado, S., Aldega, L., Bigi, S., Chiodi, A., Di Paolo, L., Giordano, G. and Invernizzi, C. Cap rock efficiency of geothermal systems in fold-and-thrust belts: Evidence from paleo-thermal and structural analyses in Rosario de La Frontera geothermal area (NW Argentina). *Journal of Volcanology and Geothermal Research*, (2016), 328: 84-95.

Martin, A. and Palazzo, R. Procesos tectónicos y su relación con los acuíferos hidrotermales del centro oeste de la provincia de Santiago del Estero (Parte 1). *5° Congreso Argentino de Hidrogeología,* Actas, (2007), Paraná, Argentina, 15–28.

MAS, L. C.. Present status of the Copahue geothermal project. *Proceedings World geothermal congress, Antalya*, (2005), p. 1-10.

Mas, G.R. Bengochea, L., Mas, L.C. and Lopez, N. Hydrothermal explosion due to seal effect in El Humazo geothermal manifestation, Domuyo volcano,Neuquén, Argentina. Proceeding, *34 Workshop on Geothermal Reservoir Engineering Stanford University*, (2009), California, 9-11.

Mas, L. C. and Ms, G. R. Geothermal energy development at Copahue volcano. In *Copahue Volcano*. Springer, Berlin, Heidelberg, (2016), p. 257-271.

Mazzuoli, R., Vezzoli, L., Omarini, R., Acocella, V., Gioncada, A., Matteini, M., Dini A., Guillou H., Hauser N., Uttini A. and Scaillet, S. Miocene magmatism and tectonics of the easternmost sector of the Calama–Olacapato–El Toro fault system in Central Andes at~ 24 S: Insights into the evolution of the Eastern Cordillera. *Geological Society of America Bulletin*, (2008), 120(11-12), 1493-1517.

Ministerio de Economía (September 20, 2022). Balance_2021_V0_horizontal. https://www.argentina.gob.ar/economia/energia/hidrocarburos/balances-energeticos

Miranda, F., Folguera, A., Leal, P. R., Naranjo, J. A., and Pesce, A. Upper Pliocene to Lower Pleistocene volcanic complexes and Upper Neogene deformation in the south-central Andes (36^ o30'-38^ oS). *Special Papers-Geological Society of America*, (2006), 407, 287.

Nakanishi, S., Abe, M., Todaka, N., Yamada, M., Sierra, J. L., Gingins, M. O. and Pedro, G. E. Copahue geothermal system, Argentina-study of a vapor dominated reservoir. *Proceedings World Geothermal Congress*, (1995), 95: 1167-1172.

Norini, G., Baez, W., Becchio, R., Viramonte, J., Giordano, G., Arnosio, M., Pinton A. and Groppelli, G. The Calama–Olacapato–El Toro fault system in the Puna Plateau, Central Andes: geodynamic implications and stratovolcanoes emplacement. *Tectonophysics*, (2013), 608, 1280-1297.

Peralta Arnold, Y., Cabassi, J., Tassi, F., Caffe, P. J. and Vaselli, O. Fluid geochemistry of a deep-seated geothermal resource in the Puna plateau (Jujuy Province, Argentina). *Journal of Volcanology and Geothermal Research*, (2017), 338: 121-134.

Pesce, A. H. The Domuyo Geothermal Area, Neuquén, Argentina. *GRC Trans*, (2013), 37, 309-314.

Pesce, A. H. Evaluación del potencial geotérmico en la zona de Termas de Río Hondo para la generación eléctrica, Provincia de Santiago del Estero, 1, 2 y 3 º Etapa, SEGEMAR, (2014), Inédito.

Pesce, A. H. Argentina Country Update. *World Geothermal Congress,* (2015), 10: 24-29.

Petrinovic, I. A. and Colombo Piñol, F. Pheatomagmatic and phreatic eruptions in locally extensive setting of Southern central Andeas: the Tocomar Volcanic Centre (24 10′ S-66 34′ W), Argentina (2006) J. *Journal of Volcanology and Geothermal Research*, (2006), 158(1), 1-5.

Petrinovic, I. A., Mitjavila, J., Viramonte, J. G., Martí, J., Becchio, R., Arnosio, M. and Colombo, F. Descripción geoquímica y geocronológica de secuencias volcánicas neógenas de Trasarco, en el extremo oriental de la Cadena Volcánica Transversal del Quevar (Noroeste de Argentina). *Acta Geológica Hispánica,* (1999), vol. 34, 2-3, p. 255-272.

Petrinovic, I. A., Riller, U., Brod, J. A., Alvarado, G. and Arnosio, M. Bimodal volcanism in a tectonic transfer zone: evidence for tectonically controlled magmatism in the southern Central Andes, NW Argentina. *Journal of Volcanology and Geothermal Research*, (2006), 152(3-4), 240-252.

Petrinovic, I. A., Martí, J., Aguirre-Diaz, G. J., Guzmán, S., Geyer, A. and Paz, N. S. The Cerro Aguas Calientes caldera, NW Argentina: an example of a tectonically controlled, polygenetic collapse caldera, and its regional significance. *Journal of Volcanology and Geothermal Research*, (2010), 194(1-3), 15-26.

Petrinovic, I. A., Villarosa, G., D'elia, L., Guzman, S. R., Paez, G. N., Outes, A. V., and Hernando, I. R. La erupción del 22 de diciembre de 2012 del volcán Copahue, Neuquén, Argentina: caracterización del ciclo eruptivo y sus productos. *Revista de la Asociación Geológica Argentina*, (2014), 71(2), 161-173.

Pleitavino, M., Carro Pérez, M. E., García Aráoz, E. and Cioccale, M. Determinación de difusividad térmica aparente in situ en suelo loéssico a partir de registro térmico. *Proceedings XXI Congreso Geológico Argentino*, (2022), Puerto Madryn, Argentina, .X: 489-490.

Raco, B. Socompa Geothermal Prospect. *Report on fluid geochemistry (soil CO2 degassing),* SEGEMAR, (2018).

Riller, U., Petrinovic, I., Ramelow, J., Strecker, M., and Oncken, O. Late Cenozoic tectonism, collapse caldera and plateau formation in the central Andes. *Earth and Planetary Science Letters*, (2001), 188 (3-4), 299-311.

Sainato, C. M. and Pomposiello, M. C. Two-dimensional magnetotelluric and gravity models of the Tuzgle volcano zone (Jujuy province, Argentina). *Journal of South American Earth Sciences*, (1997), 10(3-4), 247-261.

Salfity, J. Lineamientos transversales al rumbo andino en el noroeste argentino. Proceedings *4° Congreso Geológico Chileno,* (1985), 2: 119-137, Antofagasta.

Sanyal, S. K. Cost of geothermal power and factors that affect it. *Proceedings of World Geothermal Congress,* (2005), pp. 24-29.

Schurr, B., Asch, G., Rietbrock, A., Kind, R., Pardo, M., Heit, B. and Monfret, T. Seismicity and average velocities beneath the Argentine Puna plateau. *Geophysical Research Letters*, (1999), 26(19), 3025-3028.

Springer, M. and Förster, A. Heat-flow density across the Central Andean subduction zone. *Tectonophysics*, (1998), 291(1-4), 123-139.

Tassi, F., Liccioli, C., Agusto, M., Chiodini, G., Vaselli, O., Calabrese, S., Pecoraino G., Tempesti L., Caponi C., Fiebig J., Caliro S. and Caselli, A. The hydrothermal system of the Domuyo volcanic complex (Argentina): a conceptual model based on new geochemical and isotopic evidences. *Journal of Volcanology and Geothermal Research,* (2016), 328, 198-209.

Tassi, F., Agusto, M., Lamberti, C., Caselli, A. T., Pecoraino, G., Caponi, C. and Vaselli, O. The 2012–2016 eruptive cycle at Copahue volcano (Argentina) versus the peripheral gas manifestations: hints from the chemical and isotopic features of fumarolic fluids. *Bulletin of Volcanology*, (2017), 79(10), 69.

Terzariol R E. 40 años de estudio de los suelos loéssicos en Córdoba, Argentina. *Desafíos y Avances de la Geotecnia Joven en Sudamérica*, (2009), 1: 323–337.

Vieira, F. and Hamza, V. Assessment of Geothermal Resources of South America - A New Look. *International Journal of Terrestrial Heat Flow and Applications,* (2019), 2, 46-57.

Viramonte, J.G., Galliski, M.A., Araña Saavedra, V., Aparício, A., García Cucho, L. and Martín Escorza, C.. El finivulcanismo básico de la depresión de Arizaro, provincia de Salta. Proceedings *9° Congreso Geológico Argentino*, (1984), Bariloche, 3: 234-251,