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GEOTHERMAL DEVELOPMENT IN EL SALVADOR AND THE IMPORTANCE OF THE CONTRIBUTION OF FELLOWS OF THE UNU-GTP PROGRAMME

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ABSTRACT

The geothermal development in El Salvador has improved and advanced over time, El Salvador currently being a country of reference in Latin America for best practices in geothermal energy. Many professionals have had the opportunity to study abroad, and the most important training is offered by the United Nations University Geothermal Training Programme in Iceland. It is noticeable that, since the first years of the participation of professionals in trainings in Iceland, use of geothermal energy in the country has increased, providing increasingly more energy to El Salvador's energy matrix. Additionally, these graduated professionals have become the new professors for Latin America on the geothermal subject, transferring the knowledge they have acquired to new generations of geothermal professionals.

1. INTRODUCTION

The United Nations University Geothermal Training Programme (UNU-GTP) was established in 1978 by the Government of Iceland and the United Nations University (UNU), with Orkustofnun (the National Energy Authority of Iceland) as its host institution. The purpose of the Programme has been to assist developing countries with significant geothermal potential, to establish groups of specialists in geothermal exploration and development, first by offering specialized 6-month training to professionals employed in the research and/or development of geothermal resources, adding later the possibility of MSc studies in geoscience or engineering as well as PhD studies through special academic fellowships.

The distinctive feature of the programme is to provide intensive training in the desired field of specialization to professionals with university degrees, employed in fields related to geothermal energy. The fellows work together with geothermal professionals in Iceland. The training is tailored to both the fellow and his institution/country (UNU-GTP, 2018).

Since 1980, El Salvador has had professionals participating in the United Nations University Geothermal Training Programme.

2. GEOTHERMAL DEVELOPMENT IN EL SALVADOR

2.1 Brief history of geothermal energy in El Salvador

The first investigations in El Salvador on the geothermal resource began at the beginning of the1960s. In the year 1975, CEL inaugurated the first geothermal plant of El Salvador, in the geothermal field of Ahuachapán (Figure 1), with the operation of a condensation unit of 30 MW. The following year, in 1976, CEL inaugurated a second 30 MW unit, and in 1981, a third 35 MW generating turbine was added. Thus, the installed capacity of the Ahuachapán geothermal power plant reached 95 MW, with a current net generation of 81 MW. Thanks to this, in the 1970s El Salvador became the first country in Central America, the second in Latin America, and the eighth country in the world to take advantage of geothermal resources for the production of electric energy. After the development of the Ahuachapán geothermal field, CEL continued with the project of increasing generation of geothermal energy in the national territory. As a result, in 1992, electric production in the Berlín geothermal field (Figure 1) began in the county of Usulután, with the generation of 10 MW through 2 wellhead units. In the following years, extensive surface and deep exploration works were carried out in the Berlín area with the objective of characterizing the resource and increase the production. In 1999, this resulted in the installation and operation of 2 condensation units of 28.1 MW each, by the recently created GESAL (Geotérmica Salvadoreña S.A. de C.V., which would later change its name to LaGeo S.A. de C.V.).

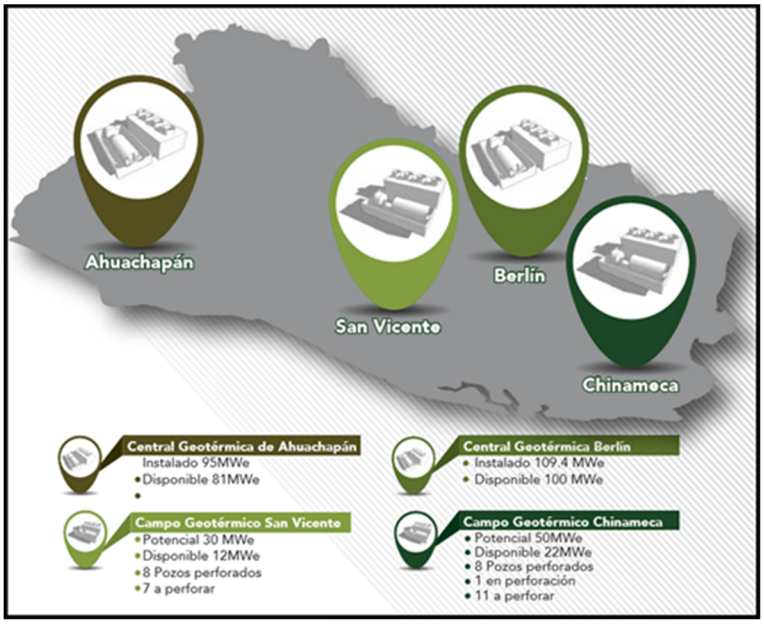

FIGURE 1: Map of El Salvador showing the location of the Ahuachapán and Berlin geothermal power plants and the new geothermal prospects in SanVicente and Chinameca

With the beginning of the production of the condensation units, the operation of the backpressure wellhead units ceased in Berlín. In 2007, a third unit of 44 MW was added as well as the fourth unit of 9.2 MW, the latter of binary cycle. The Berlín geothermal power plant thus reached its current installed capacity of 109 MW with a net generation of 100 MW.

In 2004, San Vicente 7 (subsidiary of LaGeo) obtained the concession for the exploration of the San Vicente and Chinameca geothermal fields (Figure 1), located in the central and eastern parts of the country, respectively. Between the years 2004 and 2005, the pre-feasibility stage began, between 2007 and 2013 deep exploration followed, and in 2014 - 2016 stage of feasibility and development. In the Chinameca geothermal field the construction of four new drilling platforms was carried out after the adaptation of its access roads, as well as the parallel drilling of four wells (two for production and two for reinjection). In San Vicente, two new drilling platforms were built and two existing platforms and access roads were adapted. Drilling of two geothermal wells was carried out (one for production and one for reinjection).

As a result of the completion of the feasibility studies of these fields, it is possible to determine a certified generation potential of 30 MW for San Vicente and 50 MW for Chinameca. With the development of these two new fields, it is estimated that by the year 2020 there will be an additional 80 MW increase in the installed capacity of geothermal energy in El Salvador.

2.2 Current geothermal development in El Salvador

Currently, the share of geothermal energy in the national electricity market is 24%, the highest percentage in Latin America and the third highest in the world. The increasing participation of geothermal energy has allowed, since the 1970s, reduced energy prices by up to 80% in recent years.

CEL works in an integrated manner with its subsidiaries (LaGeo is a subsidiary of CEL) through GrupoCEL. The benefit of working in an integrated manner translates into: knowledge transfers, the best practices of each company are repeated if applicable. Other assessments are considered in the work philosophy such as *gender equity*, *solidarity with fellow countries* that have geothermal resources, *advances in Academia*, *social support*, besides increase in electricity generation.

This way, LaGeo currently continues with the development of power generation projects and the moulding of new projects:

1. LAGEO through its subsidiary San Vicente 7, Inc., continues with the development of the San Vicente and Chinameca geothermal fields.
2. BINARY CYCLE 2: LaGeo is in the working stage of review of bidding documents for the construction of a new binary cycle in the Berlin geothermal field, with an estimated generation capacity of 6 MW.
3. LAGEO MULTILATINA: It is a solidarity support to fellow Latin American countries that are starting their geothermal development. There are contacts and agreements with several countries in South America such as Chile, Argentina, Colombia, Ecuador, Bolivia, among others. In some countries LaGeo is supporting the field exploration stage.
4. GEOTHERMAL DIPLOMA COURSE FOR LATIN AMERICA: In conjunction with the UNU-GTP, LaGeo, since 2010, has carried out the Geothermal Diploma Course for Latin America. For 5-6 months, students from El Salvador and other Latin American countries are trained in geothermal subject. In 2015, LaGeo signed an important *Cooperation Agreement* with UNU-GTP, in cooperation with the Nordic Development Fund, for the continuation of the Geothermal Diploma Course for Latin America, see Figure 2.

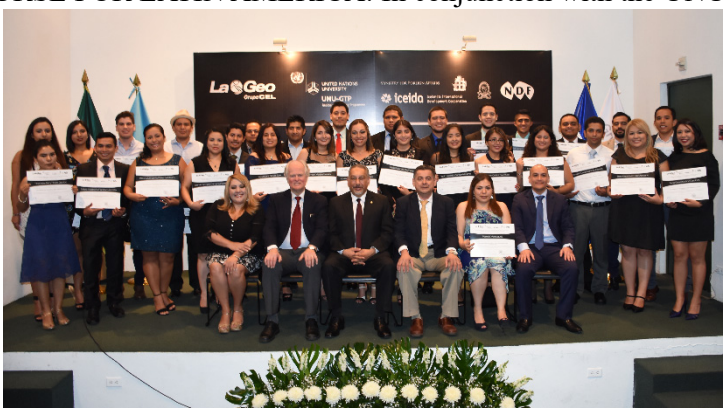

FIGURE 2: From the closing ceremony of the Geothermal Diploma Course for Latin America, 2017

5. GEOTHERMAL SHORT COURSES FOR LATIN AMERICA AND THE CARIBBEAN, LAGEO AND UNU-GTP: The development of short courses continues, aiming to build capacities and increase cooperation among specialists in the sustainable use of geothermal resources, see Figure 3.

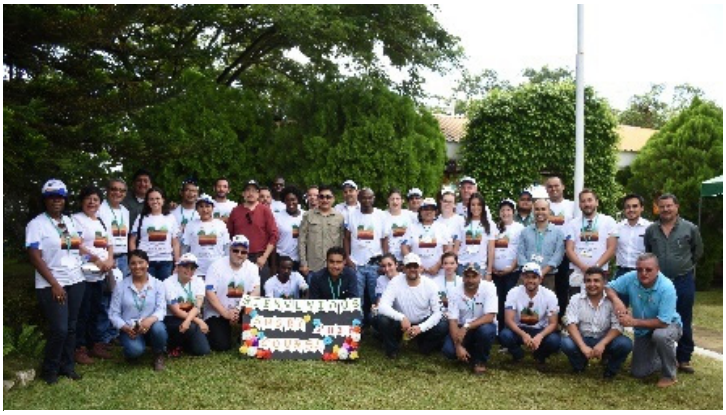

FIGURE 3: Short Course students in the field in 2017

6. REGIONAL GEOTHERMAL CENTER OF EXCELLENCE: It is based on the objective of formalizing higher education in geothermal energy in El Salvador at a Master's level, aiming at contributing to solve the primary need of the countries of the region in terms of training of professionals in the geothermal sector. This is done by encouraging them to contribute and optimize the use of geothermal resources in a sustainable manner, and in this way promote and strengthen scientific research in geothermal energy in El Salvador and Latin America, with a focus on social projection that contributes to the development of communities (LaGeo, 2018).
7. LOW ENTHALPY PROJECTS: LaGeo is currently developing studies for the application of low enthalpy resources in production systems. There is a prototype for drying coffee and cocoa in the Berlín geothermal field, which has worked successfully; Studies have been developed for mushroom drying, pasteurizing milk, dehydrate fruit (here is also a prototype), among others. LaGeo won the UN World Award in 2015 in the category of "Moments of Change" in the UNFCCC Climate Framework Convention, based on the fact that rural women have been able to change their lives through the activities of dehydrating fruits and watering flowers with condensed waters in the Berlín geothermal field.
8. GENDER EQUITY IN THE GEOTHERMAL SECTOR: With the new Vision of GrupoCEL, LaGeo has developed several projects aimed at strengthening women in the geothermal world. An example of this is the formation of the group *WING El Salvador* (Woman in Geothermal). To this day, they have registered all the employees of the company LaGeo and its subsidiaries, carrying out the first objective, which is to *CONNECT*. Additionally, the intention is to find out in which subjects education of women in the different areas of geothermal energy can be strengthened. The plan is to carry out two days of work during 2018, with the objectives of rapprochement and education. Another objective is to achieve equity in the participation of women in the Geothermal Diploma Course, which was successfully achieved in 2017. The VIDA project is also developed, with which GrupoCEL has the objective of reforesting the adjacent areas of geothermal power plants, establishing also an employment policy of 70% women. In the major maintenance programme of the two geothermal power plants, more women are being hired to perform jobs, traditionally executed by men (Figure 4)

FIGURE 4: Members of the Wing El Salvador group (top), participation of women in the maintenance of the Ahuachapán plant (centre), and a graph showing the participation of women in the Geothermal Diploma Course (bottom)

3. CONTRIBUTION OF UNU FELLOWS IN GEOTHERMAL DEVELOPMENT IN EL SALVADOR

3.1 Summary of the participation of Salvadorian professionals in geothermal training in Iceland

In 1980, a CEL professional became the first Latin American to participate in the six-month UNU Geothermal Training Programme in Iceland. Subsequently, in the period from 1991 to 2017, thirty-nine additional professionals of CEL-LaGeo (including one employee of MARN) have attended this postgraduate course in geothermal energy. Furthermore, between 2009 and 2017, five LaGeo Salvadoran professionals have also successfully completed their Master's degree in geothermal studies awarded by University of Iceland, on a UNU-GTP fellowship.

In the attached Tables 1 and 2, and graphs the graduates of the programme are detailed by speciality. There are 3 graduates in geology, 4 graduates in geophysics, 5 graduates in reservoir engineering, 9 graduates in geochemistry, 5 graduates in environmental studies, 10 graduates in geothermal utilization and 4 graduates in drilling, or 40 in total. It can be thus concluded that, in all the specialties that make up geothermal energy, there have been professionals who have been trained and who have applied what they learned in the training programme. It can also be observed that, of the all LaGeo professionals trained in the programme, 23% have been women. They were trained in: geology, environmental studies, geochemistry, utilization and drilling (UNU-GTP, 2018).

In addition to the graduates of the 6-month geothermal training, five professionals have continued their studies for MSc degree on a UNU-GTP fellowship, which can be seen in Table 3.

TABLE 1: Professionals trained in Iceland's geothermal training between the years 1980 and 2000 and description of thesis topics

Year	Name of participant	Thesis topic
1980	J.L. ZUNIGA	Geophysical logging in well SG-9, Svartsengi geothermal field, SW-Iceland.
1991	C.R. PULLINGER	Geological and geothermal mapping at Núpafjall and Svartsengi in the Reykjanes Peninsula, SW-Iceland.
1992	J.A. AREVALO M.	Geothermal drilling techniques.
1993	L.A. BARRIOS DE LUNA	Borehole geology and hydrothermal alteration of well CHA-1, Chipilapa geothermal field, El Salvador, C.A.
	M. MONTERROSA	A 3-D natural state modelling and reservoir assessment for the Berlin geothermal field in El Salvador, C.A.
1994	J.E. QUIJANO	A revised conceptual model and analysis of production data for the Ahuachapán-Chipilapa geothermal field, El Salvador.
	F.E. MONTALVO L.	Geochemical evolution of the Ahuachapán geothermal field, El Salvador, C.A.
1995	G.G. MOLINA	Rehabilitation of geothermal wells with scaling problems
	P.A. SANTOS L.	One- and two-dimensional interpretation of DC-resistivity data from the Berlin geothermal field, El Salvador.
1996	M.A. QUEZADA	Interpretation of geophysical well logs from the Nesjavellir geothermal field, Iceland.
1997	R.A. VENTURA H.	Preliminary database design for geothermal fields in El Salvador.
	J.L. HENRIQUEZ	Berlín geothermal project, preliminary power plant design.
	M.A. MARTINEZ	Chemical interpretation and scaling potential of fluid discharge from wells in the Berlín geothermal field, El Salvador.
1998	A.S. AREVALO AMAYA	Environmental aspects of the Berlín geothermal power station in El Salvador.
	C.E. GUERRA	Cementing of geothermal wells.
1999	MARIA INES MAGAÑA	Geochemical interpretation of thermal fluid discharge from wells and springs in the Berlín geothermal field, El Salvador.
2000	JOSE ANTONIO RIVAS	Seismic monitoring and its application as an exploration tool in Berlín geothermal field, El Salvador.

TABLE 2: Professionals trained in Iceland's geothermal training between the years 2001 and 2017 and description of thesis topics

Year	Name of participant	Thesis topic
2001	RAÚL E. LÓPEZ	Preliminary study of noise propagation behaviour at the Nesjavellir geothermal field, SW-Iceland.
2002	ROBERTO E. RENDEROS	Chemical characterization of the thermal fluid discharge from well production tests in the Berlín geothermal field, El Salvador.
2003	PATRICIA JACOBO	Gas chemistry of the Ahuachapán and Berlín geothermal fields, El Salvador.
2005	BLANCA E. MINERVINI M. ANIBAL RODRÍGUEZ	Geothermal tourist park in the Berlín field, El Salvador, assessment of the use of geothermal brine for bathing and spa. Analysis of temperature and pressure measurements and production data for Berlín geothermal field, El Salvador.
2007	MANUEL RIVERA E. KEVIN PADILLA JUAN CARLOS ABREGO	Design considerations for reliable electrical, control and instrumentation systems in geothermal power plants with emphasis on hydrogen sulphide related problems. Preliminary study on emission abatement and use of gas from geothermal power plants in El Salvador. Cost estimation of using an absorption refrigeration system with geothermal energy for industrial applications in El Salvador.
2008	ROSA ESCOBAR GODOFREDO LÓPEZ	Main considerations in the design of a geothermal drilling platform, El Salvador. Maintenance systems of the Ahuachapán power plant, El Salvador and the Svartsengi power plant, Iceland, comparison and optimization proposal for the Ahuachapán maintenance system.
2009	JOSÉ R. ESTEVEZ	Electrical protection in geothermal power plant projects.
2010	LUIS FRANCO LUIS AGUIRRE	Hydrogen sulphide abatement during discharge of geothermal steam from well pads: A case study of well pad TR-18, El Salvador. Main considerations in the protection system design for a geothermal power plant.
2011	VÍCTOR AVILES EDWIN E. MELARA	Instrumentation appraisal in single and double flash power plants. Calcite scaling in geothermal production wells in El Salvador, current situation and control methodology.
2012	BALTAZAR HERNANDEZ OSCAR F. CIDEOS	Aquifer fluid compositions at the Berlín geothermal field, El Salvador in 2012. Power production using low-temperature heat sources in El Salvador.
2013	ÁNGEL MONROY CLAUDIA PICHARDO	Geothermal binary cycle power plant principles, operation and maintenance. Borehole geology and hydrothermal alteration of well SV-5A, San Vicente geothermal field, El Salvador, C.A.
2014	JAIME HERNÁNDEZ YID-LAÍ ZELADA Q. (MARN)	Gas - mineral equilibrium in the Berlín geothermal field, El Salvador. Analysis of variations in the characteristics of the geothermal fluid produced from the Sudureyri low-temperature geothermal system in NW-Iceland.
2016	BERTHA ARENIVAR	Environmental considerations in production tests and geothermal wells stimulation.
2017	BRISEIDA SALAZAR	Metal sulphide scaling in production wells in Ahuachapán geothermal field, El Salvador.

TABLE 3: Master's graduates and their thesis topics

Year	Name of participant	Thesis topic
2009	ROBERTO E. RENDEROS	Carbon dioxide fixation by calcite and diffusive degassing in the southern region of the Berlín geothermal system, El Salvador.
2011	E. KEVIN PADILLA RIVAS	Transport and precipitation of carbon and sulphur in the Reykjanes geothermal system, Iceland.
2012	JOSÉ R. ESTÉVEZ	Geothermal power plant projects in Central America: technical and financial feasibility assessment model.
2013	LUIS A. AGUIRRE	Modelling and stability analysis of Berlin geothermal power plant in El Salvador.
2015	OSCAR F. CIDEOS	Predictive techniques applied to geothermal power plants data.

3.2 Geothermal development and the contribution of the UNU Geothermal Training programme

The contribution of Iceland through the UNU-GTP to El Salvador has been big. The successful geothermal projects have been developed by professionals who have mostly received training abroad. The programme in Iceland has allowed LaGeo professionals:

1. To acquire the knowledge of worldwide experiences (best practices);
2. The opportunity of scientific research;
3. To be advised by world-class specialists;
4. To generate bonds of solidarity between colleagues;
5. To subsequently transfer experiences to the region (professors in the Geothermal Diploma Course);
6. To live a unique experience, share with the Icelandic people and learn from their culture.

Figure 5 shows the most important advances in geothermal generation over the years related to the participation of professionals in geothermal training in Iceland.

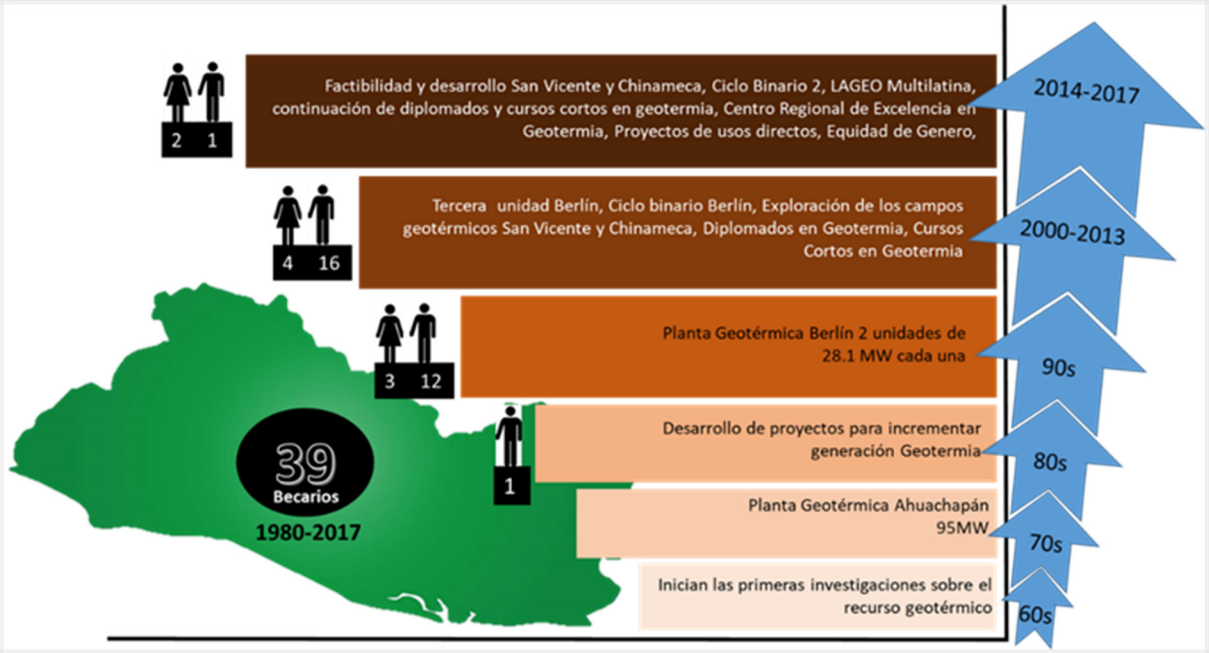

FIGURE 5: Description of the most important generation projects over time, related to the participation of LaGeo professionals in geothermal training in Iceland

4. CONCLUSION

The contribution of the professionals of LaGeo, who have graduated from the geothermal training in Iceland, to the geothermal development of El Salvador has been significant. This can be seen in the advances in technological, scientific, social and environmental aspects which the company currently has experienced which have allowed it to maintain a sustainable energy production in the two geothermal production fields, and in the design and development of new geothermal projects. It can also be seen in academic contributions, where the professionals trained in Iceland are now the specialist teachers in different areas of geothermal energy, transferring their knowledge to young people through the short courses and through the Geothermal Diploma Course, where employees of LaGeo teach year after year, as well as assisting in solidarity other Latin American countries under LaGeo Multilatina.

There is full belief in El Salvador, that we have additional areas which will allow continued development of geothermal energy and thus generation of renewable energy can be increased. There is also a believe

in the academia, related to the Geothermal Center of Excellence for Latin America, where the aim is to be able to offer an MSc degree in Geothermal Energy. There is also work to be done on gender equality in the geothermal industry, innovations in social issues as a contribution to the communities and in that way contribute to the economy of the poorest people in the country, and to work on environmental aspects to provide innovative ideas in the issue of climate change. There is no doubt that the continuation of new professionals specializing in the United Nations University Geothermal Training Programme will strengthen LeGeo even further in the capability to face these new challenges.

ACKNOWLEDGEMENTS

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