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LaGeo S.A. de C.V.

CURRENT STATUS OF GEOTHERMAL RESOURCES DEVELOPMENT IN CENTRAL AMERICA

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ABSTRACT

Central America is rich in geothermal resources, however only a small portion has been developed and is currently used for electricity generation. In countries like El Salvador, Nicaragua, Costa Rica and Guatemala, the geothermal exploration led to the first resource evaluation and the beginning of commercial exploitation of some areas such as Ahuachapán in 1975, Momotombo in 1983, Berlin in 1992, Miravalles in 1994, Zunil in 1998, San Jacinto Tizate in 2005, Amatitlán in 2006 and recently Las Pailas in 2011. Currently, the region has the installed capacity of 583.5 MWe, generating an annual average of 392.4 MWe. From the existing geothermal potential in Central America the electricity generated providing an average of 11%, but seems to be significant in countries like El Salvador and Costa Rica contributing 24 and 12% respectively of total electricity consumption in each country. Geothermal generation capacity in Central America in 2010 was 3131 GWh which was equivalent to 7.7% of total electricity generated by different sources. The potential resource in Central America, has been estimated very close to the total amount currently used in electricity power generation, which is about 4642 MWe.

1. INTRODUCTION

Central America belongs to the so-called Pacific Ring of Fire and has been affected throughout its history by intense seismic and volcanic activity, resulting in catastrophic events that have impacted negatively on economic, social and cultural development of the region. The geodynamic situation of the isthmus and the occurrence of these natural phenomena can be attributed mainly to the subduction of the Cocos plate beneath the Caribbean plate (whose limits are known as Middle America Trench, which are within the Pacific Ocean), and the presence of faults (fractures of the crust) that are active in the Motagua-Chamalecón Polochic fault system, thus separating the Caribbean plate from the North American plate.

In Figure 1, the Cocos and the Caribbean tectonic plates collide, about 100 km parallel to the Pacific coast of Central America. The black arrows indicate the direction of movement. Volcanoes are formed in a narrow strip parallel to the shock zone. The process of subduction occurs when the Cocos plate disappears beneath the continental crust producing fusion of mass and extensional faulting. Along the trench, the subduction of the Cocos oceanic plate beneath the Caribbean plate is given at a rate of 73-84 mm/year. The convergence movement of the Cocos plate is to the northeast. Some of the material melted by the high temperatures of Earth's mantle Cocos plate, rises almost vertically and

enters the Caribbean plate along a nearly straight line, forming the Central American volcanic chain that runs northwest -southeast.

2. GEOTHERMAL RESOURCES IN CENTRAL AMERICA

Central America is rich in geothermal resources, however only a small portion has been developed and is currently used for electricity generation. The subduction process as mentioned above is responsible for the creation of the volcanic chain in the region which provides a potential source of energy because the exploited geothermal fields, are located in areas of anomalous heat flow in the vicinity of shallow magma chambers associated with volcanoes, producing temperatures between 200-300 °C at depths between 500 and 3,000 m, where the heat is transported by conduction in the rocks and convection in the geothermal fluids.

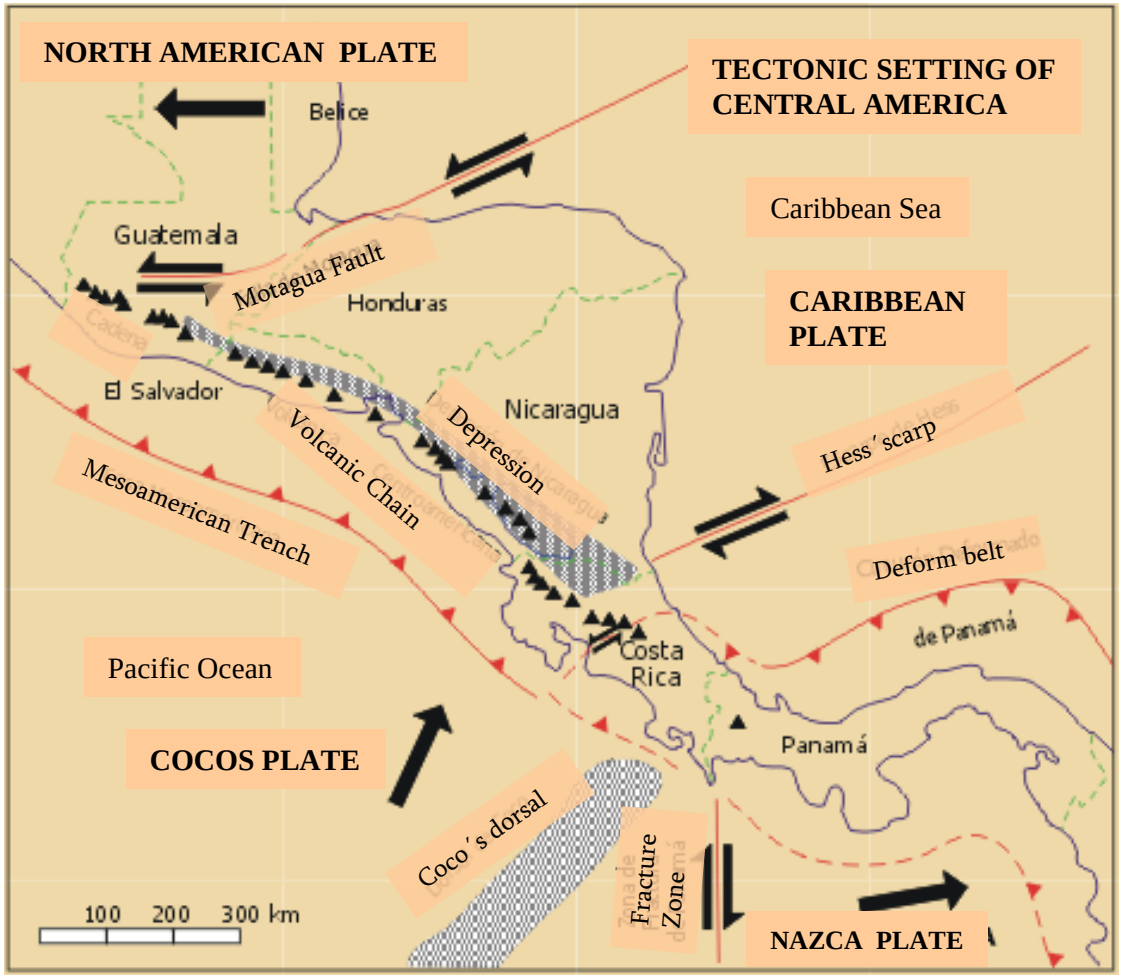

FIGURE 1: Subduction of the Cocos plate over the Caribbean plate and the volcanic chain (modified from CEPREDENAC)

In countries like El Salvador, Nicaragua, Costa Rica and Guatemala, the geothermal exploration began in the late fifties and early sixties, resulting the identification of several promising areas for the start of drilling that led to the first resource evaluation and the beginning of commercial exploitation of some areas such as Ahuachapán in 1975, Momotombo in 1983, Berlin in 1992, Miravalles in 1994, Zunil in 1998, San Jacinto Tizate in 2005, Amatitlán in 2006; and recently Las Pailas in July 2011 and San Jacinto Tizate with 36 MWe (actually in testing period).

In Figure 2, shows the location of the geothermal fields currently in operation and main geothermal areas that have been subject to exploration in Central America. Those with high temperature (> 200°C) have been utilized for generating electricity and very low application of low temperature resources have been done.

FIGURE 2: Location of the geothermal fields in operation and main geothermal areas in Central America (modified from Google)

Since the mid 90's to early 2003, the energy development in the region was focused mainly on production sustainability of existing power plants, with significantly reduction of the exploration studies of new geothermal areas.

The main reasons for this were:

- Priority of government investment to other sectors of their economies.
- Low oil prices (in the range of 10-20 dollars per barrel).
- Private companies preferred power generation investment in "traditional" electricity generation schemes (such as hydro and thermal plants).
- The geothermal projects had difficulty obtaining long-term loans as Banks and private investors had become less willing to take the risks associated with this industry.
- Support for geothermal exploration and development by local and international governments had fallen.

Today, governments in the region show more interest in developing renewable energy resources in their countries, especially in the geothermal energy. This change is probably the result of high oil prices, instability in this market, uncertainties in future climate conditions (which could affect the output of hydroelectric projects), the need of reducing CO_2 emissions by overriding the environmental impacts associated with burning wood and fossil fuels to generate electricity.

3. GEOTHERMAL RESOURCES AND CURRENT ESTIMATED POTENTIAL

Geothermal resource development in Central America should contribute significantly to achieving the Millennium Development Goals, generating electricity based on geothermal fluids that are clean, renewable, sustainable and indigenous source of energy.

Their use can provide several advantages:

- offset the price of electricity,
- protecting the Central American countries against future rises in the oil market,
- contributing to reduced environmental pollution,
- creating more job opportunities especially in rural areas where the developing of the geothermal projects are carried out.

Lippmann (2006) reports the total electricity generation capacity that can be achieved in Central America from geothermal resources, could be in the range of 2000 to 16.000 MW, giving a most likely value around 4.000 MW.

Table 1 shows the estimated geothermal potential of different sources including the data reported in this report and the geothermal potential to be developed given the current installed capacity. It can be seen that the total estimated potential for the region by the various sources is about 3500 MWe (average of the estimated potential for various publications in Table 1).

TABLE 1: Estimated geothermal potential (MWe) for electricity generation

Pot. Geot. (Mwe)	Total	Develop.	Total	Develop.	Total	Develop.	Total	Develop.	Total	Develop.	Total	Develop.
	Lippmann 2002		CEPAL 2004		JICA 2005		SICA 2006		EPI 2007		IILA 2010	
Nicaragua	1750	1662.5	1200	1112.5	992	904.5	1000	912.5	345	257.5	1519	1396
Costa Rica	1000	834.3	235	69.5	750	584.3	235	69.3	1059	893.3	865	658
Guatemala	1000	950.8	1000	950.8	480	423	1000	950.8	993	943.8	400	351
El Salvador	500	295.6	333	128.6	362	157.6	450	245.6	595	390.6	644	440
Honduras	130	130	120	120	122	122	126	126	677	677	116	116
Panama	50	50	40	40	42	42	40	40	719	719	0	0
Total	4430	3923.2	2928	2421.4	2748	2233.4	2851	2344.2	4388	3881.2	3544	2961

4. GEOTHERMAL RESOURCES AND CURRENT ELECTRICITY GENERATION

Currently from the existing geothermal potential in Central America only a relatively small amount has been used to generate electricity providing an average of 11%, but seems to be significant savings fossil fuels, especially in countries like El Salvador and Costa Rica contributing 24 and 12% respectively of total electricity consumption in each country (Table 2). The data in Table 2 is from 2010, but it also include information regarding the installed capacity for the new power plants in Costa Rica and Nicaragua (Las Pailas and San Jacinto Tizate I respectively), however, only the data for 2011 (*) on generation is available for Las Pailas.

By the year 2009, the region has installed capacity of 506.6 MW, generating an annual average of 417.5 MWe. In 2010, the installed capacity remained the same and the annual generation was 357.4 MWe. Currently, the installed capacity has increased in 2011 up to 583.5 MW, generating annually 392.4 MWe.

Table 3 shows the companies and institutions operating commercially at 8 power stations actually in generation, operating a total of 25 units, distributed as follows: Costa Rica 5, El Salvador 7, Guatemala 8 and Nicaragua 5. It should be noted that a 5-MWe unit in Amatitlán has

been closed since 2007. In the table is included the installed power in kW and the net generation in MWh. Among the companies ICE (Instituto Costarricense de Electricidad) is the only government institution, and LaGeo is semi-private, the rest are private companies.

Geothermal generation capacity in Central America in 2010 was 3131 GWh which is equivalent to 7.7% of total electricity generated by different sources. As shown in Figure 3, the geothermal generation is third in importance as a percentage compared to other types of energy used in Central America. Figure 4 shows the percentage of each power plant to the total generated from geothermal resources in 2010.

TABLE 2: Geothermal power generation in 2010 (*Updated 2011)

Country	Installed capacity (MWe)	Available capacity (MWe)	Annual energy produced (GWh/y)	National participation rate (%)
El Salvador	204.4	162.9	1427.1 *(1430)	24.3*(24.8)
Costa Rica	165.5 *(+41.5)	134.3 *(+35)	1176.1 *(+150.6)	12.4
Nicaragua	87.5 *(+36)	30.6	268.2	7.9
Guatemala	49.2	29.6	259.3	3.3
Total	506.6 *(583.5)	357.4 *(392.4)	3130.7 *(3281.3)	

TABLE 3: Utilities on geothermal power generation 2010

Country	Company	Installed power (kW)	Net generation (MWh)	Number of power stations
Costa Rica	ICE	136,160.0	963,837.0	1
	G.G. Ltd.	29,550.0	212,244.0	1
El Salvador	LaGeo	204,400.0	1,427,458.1	2
Guatemala	ORZUNIL	24,000.0	114,429.0	1
	ORTITLAN	25,200.0	144,879.0	1
Nicaragua	ORMAT	77,500.0	199,617.8	1
	PENSA	10,000.0	68,628.7	1
Total		506,810.0	3,101093.6	8

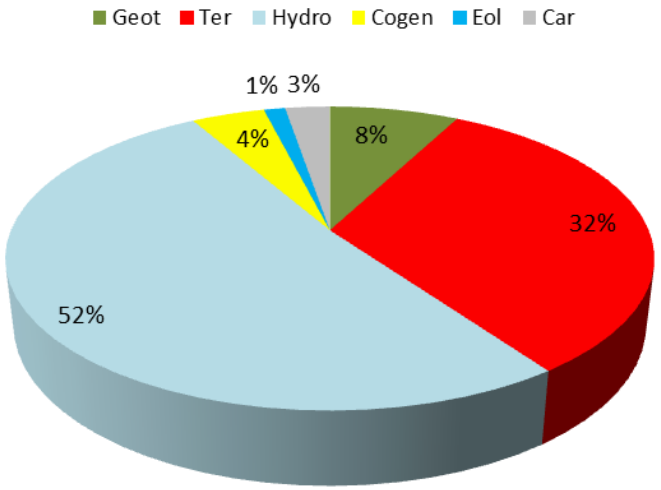

FIGURE 3: Electrical generation by energy source in Central America 2010

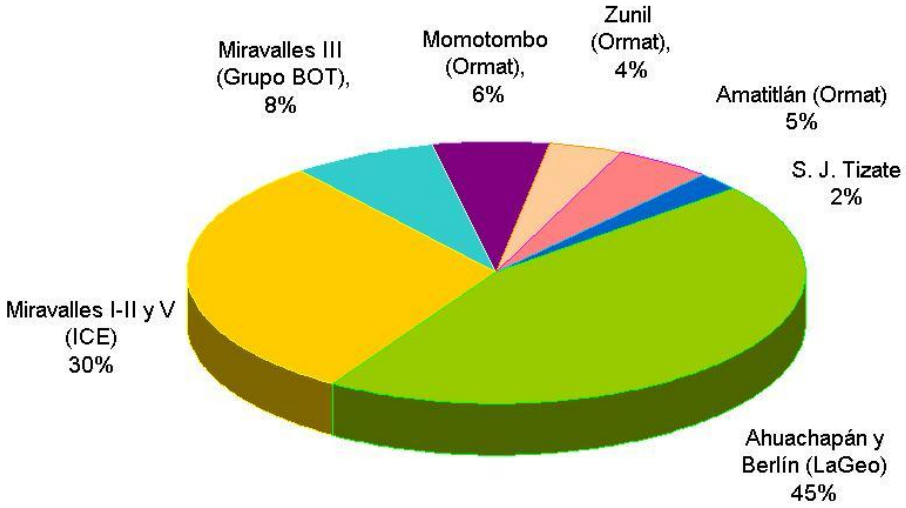

FIGURE 4: Percentage of each geothermal power plant in Central America by 2009

Table 4 shows in detail by country the number of units installed, the available capacity in MW and annual average generation in 2010.

In Table 4, the beginning and ending of the operation is included (only in the case of the wellhead units in Berlin and Amatitlán).

The contribution of geothermal power to the national grid of each country in Central America (Figure 5) contains the updated data for 2010 both in percentage and geothermal generation (GWh).

TABLE 4: Details of the Central American geothermal plants (Data 2010)

Country	Geothermal power plant	Initial operation	End of operation	Installed capacity (MWe)	Available capacity (MWe)	Annual generation (GWh)
El Salvador				204.4	183.3	1427.1
	Ahuachapán I-II-III	1975	***	95.0	79.0	667.3
	Berlin Boca Pozo	1992	1999	-10.0	0.0	0.0
	Berlin I-II	1999	***	56.2	54.4	443.4
	Berlin III	2007	***	44.0	41.4	266.4
	Berlin CB	2009	***	9.2	8.5	50.0
Guatemala				49.2	36.2	259.3
	Zunil (8)	1998	***	24.0	16.1	114.4
	Amatitlán	2006	***	25.2	20.1	144.9
	Amatitlán	2006	2007	-5.0	0.0	0.0
Costa Rica				165.5	156.0	1176.1
	Miravalles I	1994	***	55.0	55.0	422.3
	Miravalles II	1998	***	55.0	55.0	415.3
	Miravalles Boca Pozo	1998	***	5.0	5.0	16.0
	Miravalles III (BOT)	2000	***	29.5	26.0	212.2
	Miravalles V	2003	***	21.0	15.0	110.3
Nicaragua				87.5	42.0	268.2
	Momotombo (3)	1983	***	77.5	35	199.6
	San Jacinto Tizate (2)	2005	***	10.0	8.0	68.6

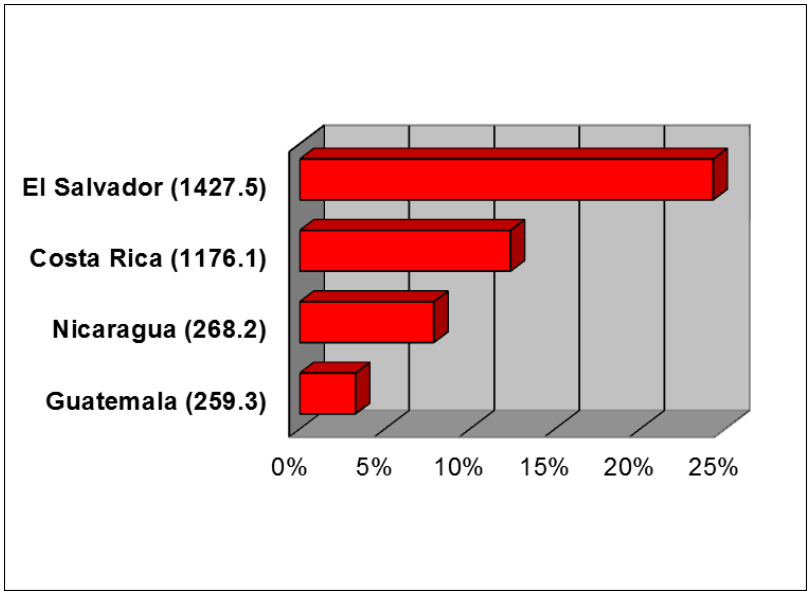

FIGURE 5: Percentage of contribution and electrical generation for 2010

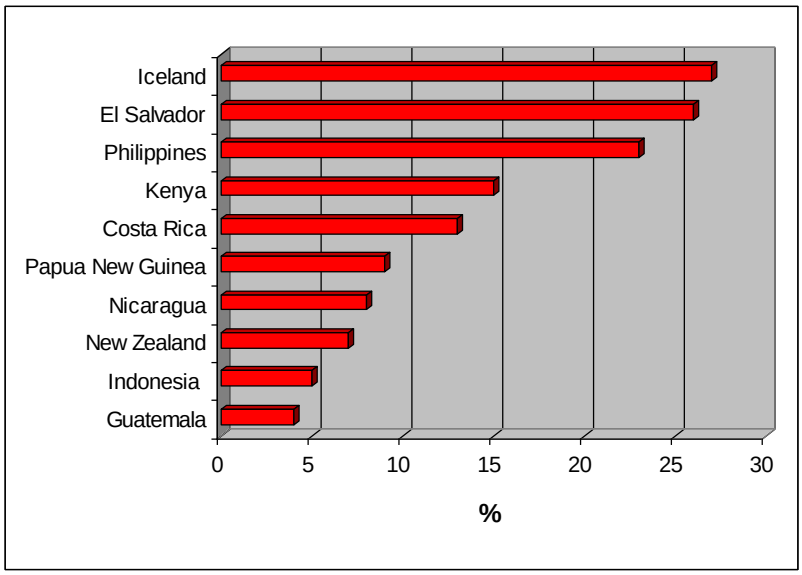

FIGURE 7: The 10 countries with the highest percentage contribution of geothermal power to the national grid of each country (Source: Bertani, 2007)

It should be noted that El Salvador, Costa Rica, Nicaragua and Guatemala are considered among the first 10 countries in the world producing a good percentage of total electricity consumption in each country (Figure 6).

5. GEOTHERMAL DEVELOPMENT HISTORY

The geothermal development in Central America since 1975 is shown in Figure 7. The increasing in installed capacity was faster in the first twenty five years, with an increment of around 400 MWe, after that, developing projects seemed to be of minor importance. Similar behaviour was reported for the geothermal generation increasing from 72 to 3131 GWh in 35 years.

Worldwide, only 25 countries use geothermal power for electricity production (IGA). In 2010, total global capacity was 10,717 megawatts (Figure 8).

Even if Larderello (Italy) started the first commercial geothermal plant in the first part of twentieth century, within the last 50 years of commercial electricity generation, several plants installed in different countries, have established and proven the geothermal industry as a cost-competitive renewable power generation technology. The majority of the generation capacity is concentrated in some few countries: the U.S., the Philippines, Indonesia, Italy, Mexico, Iceland, Japan and New Zealand (Figure 9).

After the first experiment of geothermal exploitation carried out at Larderello in 1904, the first industrial power plant (250 kW) was put into operation in 1913, and geothermal power production has since increased continuously up to the present value of 810 MW installed capacity (711 MW running capacity). The first geothermal power plants in the U.S. were built in 1962 at The Geysers dry steam field, in northern California. It is still the largest producing geothermal field in the world, with a peak

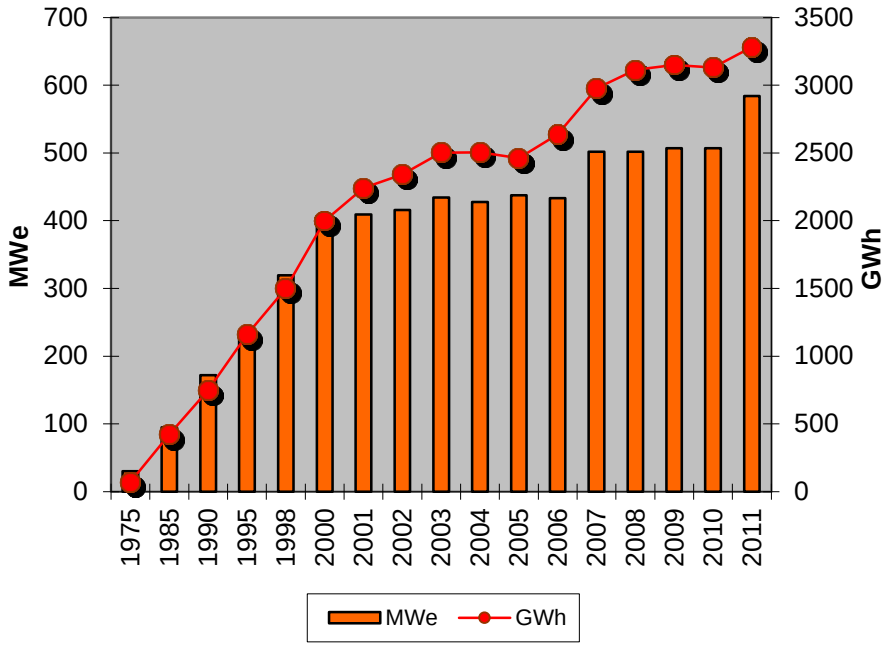

FIGURE 7: Geothermal development history and generation in Central America

capability of nearly 1,100 MW enough electricity to supply a city of over a million inhabitants. The largest field that generates the most electricity in Latin America is Cerro Prieto, Baja California, Mexico (720 MW).

While these established markets continue to account for the geothermal growth in the short term, several regions, including Central America, the Caribbean and East Africa, and other countries like Chile, Argentina, Turkey, Russia and Canada are looking to exploit robust geothermal resource as power generation demand and global fuel price increase (Figure 9).

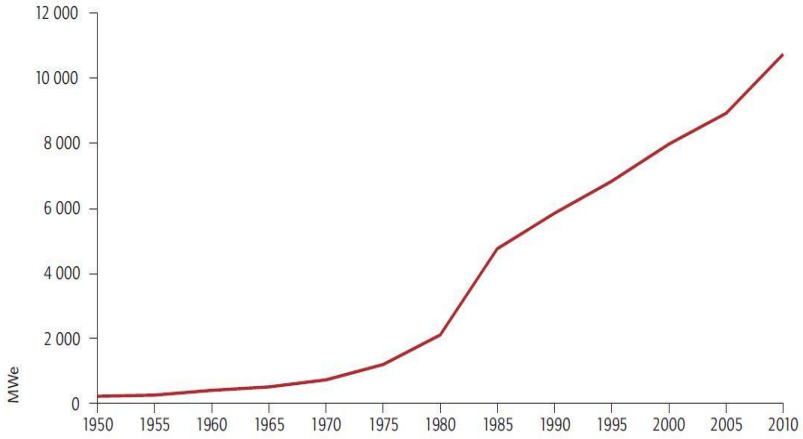

FIGURE 8: World geothermal development – Installed capacity

Figure 9, also shows other countries like Hungary, Germany, India, China and Australia exploring low enthalpy resource technology or with Enhanced Geothermal System (EGS).

Geothermal exploration is increasing, mostly due to improved technology and techniques. Several projects are underway around the world, but face financing, drilling risk, skilled labour shortages and other factors like environmental regulations (mainly related to the location of geothermal resources in national parks) could limit the development over the next decade.

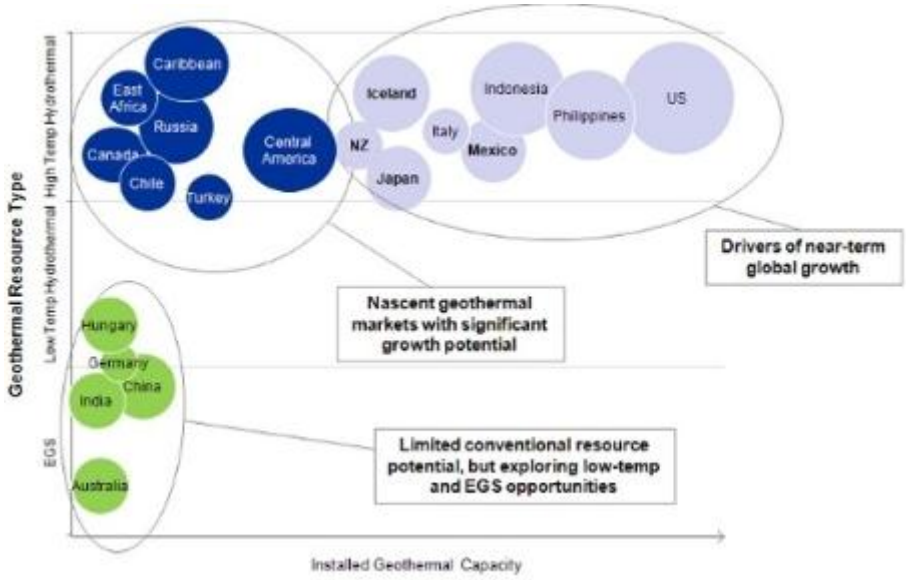

FIGURE 9. Global Geothermal Country Rankings by Installed Capacity and Pipeline.
Note: Bubble size reflects MW resource potential

6. FUTURE DEVELOPMENT IN CENTRAL AMERICA

According to Earth Policy Institute estimates 2007 (www.earth-policy.org), the MW required to meet the total demand for electricity in each country for 2010 are shown in Figure 8. Should be noticed the importance for the governments and private companies to accelerate research and development of geothermal resources in the region. As has been mentioned the potential resources in Central America has been estimated very close to the total amount currently used in electric power that is about 4317 MWe (4642 MWe for the year 2010).

The Figure 10 shows the MWe required from geothermal resources in the Central American countries for achieved the annual current total demand of electricity by 2010. See Table1.

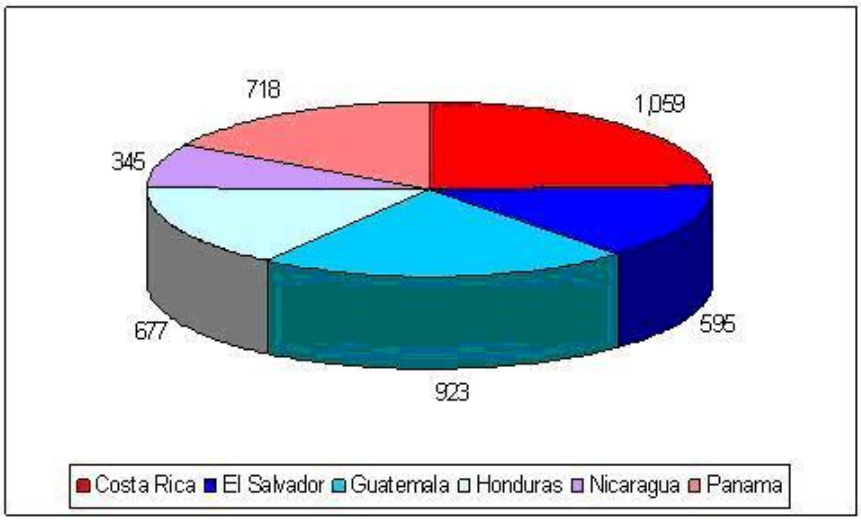

FIGURE 10: MWe required from geothermal resources in the Central American countries for achieved the annual current total demand of electricity by 2010

Bertani (2010) presents a forecasting for the geothermal installed capacity in Central American countries by the year 2015 as shown in Table 5.

These estimations gave an increase in installed capacity of 302 MWe (considering the total installed capacity in 2011 of 583.5 MWe) for the next years.

Some new projects that are underway and will be developed in the near future are described in Table 6, which would imply an increase in geothermal capacity in the region of about 230-260 MWe for the next few years.

TABLE 5: Geothermal installed capacity forecasting by the year 2015 (Bertani, 2010)

Country	MWe
Costa Rica	200
El Salvador	290
Guatemala	120
Nicaragua	240
Honduras	35
Total	885

Currently, in Costa Rica there are two operating geothermal fields, Miravalles in which are operated five power plants units with an a total installed capacity of 165.5 MWe. In the second half of 2011 (25th July) the first plant in Las Pailas geothermal field was commissioned, located on the Pacific side on the slopes of Rincón de la Vieja Volcano in Guanacaste province, with a gross capacity of 41.6 MWe (35 MWe net power). The power plant is formed by two ORMAT Binary Units with a net generation during 2011 of 150,6 Gw/h (Mainieri, ICE, 2012). Instituto Costarricense de Electricidad (ICE) is also exploring two steam fields in the western part of the country, financed by the Japanese government, under an agreement of understanding between the Costa Rican Electricity Institute (ICE) and the International Cooperation Agency of Japan (JICA) in order to install two new geothermal plants, called Las Pailas II and Borinquen.

TABLE 6: Future development projects in Central America

Country	New geothermal development
Costa Rica	Las Pailas 41.6 MWe; Las Pailas II; Borinquen
El Salvador	Chinameca 50 MWe, San Vicente 10 MWe; Quinta U 28 MWe + Segunda Binaria 5.7 MWe; Optimization Ahuachapán Fase III 5 MWe
Guatemala	Amatitlán 20 - 50 MWe Tecuamburro; Moyuta ; San Marcos Concesiones: La China; La Gloria; Joaquina; Atitlán
Nicaragua	San Jacinto Tizate I y II 36 MWe + 36 MWe El Hoyo-Monte Galán ; Managua-Chiltepe San Cristóbal-Casitas; Mombacho ; Caldera de Apoyo
Honduras	GeoPlatanares 35 MWe Azacualpa (20 MWe); Pavana (20 MWe)

The company GTherm is negotiating with ICE for a pilot project using the SWEGS system (Single-Well Engineered Geothermal System), which is a closed loop system, which doesn't require a water reservoir. GTherm is reported to be involved in negotiations for a 12 MW geothermal power project in Costa Rica. The technology uses underground infrastructure and the system generates next to no pollution at all. This so called "dry geothermal power" has a significant advantage against traditional enhanced geothermal systems.

This project is also the starting point for expanding "dry geothermal power" technology to other countries in the region.

El Salvador has increased its total geothermal power since 2007 from 151.2 MWe to 204.4 MWe, building two new units in the area of Berlin and the project of optimization in Ahuachapán which has reached levels of up to 85% of total capacity installed. El Salvador is continuing to develop geothermal energy projects in the areas of San Vicente and Chinameca, where drilling to confirm the resource and exploitation is scheduled to continue in 2011 in San Vicente and currently taking place in Chinameca where temperatures of about 250 ° C and 230 ° C respectively have been recorded in the recently drilled wells in both fields. In these fields five more exploratory wells will be drilled in the second half of 2012.

In Nicaragua, in addition of Momotombo, has begun the exploitation of the geothermal field of San Jacinto-Tizate property of Polaris Energy Nicaragua (PENSA), with the installation of two wellhead units with a total installed capacity of 10 MWe. The plant is expected to expand to 36 MWe. It has recently been given to PENSA the Mombacho volcano and Caldera de Apoyo concessions. On the other hand, Enel from Italy and its partner LaGeo of El Salvador has begun exploratory drilling concession in two geothermal areas: El Hoyo Monte - Galán and Managua -Chiltepe. Exploration activities looking to confirm the generation potential currently estimated for the new fields between 100 MWe and 200 MWe. Recently, Ram Power reports successful steam turbine generator tests by Fuji as well as progress on its construction of the San Jacinto 36 MW Phase I expansion in Nicaragua. Updating on the progress of construction of the San Jacinto Phase II 36 MW expansion, the company reports the continuation of construction with phase II construction with approximately 60% completed, expecting the final completion in December 2012.

For Guatemala, the potential of geothermal energy has been estimated at 400 MWe, has been successful in use so far in the fields of Zunil and Amatitlan. Feasibility studies are conducted in geothermal fields Tecuamburro, San Marcos and Moyuta. In addition, expansion of 30 MWe are planning in Amatitlán. The government of Guatemala has granted four concessions in 2011, which focus on analyzing the potential for possible development. The concessions are Atitlan, Joaquina, La Chinita and La Gloria project.

Honduras will develop its first geothermal power plant in Platanares geothermal field, located in a different geological structure of the typical features of high-temperature fields associated with volcanic structures. Geoplatanares, the company that holds the concession is starting in the middle of 2012 to drill exploration wells to confirm the feasibility and proceed to commercial development. Exploration activities are on the way in Azacualpa and Pavana geothermal areas. In the future, the completion of feasibility studies, environmental and financial studies, exploration drilling, production drilling, infrastructure adequacy of access, connection to the national transmission system, supply of equipment, plant construction and commercial operation are programmed.

In Central America, geothermal constitutes the second most important renewable energy source in the region. To date, there has been progress in exploration, development and exploitation potential of this resource estimated in the order of 3000-4000 MW distributed among Costa Rica, Guatemala, El Salvador and Nicaragua. In the case of Panama and Honduras, there are only preliminary estimates, but the geological-tectonic point of view indicates that there are also potential resources for electricity generation, probably limited compared with the other countries related to the volcanic activities.

The Figure 11 shows the total estimated geothermal potential (from Table 1, IILA, 2010) and the geothermal potential that could be developed in the future. If we can assume an average of the total estimated geothermal potential of 3544 MWe and taking into account the installed by 2011, the geothermal potential to be developed in the future reach about 3000 MWe (84 % of the total estimated). Although currently the geothermal energy in Central America has been successfully developed in several countries, there is still much work to do according to estimates of existing geothermal potential in the region.

The potential resource in Central America, has been estimated very close to the total amount currently used in electricity power generation, which is about 4642 MWe (Cepal,2010).

7. DIRECT USES OF GEOTHERMAL ENERGY IN CENTRAL AMERICA

Direct use of geothermal energy is well known in ancient times in Central American pre-Columbian cultures using the hot springs for medicinal purposes, culinary, religious or social aspects. Some of the sites where geothermal areas in El Salvador are located, were known to the Indians who inhabited

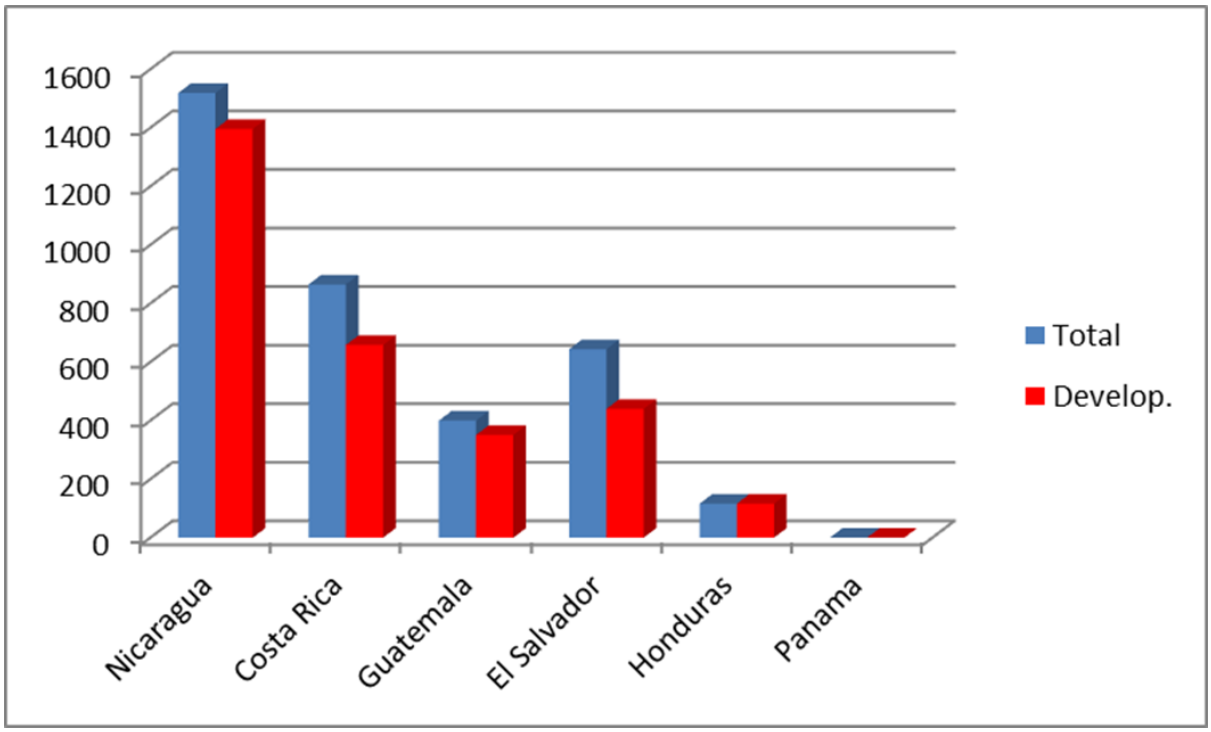

FIGURE 11: Total estimated geothermal potential and to be developed (IILA, 2010)

these areas as "ausoles". The word according to some historians, comes from the Nahuatl "atl" (water) and "Soloni" (loud boiling sound) and the Dictionary of the Royal Academy of Spanish Language (RAE) means loud boiling water, because boiling springs form impressive fumaroles (Jose Perez Bouza: Spanish Influences on the Nahuatl of El Salvador 1994).

In general, direct uses of geothermal energy currently used in Central America include mostly the drying of fruits, cement blocks and as pools or hot springs.

Due to the warm temperate climate of Central America, it currently does not apply the use of heating systems of buildings and greenhouses, however, few research studies for cooling spaces have been made.

More specifically, some studies have been performed and are using the resource for moderate to low temperature as follows:

• Costa Rica, practically limited to the use of thermal pools, although there are technical studies for drying fruits and grains in the geothermal field of Miravalles.
• El Salvador has domestic application in the drying of fruits in the Berlin geothermal field in a natural dehydration process.
• Guatemala has thermal baths at different sites and also applies to industrial drying of fruits and concrete blocks in the geothermal field of Amatitlán.
• Honduras has several places with hot springs in Copan and Gracias.

Lund et al. (2010) has estimated that in Central America there are currently a total installed capacity of 7.2 MW thermal, with a total amount of energy used of 162.5 TJ / year equivalent to 45.1 GWh per year (Table 7).

TABLE 7: Direct uses in Central American countries (Lund et al., 2010)

Country	Capacity MWt	Annual TJ/año	Annual GWh/año	Capacity factor
Costa Rica	1.0	21.0	5.8	0.67
El Salvador	2.0	40.0	11.1	0.63
Guatemala	2.3	56.5	15.7	0.78
Honduras	1.9	45.0	12.5	0.74
Total	7.2	162.5	45.1	0.71

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