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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 a gross installed capacity of 625.3 MWe, generating an annual average of 454.9 MWe. From the existing geothermal potential in Central America, the electricity generated provides an average of 13%, which seems to be significant in countries like El Salvador, Costa Rica and Nicaragua contributing 23.45%, 13.59% and 12.11% respectively of the total electricity consumption in each country for the year 2012. Geothermal generation capacity in Central America in 2012 was 3429 GWh which is equivalent to 7.9% 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 electric power, that is, about 5105 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 (De Mets, 2001). 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.

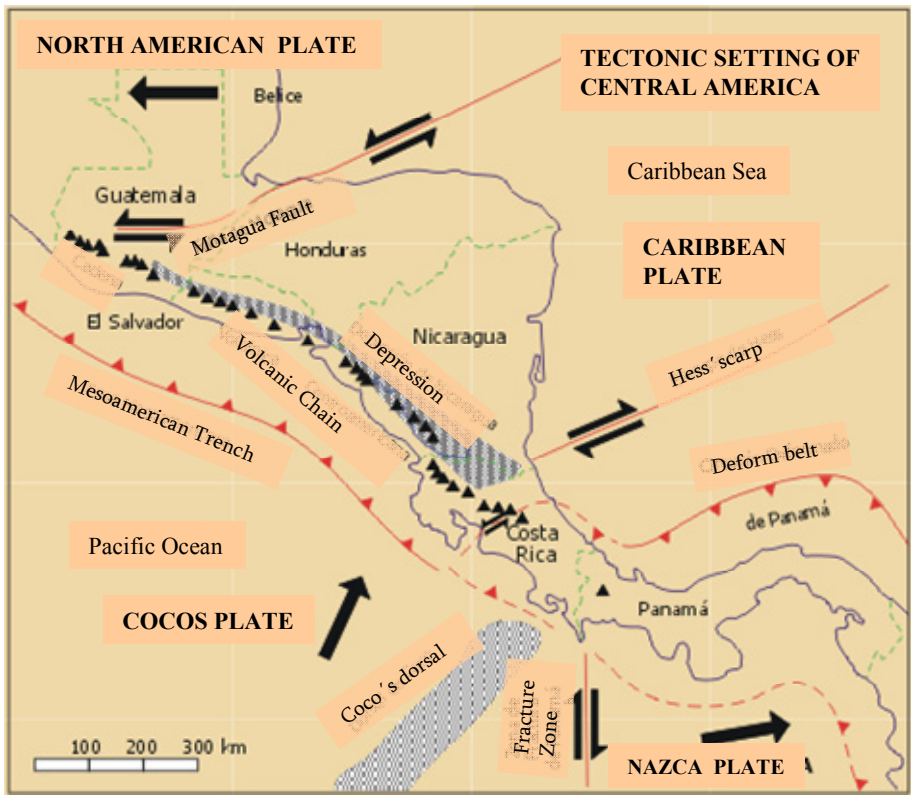

FIGURE 1: Subduction of the Cocos plate over the Caribbean plate and the volcanic chain (Source: modified from CEPREDENAC)

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.

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 in January (U3) and December 2012 (U4).

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.

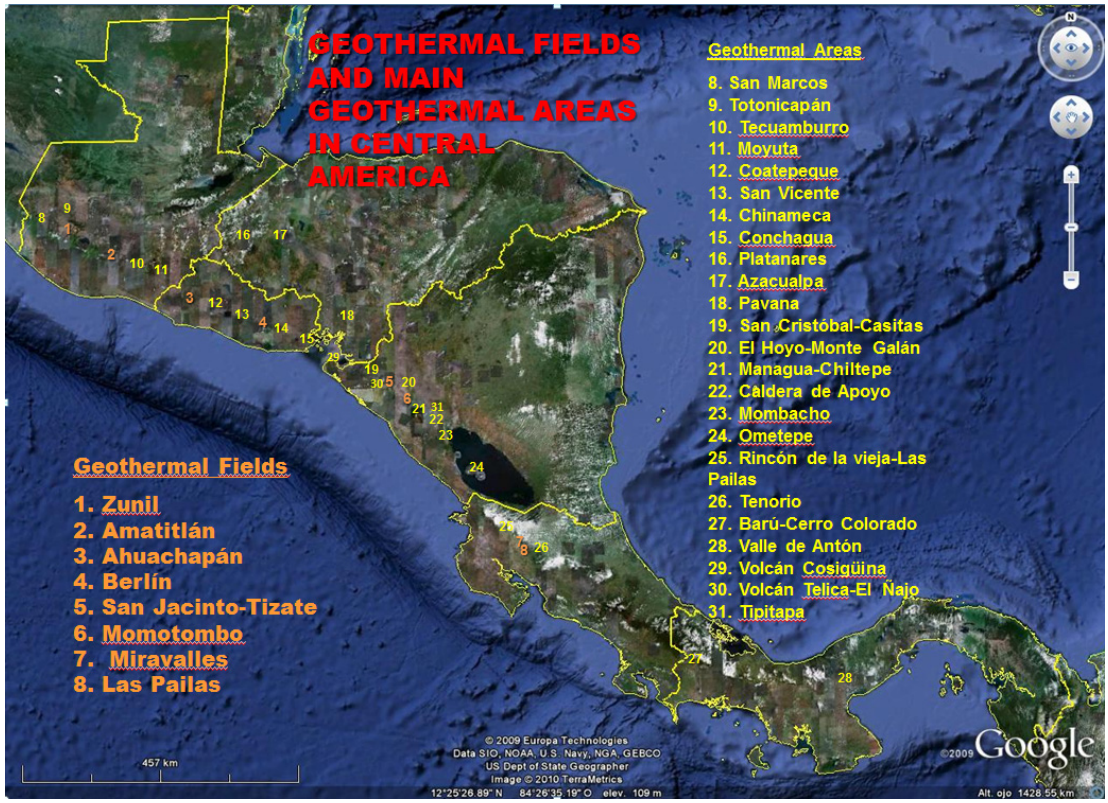

FIGURE 2: Location of the geothermal fields in operation and main geothermal areas in Central America (modified from Google)

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 (2002) 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 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

Geot. Pot. (Mwe)	Total	Develop.	Total	Develop.	Total	Develop.	Total	Develop.	Total	Develop.	Total	Develop.
Nicaragua	1750	1662.5	1200	1112.5	992	904.5	1000	912.5	345	257.5	1519	1431.5
Costa Rica	1000	834.3	235	69.5	750	584.3	235	69.3	1059	893.3	865	699.3
Guatemala	1000	950.8	1000	950.8	480	423	1000	950.8	993	943.8	400	350.8
El Salvador	500	295.6	333	128.6	362	157.6	450	245.6	595	390.6	644	439.6
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	3037.2
Source:	Lippmann 2002		CEPAL 2004		JICA 2005		SICA 2006		EPI 2007		IILA 2009	

4. GEOTHERMAL RESOURCES AND CURRENT ELECTRICAL 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 13%, but seems to be significant savings fossil fuels, especially in countries like El Salvador, Costa Rica and Nicaragua contributing 23.45, 13.59 and 12.1% respectively of total electricity consumption in each country (Table 2).

The data in Table 2 is from 2012, including information regarding the installed capacity for the new power plants in Costa Rica and Nicaragua (Las Pailas and San Jacinto Tizate respectively), hovewer, only the data for 2011 is available for Guatemala.

TABLE 2: Geothermal power generation in 2012. * Data from 2011

Country	Installed Capacity (MWe)	Available Capacity (MWe)	Annual Energy produced (GWh/y)	National participation rate (%)
El Salvador	204.4	179.1	1420.2	23.45
Costa Rica	207.2	180.0	1280.0	13.59
Nicaragua	164.5	68.8	491.8	12.11
Guatemala	*49.2	*27.0	*237.1	*2.91
Total	625.3	454.9	3429.1	

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 2012 up to 625 MW, generating annually 455 MWe and 3429 GWh which is equivalent to 7.9% of total electricity generated by different sources. As shown in Figure 3, the geothermal generation is the third in importance as a percentage compared to other types of energy used in Central America. Figure 4 shows the percentage of each country of the total generated from geothermal resources in 2012.

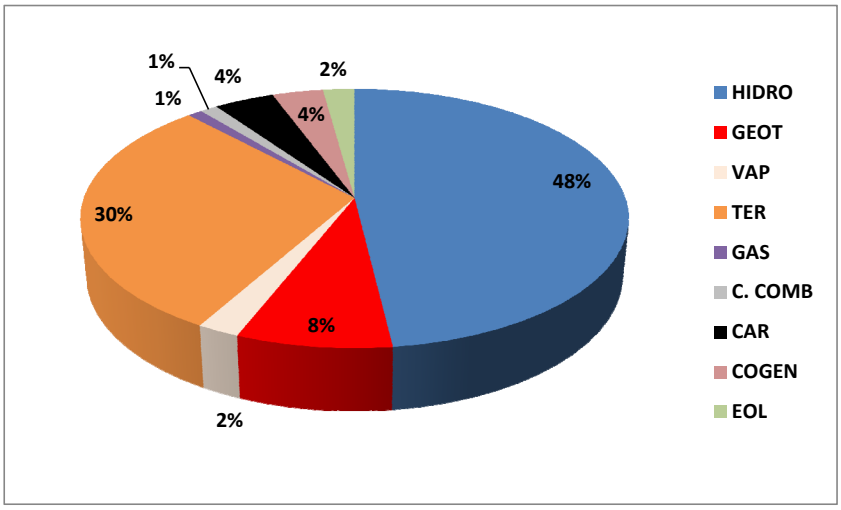

FIGURE 3: Electrical generation by energy source in Central America 2012

Figure 5 shows the percentage of the different geothermal fields on the total generated from geothermal resources in 2012.

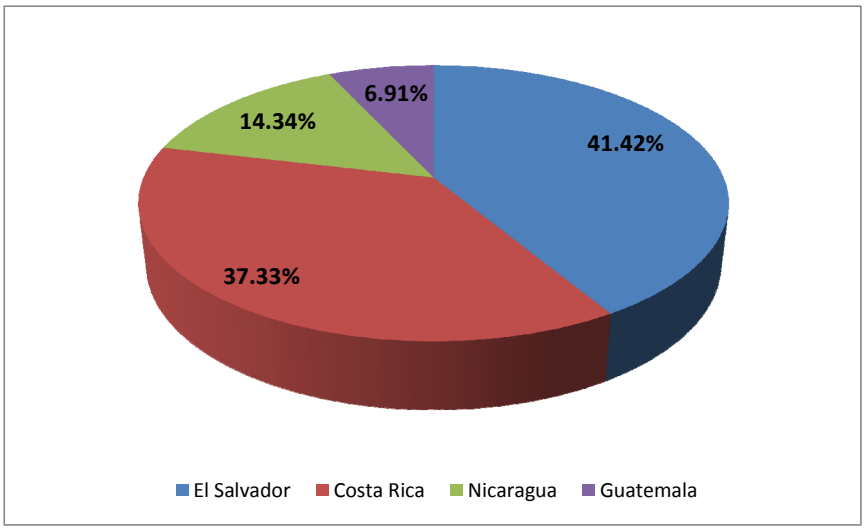

FIGURE 4: Electrical generation by geothermal resources in Central America 2012

Table 3 shows the detailed number of units installed by each country, the available capacity in MW and annual average generation in 2012. It should be noted that a 10-MWe wellhead unit in Berlin and 5-MWe unit in Amatitlán have been shut down since 1999 and 2007 respectively. In the table the installed capacity is included, available capacity and the annual generation. Among the companies only the ICE (Instituto Costarricense de Electricidad) is the only government institution and LaGeo that is semi-private, the rest are private companies.

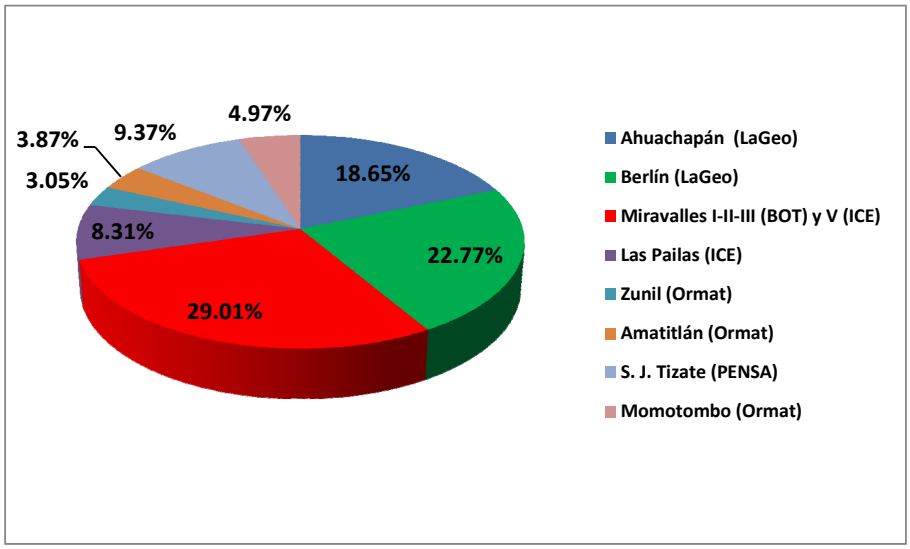

FIGURE 5: Percentage of geothermal production for each field in Central America by 2012

TABLE 3: Details of the Central American geothermal plants

Country	Geothermal Power Plant	Initial Operation	End of Operation	Installed Capacity (MWe)	Available Capacity (MWe)	Annual Generation (GWh)
El Salvador				**204.4**	**179.1**	**1420.4**
	Ahuachapán I-II-III	1975	***	95.0	74.1	639.5
	Berlin Boca Pozo	1992	1999	-10.0	0.0	0.0
	Berlin I-II	1999	***	56.2	53.6	422.0
	Berlin III	2007	***	44.0	42.6	308.0
	Berlin CB	2009	***	9.2	8.8	50.9
Guatemala				**49.2**	**27.0**	**237.1**
	Zunil (8)	1998	***	24.0	11.4	100.0
	Amatitlán	2006	***	25.2	15.6	137.1
	Amatitlán	2006	2007	-5.0	0.0	0.0
Costa Rica				**207.2**	**180.0**	**1280.0**
	Miravalles I	1994	***	55.0	50.0	370.0
	Miravalles II	1998	***	55.0	50.0	350.0
	Miravalles Boca Pozo	1998	***	5.0	5.0	15.0
	Miravalles III (BOT)	2000	***	29.5	25.0	150.0
	Miravalles V	2003	***	21.0	15.0	110.0
	Las Pailas	2011	***	41.7	35.0	285.0
Nicaragua				**164.5**	**68.8**	**491.8**
	Momotombo (3)	1983	***	77.5	30.3	191.8
	San Jacinto Tizate (2)	2005	***	10.0	38.5	300.0
	U3	2012	***	38.5		
	U4			38.5		

Note: Data available for Guatemala in 2011(CEPAL)

The contribution of geothermal power to the national grid of each country in Central America contains the updated data for 2012 both in geothermal generation (GWh) and percentage (Figure 6 and 7).

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 8).

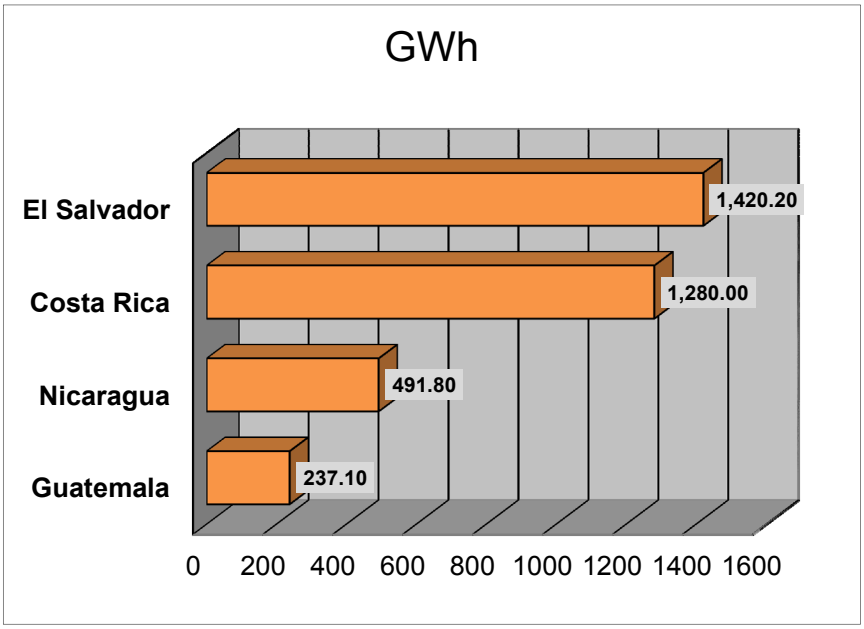

FIGURE 6: Geothermal energy production for electrical uses in 2012

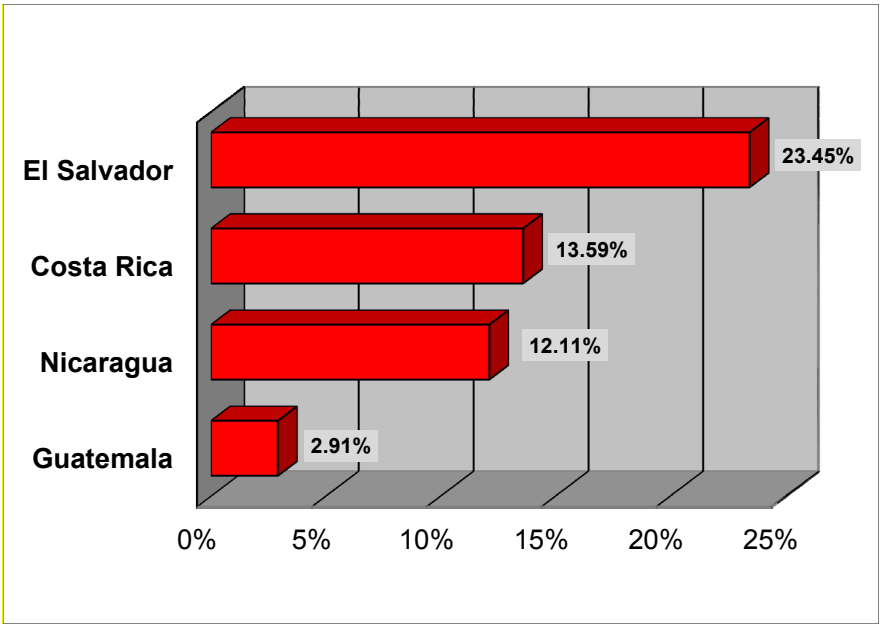

FIGURE 7: Percentage of contribution and electrical generation for 2012

5. GEOTHERMAL DEVELOPMENT HISTORY

The geothermal development in Central America since 1975 is shown in Figure 9. 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 behavior was reported for the geothermal generation increasing from 72 to 3429 GWh in 37 years.

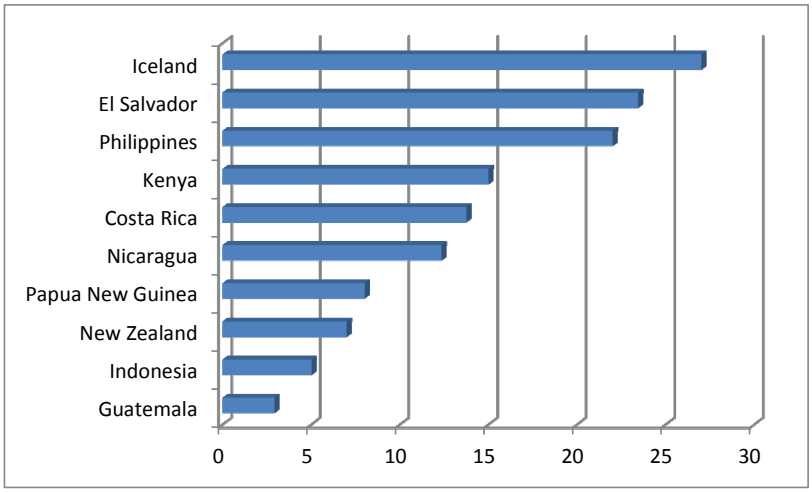

FIGURE 8: Top 10 countries with the highest percentage contribution of geothermal power to the national grid (modified from Bertani, 2007)

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

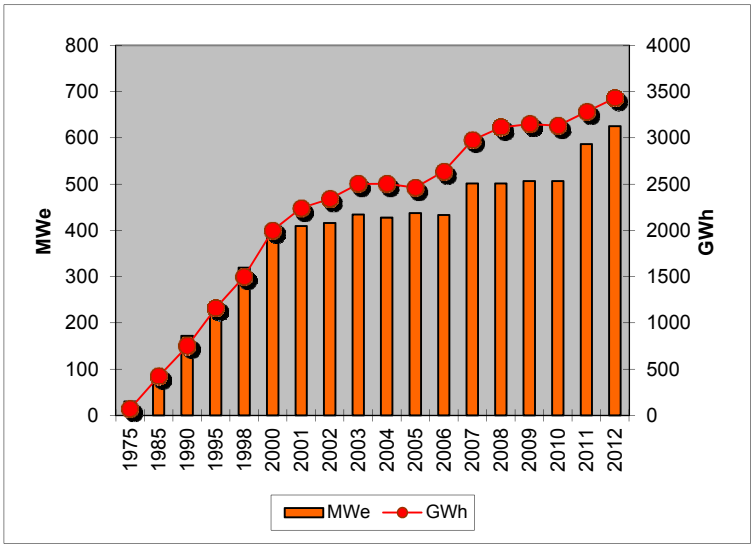

FIGURE 9: Geothermal development history and generation in Central America.

Even if Larderello (Italy) started the first commercial geothermal plant in the first part of twenty 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 generation capacity is concentrated in some few countries: the U.S., the Philippines, Indonesia, Italy, Mexico, Iceland, Japan and New Zealand (Figure 11). After the first experiment of geothermal exploitation was 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 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 will continue to account for the geothermal growth in the short term, several regions, including Central America, the Caribbean and East Africa, and others countries like Chile, Argentina, Turkey, Russia and Canada are looking to exploit robust geothermal resource potential as power generation demand and global fuel price increasing (Stephure, T., 2009; Figure 11).

The Figure 11, also shows other countries like Hungary, Germany, India, China and Australia exploring low enthalpy resources technology or with Enhance 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 labor shortages and other factors like environmental regulations mainly related to the location of geothermal resources in national parks could be limited the development over the next decade.

Figure 12 shows the geothermal-electric installed capacity by 2012. The countries of Costa Rica, El Salvador and Nicaragua are currently placed in position ten, eleven and twelve in the geothermal world, respectively.

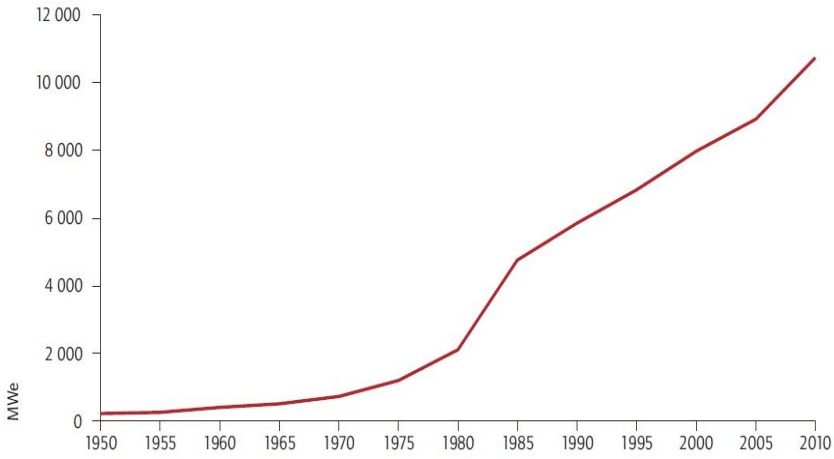

FIGURE 10: World geothermal development – Installed capacity

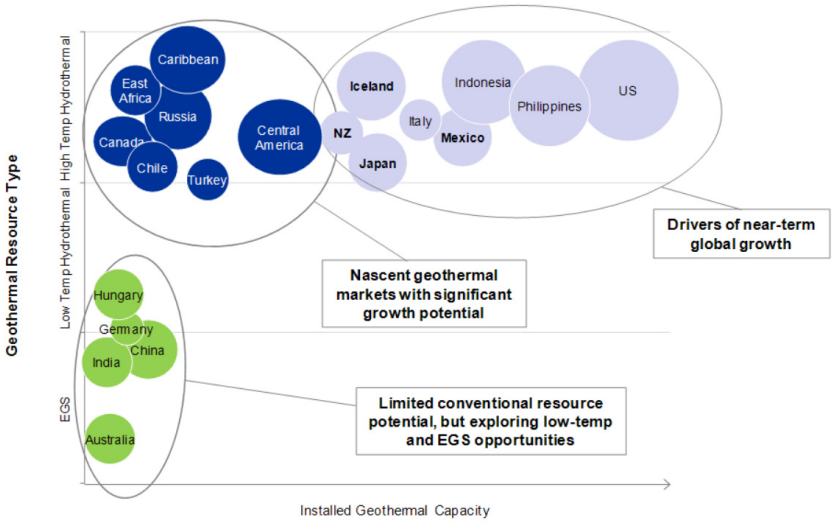

FIGURE 11: Global geothermal country rankings
by installed capacity and pipeline
Note: Bubble size reflects MW resource potential (Stephure, T., 2009)

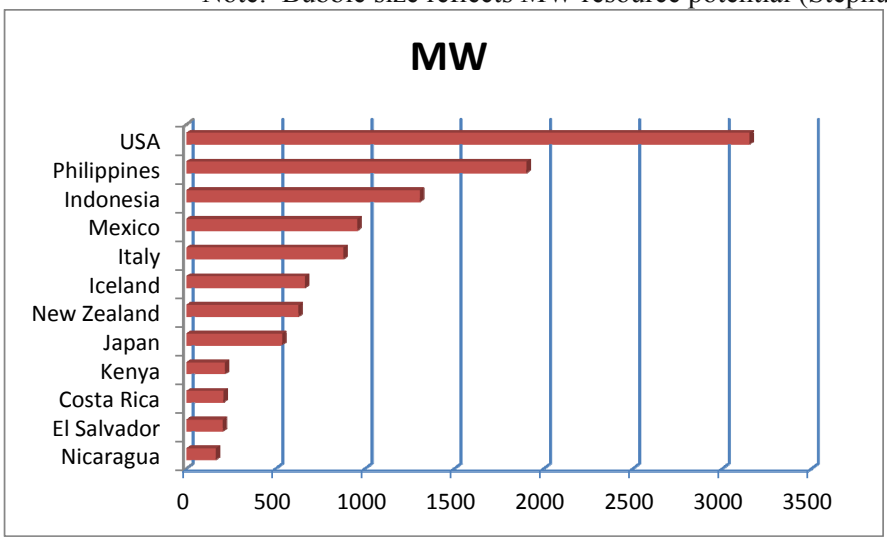

FIGURE 12: World geothermal installed capacity
(modified from IGA News 90)

6. FUTURE DEVELOPMENT IN CENTRAL AMERICA

According to Earth Policy Institute (EPI) estimates 2007 (www.earthpolicy.org), the MW required to meet the total demand for electricity in each country for 2010 are shown in Figure 13.

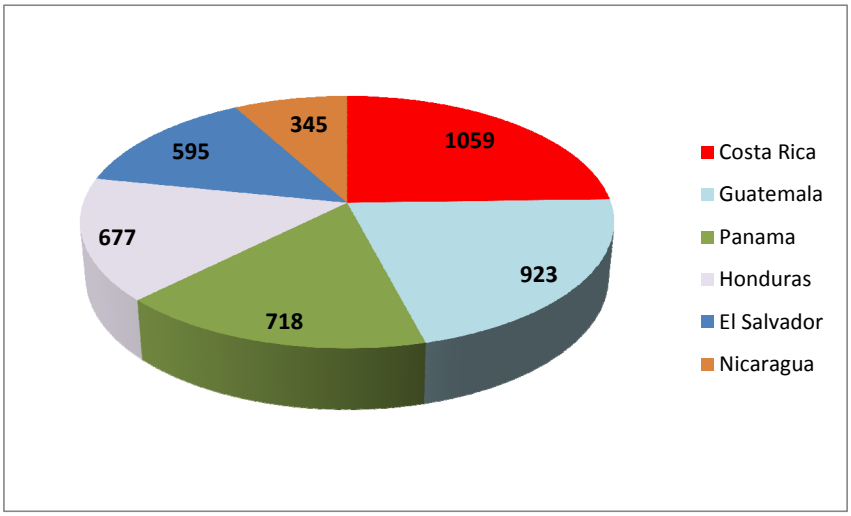

FIGURE 13: MWe required from geothermal resources in the Central American countries for achieved the annual current total demand of electricity by 2010 (EPI, 2007)

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 (5104 MWe for the year 2012).

The Figure 13, shows the MWe required from geothermal resources in the Central American countries for achieved the annual current total demand of electricity by 2010 (according to EPI). See Table 1.

Bertani (2010) presents a forecasting for the geothermal installed capacity in Central American countries by the year 2015 as shown in Table 4.

TABLE 4: 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

These estimations gave an increase in installed capacity of 260 MWe (considering the total installed capacity by 2012 of 625 MWe) for the next years.

Some new projects that are underway and will be developed in the near future are described in Table 5, which would imply an increase in geothermal capacity in the region of about 325-375 MWe for the next few years.

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 of 150,6 Gw/h in 2011 and 285 GWh in 2012 (Mainieri, ICE 2012; Castro ICE, 2013). Instituto Costarricense de Electricidad (ICE) is also exploring two steam fields in the country's west, 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.

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.

TABLE 5: Future development projects in Central America

Country	**New geothermal development**
Costa Rica	Las Pailas II 35-55 MW; Borinquen 55 MW; Tenorio; Arenal
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 38.5 MWe + 38.5 MWe + BC 10 MWe; Casitas-San Cristóbal 33 MWe; El Hoyo-Monte Galán ; Managua-Chiltepe; Mombacho ; Caldera de Apoyo
Honduras	GeoPlatanares 35 MWe Azacualpa (20 MWe); Pavana (20 MWe)

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 2012-2013 in San Vicente and in Chinameca where temperatures of about 250°C and 230°C respectively have been recorded in the recently drilled wells in both fields.

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 will focus on analyzing the potential for possible development. The concessions are Atitlan, Joaquina, La Chinita, El Ceibillo and La Gloria project.

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. Actually, two more units have started in operation by 2012, expanding the gross installed capacity to 87 MWe. It has recently been given to PENSA the Mombacho volcano and Caldera de Apoyo concessions.

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 next future 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, 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 constitute the second most important renewable energy source in the region. To date, there has been progress such as the 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, but probably at limited scale compared with the others related to the volcanic activity.

The Figure 14 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 2012, 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.

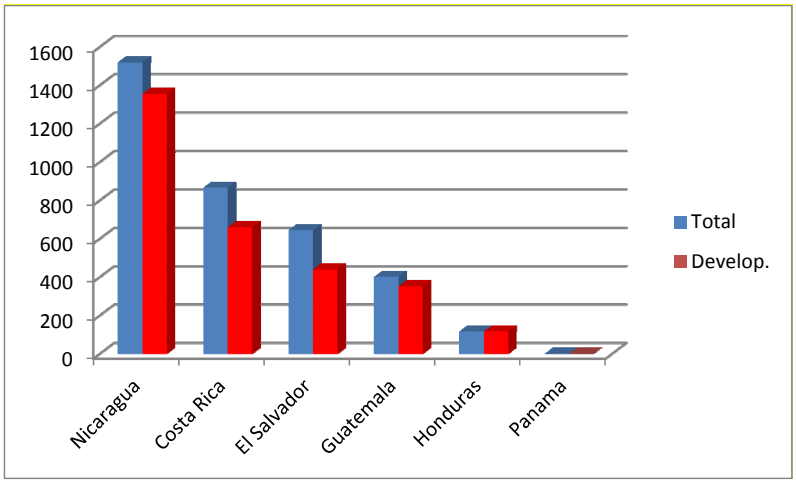

FIGURE 14: Total estimated geothermal potential and to be developed in MWe (IILA, 2010)

The potential resource in Central America, has been estimated very close to the total amount currently used in electricity power generation, which is about 4808 MWe (Cepal, 2011) and 5105 MWe (Paper, 2012).

7. DIRECT USES OF GEOTHERMAL ENERGY IN CENTRAL AMERICA

Direct use of geothermal energy is well known in ancient times, in Central America pre-Columbian cultures using the hot springs for medicinal purposes, culinary, religious or social. Some of the sites currently geothermal areas in El Salvador, were known to the Indians who inhabited these areas as "ausoles". The word according to some historians, comes from the Nahuatl "atl" (water) and "Soloni" (loud boiling sound) as the Dictionary of the Royal Academy of Spanish Language (RAE) which considers salvadoreñismo means loud boiling water, because the soil water boiling springs forming 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 pools or hot springs.

Due to the warm temperate climate of Central America currently does not apply the use of heating systems of buildings and greenhouses, but 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 thermal baths and some tests in domestic application in the drying of fruits in the Berlin geothermal field in a natural dehydration process.
• Guatemala has thermal baths at different sites 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 6).

TABLE 6: 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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