Presented at "SDG Short Course I on Sustainability and Environmental Management of Geothermal Resource Utilization and the Role of Geothermal in Combating Climate Change", organized by UNU-GTP and LaGeo, in Santa Tecla, El Salvador, September 4-10, 2016.

UNITED NATIONS UNIVERSITY
UNU-GTP
Geothermal Training Programme

LaGeo
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GEOTHERMAL SECTOR TRAINING NEEDS IN LATIN AMERICA

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ABSTRACT

A methodology for assessing human capacity needs in the geothermal sector is presented based on the number of professionals working in the sector, installed electricity generation capacity and thermal energy produced. The methodology is applied to Latin America and training needs scenarios are presented. Growth projections made in 2012 are estimated to call for the addition of close to 300 experts with university degrees to the sector in coming years. Human capacity additions due to workforce turnover outweigh capacity additions due to new projects, which suggests a need for sustained regional training opportunities going forward.

1. FOREWORD

This paper (Section 2) was first published as a chapter in the UNU-GTP evaluation report *El Salvador Geothermal Regional Training Support Program – Final report* in March 2013 (Haraldsson et al., 2013). The work was commissioned by the Nordic Development Fund (NDF) and the Inter-American Development Bank (IDB) as the first phase of support to the continued implementation of the Specialized Geothermal Diploma Course which had been run twice at the University of El Salvador (in 2010 and 2012) with financial support from the Italian Agency for Development Cooperation (Cooperazione Italiana allo Sviluppo) and implementation support from Salvadoran and Italian partners, including LaGeo S.A. de C.V. (de Velis and Montalvo, 2011; Caprai et al., 2012; Haraldsson et al., 2013; Axelsson, 2013; Haraldsson, 2015; Georgsson and Haraldsson, 2016). The publication of the final report was preceded by general information gathering, an evaluation mission to El Salvador by UNU-GTP representatives in October and November of 2012, the writing of a draft report, and a consultation workshop with stakeholders in El Salvador in February 2013.

One of the objectives of the evaluation was to assess geothermal sector training needs in Latin America. As funds were adequate for a desktop study only – rather than an on-site, in-depth review of the status of geothermal development in each country, accounting of human resources and evaluation of future development scenarios – the author settled on the methodology presented herein. It is re-published as part of the collection of papers accompanying *SDG Short Course I on Sustainability and Environmental Management of Geothermal Resource Utilization, and the Role of Geothermal in Combating Climate Change* in case it can be of use to others tasked with similar undertakings. Only minor editing changes have been made in wording and the numbering of tables and figures. The paper is therefore based on the status and history of geothermal development as it was observed in late 2012.

2. TRAINING NEEDS IN LATIN AMERICA

2.1 Introduction

Latin America holds vast stores of geothermal resources and the electricity generation potential has been estimated by the Geothermal Energy Association as shown in Table 1.

By comparison, Bertani (2010) reports the produced electricity potential for Latin America as 125 TWh/year at a capacity factor of 95%, which is equivalent to 15,000 MW. As there is a large uncertainty involved in the estimation of geothermal resource potential, different entities can arrive at different conclusions as shown in Figure 1 for Central America. This should be noted when consulting Table 1.

The low estimate in Table 1 may be too high for some countries, as suggested by comparison to Figure 1, but the high estimate may also be too low in some cases, as a recent reassessment of the generation capacity in Chile indicates the possibility to generate up to 16,000 MW for 50 years (Lahsen et al., 2010) and in 2011 the Peruvian Ministry of Energy and Mines reported a geothermal exploitation capacity of 3,000 MW in the country (ThinkGeoEnergy, 2011).

Regardless of differences, all estimates agree that geothermal potential in Latin America is large and that much remains to be harnessed. Various new geothermal projects are in the developing or advanced stages.

TABLE 1: Estimated geothermal resources in Latin America

	Estimated capacity potential (MW_e)[A]		**Installed geoth. (MW_e)**
	Low	High	
Costa Rica	970	1,990	198[B]
El Salvador	660	1,450	204[C]
Guatemala	1,050	2,260	44[D]
Honduras	310	590	0
Nicaragua	1,080	2,270	114 (61 active)[E]
Panama	130	230	0
Total Central America	**4,200**	**8,790**	
Argentina	490	1,010	0
Bolivia	510	1,260	0
Chile	780	1,630	0
Colombia	700	1,370	0
Ecuador	420	850	0
Peru	600	1,410	0
Venezuela	370	480	0
Brazil	100	200	0
Paraguay	0	200	0
Uruguay	0	200	0
Total South America	**3,970**	**8,610**	
Mexico	**2,560**	**5,180**	**983**[F]
Total Latin America	**10,730**	**22,580**	**1,543**

A: Gawell et al., 1999; B: Moya et al., 2012; C: Guidos and Burgos, 2012; D: Asturias, 2012;
E: (Ruiz, 2012a; Ruiz, 2012b); F: Morales Alcala, 2012

Pot. Geot. (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	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
Source:	Lippmann 2002		CEPAL 2004		JICA 2005		SICA 2006		EPI 2007		IILA 2010	

FIGURE 1: Different estimates of geothermal potential (MWe) for electricity generation in Central America (Montalvo, 2012a)

2.2 Allocation of professional personnel to geothermal activities

Geothermal development calls for a skilled workforce of scientists, engineers, and other professionals with specialized knowledge of the various geothermal disciplines. The International Geothermal Association has collected statistics on the allocation of professional personnel to geothermal activities through the country update reports presented at the World Geothermal Congress. An example is shown for El Salvador in Figure 2.

TABLE 7. ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES (Restricted to personnel with University degrees)

(1) Government
(2) Public Utilities
(3) Universities
(4) Paid Foreign Consultants
(5) Contributed Through Foreign Aid Programs
(6) Private Industry

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2000		280		1		1
2001		280		2		1
2002		270		1		2
2003		270		2		1
2004		270		2		1
Total		1370		8		6

FIGURE 2: Allocation of professional personnel to geothermal activities in El Salvador 2000-2004 (Rodríguez and Herrera, 2005)

While these statistics can in most cases only be viewed as approximations and in some cases as educated guesses, they can be used as an indicator of human resource needs in developing geothermal countries. Tables 2-7 summarize the available statistics for industrialized and developing countries (with reference to the United Nations classification of developing economies (United Nations, 2012)) for 2009, 2005, and 2000.

These statistics show differences in how the workforce is distributed between public and private sectors for different countries, and within countries at different points in time, as is notable in the case of the Philippines where the Energy Development Corporation was privatized in 2006 and 2007 (Catigtig, 2008). It is also apparent from the tables how various countries that have not started utilizing geothermal for electricity generation, but have shown an interest in doing so, have professionals who focus their efforts on geothermal in one way or another.

TABLE 2: Allocation of professional personnel to geothermal activities in selected industrialized countries in 2009 (restricted to personnel with university degrees)

(1) Government
(2) Public utilities
(3) Universities
(4) Paid foreign consultants
(5) Contributed through foreign aid programs
(6) Private industry

Th. / El.: Thermal energy produced / electricity produced

Country	Professional person-years of effort							MW_e[F] installed	GWh_e[F] produced	GWh_{th}[G] produced	Th. / El.
	(1)	(2)	(3)	(4)	(5)	(6)	Total				
Iceland[A]	60	40	12	1		90	203	575	4,597	6,768	1.47
Italy[B]	15		10			70	95	843	5,520	2,762	0.50
New Zealand[C]	41	30	33			218	322	628	4,055	2,654	0.65
Portugal[D]	2	19	9	5		1	36	29	175	107	0.61
USA[E]	2	2	10			1,500	1,514	3,093	16,603	15,710	0.95
Total / Mean	**120**	**91**	**74**	**6**		**1,879**	**2,170**	**5,168**	**30,950**	**28,001**	**0.90**

A: Ragnarsson, 2010; B: Cappetti et al., 2010; C: Harvey et al., 2010; D: Cabecas et al., 2010; E: Lund et al., 2010b; F: Bertani, 2010; G: Lund et al., 2010a

TABLE 3: Allocation of professional personnel to geothermal activities in selected industrialized countries in 2005 (restricted to personnel with university degrees)

Country	Professional person-years of effort							MW_e[F] installed	GWh_e[F] produced	GWh_{th}[G] produced	Th. / El.
	(1)	(2)	(3)	(4)	(5)	(6)	Total				
Iceland[A]	45	34	9			90	178	202	1,483	6,615	4.46
Italy[B]	15		10			58	83	791	5,340	2,099	0.39
New Zealand[C]	37	15	13			216	281	435	2,774	1,969	0.71
Portugal[D]	2	14	9	5		1	31	16	90	107	1.19
USA[E]	2	2	10			1,200	1,214	2,564	16,840	8,678	0.52
Total / Mean	**101**	**65**	**51**	**5**		**1,565**	**1,787**	**4,008**	**26,527**	**19,468**	**0.73**

A: Ragnarsson, 2010; B: Cappetti et al., 2010; C: Harvey et al., 2010; D: Cabecas et al., 2010; E: Lund et al., 2010b; F: Bertani, 2010; G: Lund et al., 2005b

TABLE 4: Allocation of professional personnel to geothermal activities in selected industrialized countries in 2000 (restricted to personnel with university degrees)

Country	Professional person-years of effort							MW_e[F] installed	GWh_e[G] produced	GWh_{th}[H] produced	Th. / El.
	(1)	(2)	(3)	(4)	(5)	(6)	Total				
Iceland[A]	33	34	5			42	114	170	1,138	5,603	4.92
Italy[B]	20	10	15			80	125	785	4,403	1,048	0.24
New Zealand[C]	15	5	7			50	77	437	2,268	1,967	0.87
Portugal[D]	1	3	9			1	14	16	94	10	0.11
USA[E]	100	30	50			675	855	2,228	15,470	5,640	0.36
Total / Mean	**169**	**82**	**86**			**848**	**1,185**	**3,363**	**23,373**	**14,268**	**0.61**

A: Ragnarsson, 2005; B: Cappetti and Ceppatelli, 2005; C: Dunstall, 2005; D: Carvalho et al., 2005;
E: Lund et al., 2005a; F: Bertani, 2005; G: Huttrer, 2000; H: Lund and Freeston, 2000

TABLE 5: Allocation of professional personnel to geothermal activities in selected developing and transitional countries (restricted to personnel with university degrees)

	Professional person-years of effort							**MW_e[J]**	**GWh_e[J]**	**GWh_{th}[K]**	**Th. /**
Country	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**Total**	**installed**	**produced**	**produced**	**El.**
Argentina[A]	9		8			7	24	0	0	1,085	
Chile[B]	7	10	5	8	5	14	49	0	0	36.6	
Ecuador[C]	10	9	11	0.3			30	0	0	28.4	
Guatemala[D]	2	3	2	2		8	17	52	289	15.7	0.05
Honduras[E]	2			1		7	10	0	0	12.5	
Kenya[F]	2	67		5		12	86	167	1,430	35.2	0.02
Mexico[G]	6	85	33			21	145	958	7,047	1,118	0.16
Nicaragua	10	3	1			25	39	88	310		
Philippines[H]	26			13		1,508	1,547	1,904	10,311	11.0	0.00
Turkey[I]	45	10	7	5		41	108	82	490	10,247	20.9
Total / Mean	**109**	**184**	**66**	**34.3**	**5**	**1,618**	**2,016**	**3,163**	**19,567**	**12,589**	**0.58**

A: Pesce, 2010; B: Lahsen et al., 2010; C: Beate and Salgado, 2010; D: Asturias and Grajeda, 2010; E: Lagos and Gomez, 2010; F: Simiyu, 2010; G: Gutiérrez-Negrín et al., 2010; H: Ogena et al., 2010; I: Mertoglu et al., 2010; J: Bertani, 2010; K: Lund et al., 2010a

TABLE 6: Allocation of professional personnel to geothermal activities in selected developing and transitional countries in 2005 (restricted to personnel with university degrees)

	Professional person-years of effort							**MW_e[J]**	**GWh_e[J]**	**GWh_{th}[K]**	**Th. /**
Country	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**Total**	**installed**	**produced**	**produced**	**El.**
Argentina[A]	7		6			3	16	0	0	169	
Chile[B]	2	6	3	3	2	6	22	0	0	36.4	
Ecuador[C]			2				2	0	0	28.4	
Guatemala[D]	2	3		2			7	33	212	14.6	0.07
Honduras[E]	2						2	0	0	4.7	
Kenya[F]	2	37				9	48	129	1,088	22.0	0.02
Mexico[G]	4	101	30		2	21	158	953	6,282	537	0.09
Philippines[H]	1,186			12		272	1,470	1,930	9,253	11.0	0.00
Turkey[I]	70	32	20			32	154	20	105	5,451	51.9
Total / Mean	**1,275**	**179**	**61**	**17**	**4**	**343**	**1,879**	**3,065**	**16,940**	**6,274**	**0.36**

A: Pesce, 2010; B: Lahsen et al., 2010; C: Beate and Salgado, 2010; D: Asturias and Grajeda, 2010; E: Lagos and Gomez, 2010; F: Simiyu, 2010; G: Gutiérrez-Negrín et al., 2010; H: Ogena et al., 2010; I: Mertoglu et al., 2010; J: Bertani, 2010; K: Lund, Freeston and Boyd, 2010

TABLE 7: Allocation of professional personnel to geothermal activities in selected developing and transitional countries in 2000 (restricted to personnel with university degrees)

	Professional person-years of effort							**MW_e[I]**	**GWh_e[J]**	**GWh_{th}[K]**	**Th. /**
Country	**(1)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**Total**	**installed**	**produced**	**produced**	**El.**
Argentina[A]	6		3			1	10	0	0	125	
Chile[B]		1	6	3			10	0	0	2	
El Salvador[C]		280		1		1	282	161	800		
Guatemala[D]	5				2	2	9	33	216	30	0.14
Kenya[E]	1	37		3		3	44	45	366	3	0.01
Mexico[F]	3	103	39			80	225	755	5,681	1,089	0.19
Nicaragua[G]	8					7	15	70	583		
Turkey[H]	62	22	12			32	128	20	120	4,377	36.5
Total / Mean	**85**	**443**	**60**	**7**	**2**	**126**	**723**	**1,084**	**7,766**	**5,626**	**0.86**

A: Pesce, 2005; B: Lahsen et al., 2005; C: Rodríguez and Herrera, 2005; D: Roldán Manzo, 2005; E: Mwangi, 2005; F: Gutiérrez-Negrín and Quijano-León, 2005; G: Mayorga Zuñiga, 2005; H: Simsek et al., 2005; I: Bertani, 2010; J: Huttrer, 2000; K: Lund and Freeston, 2000

It is notable in Tables 2-7 that the mix of electricity generation and direct use (thermal generation) differs between countries. In Iceland (at ~65°N), geothermal utilization started out with direct use for heating, washing, bathing, and swimming, while electricity generation came later. It has grown at a faster pace than direct utilization in recent years, however. About 90% of the population is provided with geothermal heat through district heating systems operated by utilities that on a country wide scale require a significant number of experts. District heating is not as common in other countries, but the use of heat pumps for heating individual buildings or groups of buildings has been growing substantially in many countries in the past years. Their installation and maintenance also requires a significant work force. All of the industrialized countries selected are using geothermal to supply substantial amounts of heat energy. Many of the developing countries selected are located in the tropical or subtropical regions of the planet and therefore less emphasis has been placed on using geothermal resources to supply thermal energy than in countries located in more temperate regions. However, Turkey stands out among all the countries for direct utilization, which is explained by district heating and a strong bathing tradition. Although direct utilization will not be focused on as a primary driver for geothermal training demand in Latin America, it can be looked upon as a secondary one. Many regions in South America could thus benefit from district heating systems, either due to being placed at high southern latitudes or high altitudes. In addition, geothermal can be used for various other direct utilization purposes in Latin America, even in its tropical or subtropical parts.

In order to separate the expertise demand for electrical generation and direct utilization, it can be hypothesized that demand for the services of geothermal experts for the generation of electricity is directly proportional to installed power and that the same applies to the relationship between demand for experts and annual direct use of geothermal energy. This is without a doubt a great simplification, but may nevertheless prove sufficient as a crude basis for the estimation of training needs. These relationships can be combined in the following equation for the total workforce need:

$$WF_{C,Y} = \alpha_{C,Y} \cdot IC_{C,Y} + \beta_{C,Y} \cdot DU_{C,Y} \tag{1}$$

where
- WF = Size of workforce (persons);
- C = Country index;
- Y = Year index;
- α = Expert application factor (electricity generation) (persons/MW);
- IC = Installed Capacity (MW);
- β = Expert application factor (direct utilization) (persons/GWh); and
- DU = Direct Utilization (GWh).

Equation 1 can be rewritten to standard linear graphical format, where $\alpha_{C,Y}$ and $\beta_{C,Y}$ are unknowns.

$$\frac{WF_{C,Y}}{DU_{C,Y}} = \alpha_{C,Y} \frac{IC_{C,Y}}{DU_{C,Y}} + \beta_{C,Y} \tag{2}$$

Three sets of points are available for many countries from Tables 2-7, though in some cases only two points or one are available. In the cases where three data points are available and a country is both generating electricity and using geothermal directly, the method of least squares is used to obtain best estimates of α and β through the sets of points (Iceland, Portugal, United States, Mexico). If either α or β turn out negative and both electricity generation and direct utilization are too large to ignore (the ratio of production of thermal energy to the production of electric energy is greater than 0.10, as shown in the last column of Tables 2-7), two points are selected that will give positive values for both factors if possible (Italy and Turkey). In these cases, data points are selected from the years indicated in the Method column in Table 8. In other cases, except for New Zealand, a weighted average method was used. For countries that are only utilizing geothermal energy directly, the size of the workforce was weighted with the thermal energy production (Argentina, Chile, Ecuador, and Honduras) to obtain β. It should be noted, however, that many countries in South America that are utilizing geothermal directly to some extent were in the phase of exploration and development of geothermal resources for electricity generation in 2009 and thus some, or a large part, of the geothermal workforce may be working towards commencing electricity generation. For countries where data were not available on direct utilization (El Salvador and Nicaragua), as well as those where the ratio of thermal energy to the ratio of electrical energy was less than 0.10 (Guatemala, Kenya, and the Philippines), direct utilization was assumed to be zero and the size of the workforce was weighted with the electrical energy production to obtain α. The data for New Zealand did not lend themselves easily to any of these methods and the values of α and β are thus given as ranges between zero and the maximum value obtained for one factor when the other is set to zero. Results are shown in Table 8.

TABLE 8: Estimates of α and β for several countries using geothermal resources

Country	α (persons/MW)	β (persons/GWh)	No. of points	Method
Iceland	0.117	0.020	3	Least squares
Italy	0.072	0.013	2 of 3	2009, 2005
New Zealand	0-0.453	0-0.103	3	Weighted av.
Portugal	0.780	0.150	3	Least squares
USA	0.278	0.047	3	Least squares
W. average*	**0.234**	**0.034**		
Argentina	-	0.036	3	Weighted av.
Chile	-	1.039	3	Weighted av.
Ecuador	-	0.563	2	Weighted av.
El Salvador	1.75	-	1	
Guatemala	0.280	Set to 0	3	Weighted av.
Honduras	-	0.698	2	Weighted av.
Kenya	0.522	Set to 0	3	Weigthed av.
Mexico	0.114	0.083	3	Least squares
Nicaragua	0.34	-	2	Weighted av.
Philippines	0.787	Set to 0	2	Weighted av.
Turkey	1.10	0.024	2 of 3	2005, 2000
W. average*	**0.535**	**0.045**		

*Weighted with installed capacity / thermal production of all years for which data were used

The outcome shows considerable variation between countries in the number of experts needed to generate a single unit of electrical power or thermal energy. This can probably, in part, be explained by different ways of counting professional person-years of efforts and differences in workforce efficiency between countries, which can be taken as a likely factor when comparing the manpower needs in industrialized and developing/transitional countries (with technology and machinery often having replaced manpower in the former). Also, the nature of direct utilization can vary between countries and thus it is to be expected that expert application varies also, as some utilization sectors are more expert intensive than others. Without a doubt, there are various other factors at play as well.

While the expert application to electricity generation appears to fall within the range 0.12-0.78 persons/MW in the industrialized countries, with a weighted mean of 0.23 person/MW in the selected group of countries for the years 2009, 2005 and 2000, it appears to be 0.11-1.75 persons/MW in the developing and transitional countries, with a weighted mean of 0.55 persons/MW. It should be noted, however, that the group of developing and transitional countries is different in Table 7 than in Tables 5 and 6 due to differences in the availability of data between the World Geothermal Congresses of 2005 and 2010. In the group of industrialized countries, the United States provides 60-66% of the weight depending on years (due to high installed capacity), while the Philippines and Mexico, with a large apparent difference in manpower needs, provide about 30% and 60%, respectively, of the weight of the group of developing and transitional countries shown in Tables 5 and 6.

Expert application to thermal energy production in the industrialized countries appears to be in the range 0.02-0.15 persons/GWh, with a weighted mean of 0.03 persons/GWh, while the range in the developing and transitional countries falls within 0.02-1.04 persons/GWh, with a weighted mean of 0.05 persons/GWh.

Capacity factors for the generation of electricity are variable between countries, but in general they are high compared to other types of power plants due to the steady base load use of geothermal power. The average world capacity factor for geothermal power generation is 0.73 (Fridleifsson and Haraldsson, 2011). This factor can be used to get a rough comparison of the expert effort needed to generate a unit of electric energy and a unit of thermal energy in a given country, although a better comparison can be made based directly on electrical energy production data, which are available from the same sources as installed capacity data. Indeed, α could be based on a unit of energy rather than a unit of power, but the latter is more useful when dealing with future projections.

2.3 Stages of geothermal development

The countries that appear in Tables 2-7 are at different stages of geothermal development. Some have already tapped a significant fraction of their geothermal potential and have mainly been concerned with maintaining that capacity (e.g. Italy (Figure 3) and the Philippines (Figure 4)). Others have been experiencing significant growth in capacity over the last decade in spite of having several decades utilization history (Iceland), while yet others have only begun to tap their potential (e.g. Kenya).

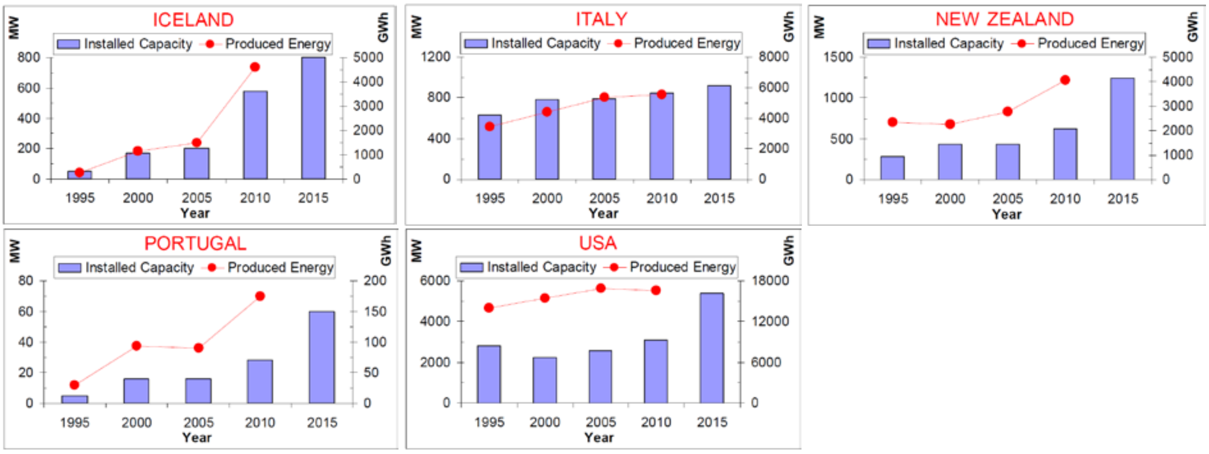

FIGURE 3: Installed geothermal capacity and electricity generation in several industrialized countries (Bertani, 2010)

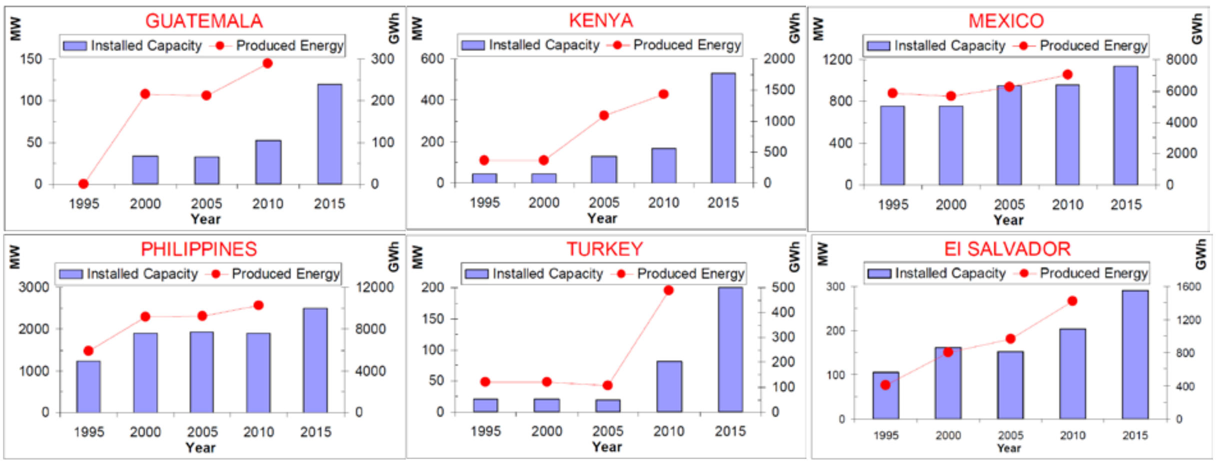

FIGURE 4: Installed geothermal capacity and electricity generation in several developing and transitional countries (Bertani, 2010)

In general, countries utilizing geothermal resources can be categorized into one of the following three groups, according to growth in generation or installed capacity on a country-wide scale:

Stagnation: On a country-wide scale, geothermal generation is steady. Make-up wells may be drilled within existing geothermal fields to replace older wells with declining output, and new fields may replace abandoned ones, but overall the generation is constant. Assuming stagnation in technology, methods, and workforce efficiency, roughly the same number of experts will be needed to maintain the production at a steady level over time. In this case, the need to train new experts depends solely on labor turnover within the geothermal sector.

Growth: Geothermal generation is growing within a country. The country may already have been generating electricity from geothermal resources for some time (a), or is starting to do so (b).

a) A country is already generating substantial electricity from geothermal resources. The development of new fields or extensions of older ones thus benefit from expertise that is already in place in the country. Regulatory bodies are familiar with the energy source, as are public institutions in charge of handing out licenses. Universities and research institutions are likewise well aware of the resource and several academic positions may be devoted partially or wholly to the study of geothermal disciplines. In this case, training is mostly focused on enhancing exploration, development and operational capacity for the new fields, as well as meeting labor turnover. New entry level positions open up within institutions and companies when new projects extract a greater toll on the experienced workforce.

b) A country is starting or greatly increasing geothermal utilization. In this case, there will be a need in the lead up to utilization to train people within government bodies and the academic sector, in addition to personnel who will be directly involved in exploration, development and operation of fields and power plants. It can thus be expected that demand for training will be higher in countries of the b-type than in countries of the a-type, for a given megawatt that is to be brought online.

Decline: A sustained significant decline in geothermal electricity generation is experienced by a country. In this case, capacity decrease may force geothermal experts from the geothermal sector. The training needs will be non-existent for some time, but if the capacity decrease takes place over a long time span and the total installed capacity in the country does not approach zero within the working lives of most geothermal experts, training needs will resurface due to turnover.

2.4 Status of geothermal development in selected Latin American countries and future projections

Argentina: In 1988, a 670 kW binary cycle pilot plant was installed in the Copahue field near the Chilean border and in 1996-1997, Neuquén Province launched a district heating project for Copahue village (Mas, 2005). The power plant was decommissioned in 1996 (Bertani, 2010). The Australian company Earth Heat Resources has had plans to construct a 30 MW power plant at the site (Jennejohn et al., 2012).

Bolivia: The State power company Empresa Nacional de Electricidad (ENDE) intends to construct a 100 MW power plant at the Laguna Colorada prospect near the border with Chile. In 2010, URS Corporation Bolivia S.A. completed an environmental impact assessment for a 170 km long 230 kV transmission line to connect the site to the national grid (URS Corporation Bolivia, 2010). The present status of the project is uncertain.

Chile: Chile has great geothermal potential and as of 2011, 54 exploration permits and 6 exploitation permits had been issued by the Ministry of Mines and the Ministry of Energy (CER, 2012). At the time, 68 additional exploration permits were pending approval and 20 new designation areas were being prepared for designation later in the year. Although the initial enthusiasm has cooled off somewhat, there are some geothermal projects on the horizon. As of September 2012, one 50 MW geothermal power plant project had been approved by the Environmental Assessment Service (Servicio de Evaluación Ambiental) and was pending construction, and another 70 MW project was undergoing environmental impact assessment (CORFO, 2012).

Colombia (Alfaro, 2012): The governments of Colombia and Ecuador have signed an agreement to develop exploration studies at the Tufiño - Chiles - Cerro Negro prospect on the border of the two countries. The involved institutions are CELEC from Ecuador and ISAGEN from Colombia. The goal is to update existing prefeasibility studies in greater detail to prepare a preliminary model for the selection of drilling targets. Efforts are also under way to develop two sites in the Nevado del Ruiz area. Drilling targets have been selected by a contractor of ISAGEN at one site and E.P.M., a municipal public energy company, has contracted US consultants to explore another. Exploration studies also continue in the Azufral and Paipa – Iza areas.

Costa Rica (Moya et al., 2012): Commercial production of electricity using geothermal steam began in the Miravalles field in early 1994. Units were added to the power plant in steps until the present installed capacity of 163 MW was reached. In 2011, a 35 MW power plant was commissioned in the Las Pailas geothermal field, but the potential for additional development of the field is very limited as it is located adjacent to the Rincón de la Vieja National Park and current laws in Costa Rica do not allow the exploration or exploitation of geothermal resources within national parks. The Costa Rican Electricity Institute (ICE) is currently exploring the Borinquen geothermal field, also in the vicinity of the Rincón de la Vieja volcano, with the intent of constructing a power plant.

In its electricity generation expansion plan, published in March 2012, ICE recommends new geothermal power plants being built and coming on line in 2018, 2019, and 2020 (ICE, 2012). Each power plant would have an installed capacity of 35 MW. Over the period 2013-2024, ICE expects geothermal electricity production to increase from 1,451 GWh to 2,216 GWh per annum (ICE, 2012).

Ecuador (Montalvo, 2012b): Preliminary studies for the Tufiño - Chiles - Cerro Negro prospect in the areas of cartography, geology, geophysics, geochemistry and seismics have been tendered internationally. Plans also exist for deep exploration drilling, but funding has not been secured. The binational project is scheduled for completion in 2014. Feasibility studies have been completed for the Chacana and Chachimbiro prospects in the northeast of the country, culminating in conceptual models for the two areas and the targeting of exploratory wells. Recommendations have been made for the drilling of slim-hole wells, but funding has not been secured. Feasibility studies, including mapping, geological, geophysical, geochemical, and seismic studies have been made for the Chalpatán area in the north of Ecuador and are currently under evaluation. Results are expected in February 2013, leading to a conceptual model of the field.

El Salvador (Guidos and Burgos, 2012): Geothermal electricity production started in 1975 when the first 30 MW unit in Ahuachapán was brought online. Production started in the Berlin geothermal field in 1992. Installed capacity is at present 95 MW in Ahuachapán and 109 MW in Berlin. The San Vicente and Chinameca fields in the east of the country both have commercial geothermal potential, each estimated at 50 MW. Exploration wells have been drilled in these fields, but exploration has been slow due to time needed to go through environmental impact assessments for drilling wells and obtaining licenses. In the next 5 years, LaGeo envisions adding a 28 MW conventional steam cycle unit and 5-9 MW binary plant at the Berlin field, and a 5-9 MW repowering unit at Ahuachapán, as well as developing a 50 MW power plant at Chinameca.

Guatemala (Asturias, 2012): A 24 MW geothermal power plant was commissioned in the Zunil I field in 1999 and a 20 MW binary power plant was commissioned in the Amatitlán field in 2007. Instituto Nacional de Electrificación (INDE) has exclusive rights to explore and develop Guatemala's geothermal resources, but lack of government policy and financial restrictions have until now prevented INDE from realizing the potential of the field. In 2012, the Ministry of Energy and Mines published the Indicative Generation Expansion Plan, which forecasts changes in the country's energy mix. The forecast model predicts an increase of 300 MW geothermal capacity by 2017 and a clear indication is given that the government will seek to promote geothermal development through private investment.

Honduras: The Platanares geothermal field is the most promising geothermal field in Honduras. A subsidiary of Ormat Technologies obtained the rights to the field in November 2012 (Ormat, 2012) from GeoPlatanares, which had been developing the field for some time prior to the agreement (Lagos and Gomez, 2010). A power purchase agreement for up to 35 MW has been made with the national utility, Empresa Nacional de Energía Eléctrica (Ormat, 2012). Another private company, GeoPower, has conducted pre-feasibility studies on the Pavana and Azacualpa fields (Lagos and Gomez, 2010).

Mexico (Flores Armenta, 2012; Morales Alcala, 2012): The net installed capacity in Mexico in November 2012 was 983 MW, having grown by 25 MW as a unit was added in the Los Humeros II geothermal field. Other fields in operation are: Cerro Prieto (720 MW), Los Azufres (188 MW), Los Humeros (40 MW), and Las Tres Vírgenes (10 MW). In 2011, there were 37 geothermal power plants operating in all the fields. Additional power plants are envisioned in the future at Los Azufres (50 MW), Los Humeros (2x25 MW) and Cerritos Colorados (25 MW). The geothermal areas of Acoculco, Baja California Norte, El Chichonal, and Cuitzeo Lake are currently under exploration.

Nicaragua (Ruiz, 2012a; Ruiz, 2012b): Geothermal power production started in Nicaragua in 1983 when the first 35 MW unit of the Momotombo power plant was commissioned. In 1989 a second 35 MW unit was added but due to rapid decline of the reservoir the power plant has never been used to full capacity. The current power production in Momotombo corresponds to only 28 MW, 8 of which are produced by binary units installed by ORMAT in 2002. Drilling in San Jacinto Tizate started in 1992 and in 2005 a 5 MW back pressure unit was commissioned by Polaris Energy. A second unit was installed shortly afterwards. In late 2011 a 36 MW condensing unit was added to the existing 10 MW power plant. The operation of the back pressure units has been discontinued but a second 36 MW condensing unit will soon be commissioned. An exploration permit for Casita San Cristobal was given to Cerro Colorado Power in 2009. One 800 m slim well has been drilled, encountering 240°C and discharging steam. Drilling of a full diameter well at the same place is planned and an installation of a ~10 MW well head unit is envisioned. Exploration has been going on since 2006 at Managua Chiltepe and El Hoyo Monte Galan by GeoNica (joint venture of LaGeo and ENEL Green Energy). One full diameter well has been drilled in Managua Chiltepe and two full diameter wells and three slim wells in El Hoyo Monte Galan. GeoNica has returned the exploration concession for Managua Chiltepe. The Ministry of Energy and Mines is currently negotiating with Albanisa about further exploration of this area.

Peru: In 2011, the Ministry of Energy and Mines reported a potential of exploitable geothermal energy capacity of 3,000 MW (ThinkGeoEnergy, 2011). In the same year, 7 concessions had been granted to Mustang Geothermal Corporation at Baños del Inca, Paclla, Ninobamba, Atecata, Coline, Condoroma South, and Condoroma (New York Times, 2011). However, the company has been unsuccessful in obtaining financing for the development of the concessions and has determined that the prospects for financing are not likely to improve in the foreseeable future (NASDAQ, 2012). As a result, the company has changed its focus to other projects. The Ministry of Energy and Mines has also authorized the exploration of geothermal resources in the regions of Arequipa and Cuzco by Hot Rock Peru SA (ThinkGeoEnergy, 2011). In May 2012, Hot Rock and the Energy Development Corporation (EDC) of the Philippines signed agreements covering the funding of the Chocopata and Quellaapacheta concessions, as well as others in Chile (HotRock, 2012; Remo, 2012).

2.5 Training needs of the Latin American geothermal sector

It is proposed that geothermal sector training needs for a given country in a given year be assessed by applying the following formula:

$$TN_{C,Y} = \alpha_{C,Y} \cdot \Delta IC_{C,Y} + \beta_{C,Y} \cdot \Delta DU_{C,Y} + \gamma_{C,Y} \cdot WF_{C,Y} \quad (3)$$

where TN = Training need (persons/year);
C = Country index;
Y = Year index;
α = Expert application to electricity generation factor (persons/MW);
ΔIC = Projected change in installed capacity (MW/year);
β = Expert application to direct utilization factor (persons/GWh);
ΔDU = Projected change in direct utilization (GWh/year);
γ = Turnover (1/year); and
WF = Size of workforce (persons).

Some of the terms are addressed in greater detail below:

Projected change in installed capacity is based on projections according to best available knowledge at a given time. In 2010, Bertani published capacity projections for 2015 for various countries as shown in Table 9.

TABLE 9: Installed geothermal generation capacity in 1990, 1995, 2000, 2005, and 2010, and forecasting for 2015 for various countries in Latin America

	Installed (MW)					**Forecast (MW)**	**Increase (MW)**	**Increase per year (MW/y)**
Country	**1990**[A]	**1995**	**2000**[C]	**2005**[D]	**2010**[D]	**2015**[D]	**2010 - 2015**	**2010 - 2015**
Argentina	0.67	0.67[B]	0	0	0	30	30	6
Chile	0	0	0	0	0	150	150	30
Costa Rica	0	55[B,C]	143	163	166	200	34	6.8
El Salvador	95	105[B,C]	161	151	204	290	86	17.2
Guatemala	0	0	33	33	52	120	68	13.6
Honduras	0	0	0	0	0	35	35	7
Mexico	700	753[B,C]	755	953	958	1,140	182	36.4
Nicaragua	35	35[C]	70	77	88	240	152	30.4
Total	**830.67**	**948.67**	**1,162**	**1,377**	**1,468**	**2,205**	**737**	**147.4**

A: Huttrer, 1995; B: Huttrer, 2000; C: Bertani, 2005; D: Bertani, 2010

Projected change in direct utilization is ideally based on projections for growth / decline in direct utilization, although such projections are not available for Latin America.

Turnover is the reciprocal of the average number of years an employee tends to stay within the geothermal sector in a given country. It is considered likely that many positions in the sector are seen as secure and reasonably well paying. The average number of years an employee stays within the sector is expected to fall within the range of 15 to 40 years, with some variation between countries. The turnover is thus expected to be in the range 0.025-0.067 y^{-1}.

The *size of the workforce* represents the number of people working in the geothermal sector and can be estimated for some countries in Latin America by consulting the data in Tables 5-7, or other sources as available. If workforce data are not available, the number of person-years of effort can be estimated by applying an appropriate expert application factor to the installed geothermal capacity of the country.

There is a large uncertainty in 5 year projections and the outlook in several countries in Latin America has changed since 2010, affecting Bertani's projections.

Projections can also be made without setting specific due dates. Table 10 summarizes the envisioned installed geothermal power increase as reported in Section 2.3. The total envisioned growth shown in the table is considerable, but it is uncertain how many of these plans will materialize, to what extent and when. Expectations for geothermal have varied around the world through the decades. At times they have been very high (e.g. during the oil crises of the 1970s and in recent years of high oil prices and threats of global warming) and at other times they have been low (e.g. when prices of competing energy sources have been low). As shown in Figure 5, the global growth in installed capacity has been roughly linear since 1980, although growth has increased and decreased (oscillated) from that long term trend over a timescale of a few years. A sustained period of exponential growth has thus not been witnessed, although hopes have at times been high.

TABLE 10: Envisioned increase in installed geothermal power in several Latin American countries

Country	**Envisioned increase (MW)**
Costa Rica	105
El Salvador	88-96
Guatemala	300
Honduras	35
Nicaragua	36
Total Central America	**564-572**
Argentina	30
Bolivia	100
Chile	120
Colombia	Exploration stage
Ecuador	Exploration stage
Peru	Exploration stage
Total South America	**250**
Mexico	**125**
Total Latin America	**939-947**

Historical growth can also be used to frame in probable future growth to provide conservative estimates in times of optimism. As evident from Table 11, the growth of installed capacity in various countries in Latin America has varied substantially over 5 year periods from 1990 to 2010. Thus, the highest growth period (1995-2000) and the lowest growth period (2005-2010) show growth rates differing by a factor of 2.3. The average growth over the period 1990-2010 was 31.9 MW/year, while the lowest average growth over a 5 year period was 18.2 MW/year, and the highest was 42.7 MW/year.

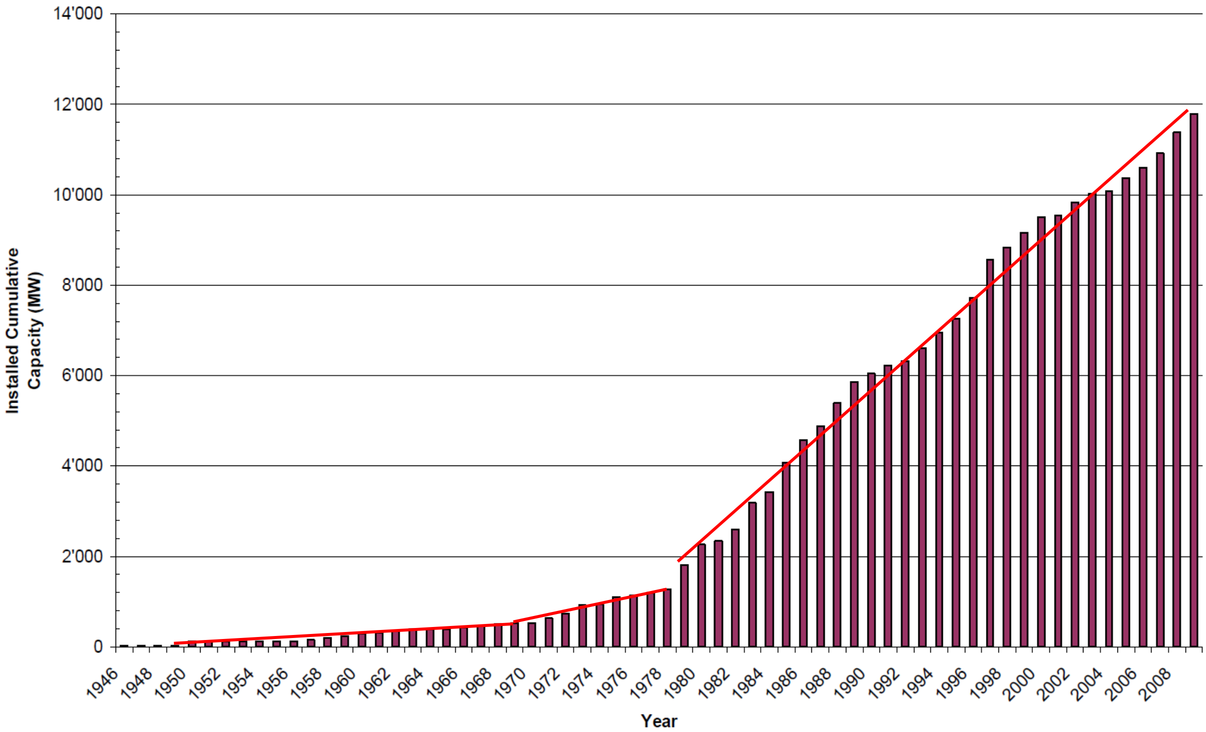

FIGURE 5: Cumulative installed global geothermal capacity from World War II. Modified from Bertani (2010)

TABLE 11: Historical growth of installed capacity for various countries in Latin America over the period 1990-2010

	Growth of installed capacity (MW)			
Country	**1990 - 1995**	**1995 - 2000**	**2000 - 2005**	**2005 - 2010**
Argentina	0	-0.67	0	0
Chile	0	0	0	0
Costa Rica	55	88	20	3
El Salvador	10	56	-10	53
Guatemala	0	33	0	19
Honduras	0	0	0	0
Mexico	53	2	198	5
Nicaragua	0	35	7	11
Total	**118**	**213.33**	**215**	**91**

It is possible that average long term growth of installed capacity in Latin America will increase if interest continues to be high in South America. On the other hand, growth in some Central American countries and Mexico may slow due to more limited options when the most feasible geothermal fields have already been put to use.

The size of the workforce of geothermal experts in each country is assumed to be as shown in Table 12.

TABLE 12: Estimated number of geothermal experts in Latin American countries with plans for geothermal power plants and estimation of α

Country	**No. of geoth. experts**	**Source**	**α (persons/MW)**	**Source**
Costa Rica	75	Estimate	0.38	75 pers / 198 MW
El Salvador	75	Estimate	0.37	75 pers / 204 MW
Guatemala	17	Table 5	0.28	Table 8
Honduras	10	Table 5	-	Table 8
Nicaragua	39	Estimate	0.34	Table 8
Total/Av. C-America	**216**		**0.36**	
Argentina	24	Table 5	-	Table 8
Bolivia	5	Estimate	-	Table 8
Chile	49	Table 5	-	Table 8
Total/Av. S-America	**78**		**-**	
Mexico	**145**	Table 5	**0.11**	Table 8
Total/Av. L-America	**439**		**0.19**	

It is considered likely that the number of professional personnel shown in Figure 2 for El Salvador is rather an estimation of the total workforce working in the geothermal sector in the country, rather than only personnel with university degrees. A more reasonable estimate of the number of geothermal experts with university degrees working in the country is considered to be 75 people. It is estimated that Costa Rica has a similar number of geothermal experts.

The following sections examine different growth scenarios and the resulting training needs for the region in accordance with Equation 3. None of the scenarios take changes in direct utilization into account.

2.5.1 Low training need scenario

The following assumptions are made:

- The expert application factor is taken to be the same as for Mexico, shown in Table 12;
- The growth of installed capacity is taken as the minimum of the 5 year periods shown in Table 11;
- Geothermal experts are expected to stay in their jobs for 40 years and therefore turnover is low;
- The size of the workforce is taken as shown in Table 12.

The variables in Equation 3 are thus assigned the values shown in Table 13.

TABLE 13: Values used for estimation of a low training need scenario for Latin America

Region	α (pers./MW)	ΔIC (MW/year)	γ (1/year)	*WF* (pers.)	*TN* (pers./year)
Latin America	0.11	18.2	0.025	439	13

The training need for this scenario is 13 persons/year.

2.5.2 Medium training need scenario

The following assumptions are made:

- The expert application factor is taken to be the average for Latin America as shown in Table 12;
- The growth of installed capacity is taken as the average over the period 1990-2010 as shown in Table 11;
- Geothermal experts are expected to stay in their jobs for 27.5 years;
- The size of the workforce is taken as shown in Table 12.

The variables in Equation 3 are therefore assigned the values shown in Table 14.

TABLE 14: Values used for estimation of a medium training need scenario for Latin America

Region	α (pers./MW)	ΔIC (MW/year)	γ (1/year)	*WF* (pers.)	*TN* (pers./year)
Latin America	0.19	31.9	0.036	439	22

The training need for this scenario is 22 persons/year.

2.5.3 High training need scenario

The following assumptions are made:

- The expert application factor is taken to be the average for Central America as shown in Table 12;
- The growth of installed capacity is taken as the maximum of the 5 year periods shown in Table 11;
- Geothermal experts are expected to stay in their jobs for 15 years and therefore turnover is rather high;
- The size of the workforce is taken as shown in Table 12.

The variables in Equation 3 are thus assigned the values shown in Table 15.

TABLE 15: Values used for estimation of a high training need scenario for Latin America

Region	α (pers./MW)	ΔIC (MW/year)	γ (1/year)	*WF* (pers.)	*TN* (pers./year)
Latin America	0.36	42.7	0.067	439	45

The training need for this scenario is 45 persons/year.

2.5.4 Training needs for the envisioned growth

As shown in Table 10, installed geothermal generation capacity is envisioned by the relevant country authorities to increase by 939-947 MW in Latin America, although the time frame for this increase to come on-line is uncertain. The need for new geothermal experts to realize this increase, irrespective of workforce turnover is estimated in Table 16.

According to the result of Table 16, 283 geothermal experts will need to join the workforce in Latin America in order to realize the envisioned capacity increase as shown in Table 10. Although it is unclear when those projects come on-line, this number indicates that the training need is substantial in the coming years. If the envisioned capacity increase were to be realized in 10 years, 28 new geothermal experts would be needed on average per year, not taking turnover, direct utilization and various other factors into account.

TABLE 16: Estimated training need to meet envisioned capacity increases as shown in Table 10

Country	α (persons/MW)	ΔIC (MW)	*TN* (persons)
Costa Rica	0.38	105	40
El Salvador	0.37	92	34
Guatemala	0.28	300	84
Honduras	0.35*	35	12
Nicaragua	0.34	36	12
Total C-America		**568**	**182**
Argentina	0.35*	30	10
Bolivia	0.35*	100	35
Chile	0.35*	120	42
Total S-America		**250**	**87**
Mexico	**0.11**	**125**	**14**
Total L-America		**943**	**283**

*Average for Central America as shown in Table 12

2.5.5 Remarks

Projections can vary between analysts depending on the premises used. The aim in the previous sections has been to establish likely lower and upper bounds for short term training needs in Latin America, with the most likely need falling somewhere in between the two extremes. The methodology presented is coarse, but is nevertheless considered more reliable than completely subjective assessments. Its transparency allows for establishing various different scenarios based on the premises of different analysts.

The assessment is considered conservative for several reasons:

- Several countries in Latin America, notably Colombia, Ecuador, and Peru, are in the exploration stage for geothermal resources and can be expected to build geothermal power plants in the future. As installed capacity projections were not available for these countries, they were not included in the training need assessment. However, as long as the drive towards harnessing geothermal resources in these countries continues, they will have the need for training additional geothermal experts.

- The need to train geothermal experts who develop and maintain various direct utilization applications is not considered. Even though the main emphasis is on electricity generation, it must be considered likely that geothermal resources in the region will also be used directly and that such use will create jobs for geothermal experts. Such utilization includes heating systems (mostly applicable for southern latitudes in South America and high altitudes, where winters can be cold), cooling systems (warmer regions), drying of various products, aquaculture, horticulture, bathing and tourism, etc.
- The expert application factor for Mexico is quite low, but weighs heavily in the low and medium training need scenarios. It is considered likely that the expert application factors for countries that are entering the geothermal scene in Latin America are higher and more in line with the average for Central America (Table 12), and not lower than the average for the industrialized countries (Table 8).

On the downside, the assessment is blind to countries' willingness to send their geothermal experts abroad for training. In this respect the quality and duration of the education program being offered is of significance, as well as financial commitments related to the studies. In reality, it can be taken for granted that regardless of the quality or expenses, not all experts who could benefit from a particular geothermal training program will apply for training.

The significance of turnover to training needs is notable and indeed the need to replace geothermal experts who are exiting the workforce will become a major component of training needs as installed capacity increases and countries reach a more mature stage of geothermal development. This may be observed by comparing the need for new geothermal experts to meet increases in installed capacity (workforce additions) to the need to replace experts exiting the workforce in the scenarios presented in subsections 2.5.1-2.5.3 (Table 17).

TABLE 17: Comparison of training needs to meet increases in installed capacity vs. replacement needs in the geothermal sector

Scenario	**Workforce additions (pers.)**	**Replacement needs (pers.)**
Low training need scenario	2	10
Medium training need scenario	6	15
High training need scenario	15	28

This indicates that geothermal training is a continuous effort and that geothermal training services must be available to the geothermal sector into the future. Even though a part of the training can be expected to move to individual countries as their geothermal sector develops, the possibility of attending training at a regional center where experiences from different countries can be shared and experts have the opportunity to form connections with colleagues from neighboring countries, must be of high value.

3. AFTERWORD

The greatest problem in assessing and projecting human resources needs for the geothermal sector is scarcity of data on which to found educated conclusions. In principle, if accurate data such as those presented in Figure 2 were available for all countries over long time spans, it should be possible to come up with functions that could be used to project human resources needs in the sector to sufficient accuracy based on given growth projection scenarios – whether those functions be linear or non-linear, single- or multi-variable. However, the author has full appreciation of the difficulty that may be inherent in gathering these data at the country level and sympathy with them perhaps sometimes being more educated guesses than concrete facts. But the collection of these data in as accurate a way as possible can be of significant value to the global geothermal community for various studies and assessments.

The few data points available at the time this study was made make it quite rudimentary. Since then, a new collection of country update papers has been published in the Proceedings of the World Geothermal Congress 2015. A quick look-up in the update papers for the countries listed in Tables 2-7 reveals that assessments of allocation of professional personnel to geothermal activities (restricted to personnel with university degrees) are available for all the countries over the period 2010-2014, except for Guatemala, Nicaragua and the Philippines (incomplete). It should therefore be possible to extend the study presented herein and re-assess α and β for the different countries with respect to the additional data. Furthermore, an improved assessment of γ is warranted.

In 2015, IRENA published a *Geothermal capacity needs assessment methodology* as part of its *Geothermal Initiative in the Andean Countries* (Rai et al., 2015). The methodology assumes capacity being added in steps (which is realistic), considers development pipelines and personnel with different expertise (science, engineering and operations), and case examples are presented for Chile and Ecuador. This is a good approach that should give a more detailed picture than the approach presented in this paper, but it also appears to require more information, which may not always be easy to get.

The methodology presented herein is based on averages, viewing capacity as continuously increasing (or decreasing), not taking personnel without university degrees into account (who of course play an important part in geothermal development) and not attempting to categorize university degrees according to discipline. The reason is of course, at least partially, the nature of the data on which the methodology is based, i.e. the standardized personnel allocation tables in the WGC country update reports. The number and mix of experts needed for geothermal development, as related to installed electrical capacity or produced thermal energy, can differ between countries and may change over time. But, in spite of some obvious limitations of the methodology, its advantage is also its simplicity. It is therefore suggested as a rudimentary tool to assess needs for human capacity additions in the geothermal sector.

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