Worldwide Geothermal Energy Utilization 2015

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Keywords

Geothermal, electricity generation, geothermal development, direct-use, spas, balneology, space heating, district heating, aquaculture, greenhouses, ground-source heat pumps, industrial applications, snow melting, energy savings, wells drilled, manpower, investment

ABSTRACT

This report presents a review of the worldwide applications of geothermal energy utilization by 2015 and updates the previous survey carried out by 2010. Both worldwide power generation and direct utilization are presented in this report. The present report is based on country update papers received from 70 countries and regions of which 24 reported electric power generation and 65 reported some direct utilization of geothermal energy. Seventeen additional countries were added to the list based on other sources of information. We also compare data from 1995, 2000, 2005 and 2010 presented at World Geothermal Congresses in Italy, Japan, Turkey, and Indonesia respectively (WGC95, WGC2000,WGC2005, and WGC2010). Power plants under construction, which are expected to be commissioned in 2015, are included in the installed capacity of 12,635 MWe with an annual energy production of 73,549 GWh. An increase of 1,738 MWe in the five year term 2010-2015 has been achieved (about 16% or 3% annually), following the rough standard linear trend of approximately 350 MWe/year, with an average value of about 200 MWe/year in the preceding 2000-2005 period. The installed capacity consists of 40.2% single flash units, 22.7% dry steam units, 20.1% double flash units, 14.2% binary units, 1.4% triple flash units, and 1.4% back pressure units. Direct utilization of geothermal energy in the total of 82 countries is an increase from the 78 reported in 2010, 72 reported in 2005, 58 reported in 2000, and 28 reported in 1995. As in previous reports, an effort is made to quantify ground-source (geothermal) heat pump data which has grown at an annual rate of 8.6% in installed capacity and 10.2% in annual energy use over the past five years. An estimation of the installed thermal power for direct utilization by 2015 equals 70,329 MWt, almost a 45% increase over the 2010 data, growing at a compound rate of 7.7% annually with a capacity factor of 0.265. The thermal energy used is 587,786 TJ/yr (163,287 GWh/yr), a 38.7% increase over 2010, growing at a compound rate of 6.8% annually. The distribution of thermal energy used by category is approximately 55.3% for ground-source heat pumps, 20.3% for bathing and swimming (including balneology), 15.0% for space heating (of which 89% is for district heating), 4.5% for greenhouses and open ground heating, 2.0% for aquaculture pond and raceway heating, 1.8% for industrial process heating, 0.4% for snow melting and cooling, 0.4% for agricultural drying, and 0.3% for other uses. For electric power generation and direct utilization combined, the energy savings amounted to 474 million barrels (71.5 million tonnes) of equivalent oil annually, preventing 74.4 million tonnes of carbon and 194.4 million tonnes of CO_2 being released to the atmosphere, this includes savings for geothermal heat pumps in the cooling mode. Approximately 2,218 well were drilled in 42 countries, 34,000 person-years of effort were allocated in 52 countries, and US$20 billion invested in projects by 49 countries.

Introduction

This report presents a review of the worldwide applications of geothermal energy utilization by 2015 and updates the previous survey carried out by 2010. Both worldwide power generation and direct utilization are presented in this report. The present report is based on country update papers received from 70 countries and regions of which 24 reported electric power generation and 65 reported some direct utilization of geothermal energy. Seventeen additional countries were added to the list based on other sources of information. We also compare data from 1995, 2000, 2005 and 2010 presented at World Geothermal Congresses in Italy, Japan, Turkey, and Indonesia respectively (WGC95, WGC2000,WGC2005, and WGC2010). Power plants under construction, which are expected to be commissioned in 2015, are included in the installed capacity of 12,635 MWe with an annual energy production of 73,549 GWh. An increase of 1,738 MWe in the five year term 2010-2015 has been achieved (about 16% or 3% annually), following the rough standard linear trend of approximately 350 MWe/year, with an average value of about 200 MWe/year in the preceding 2000-2010 period. Direct utilization of geothermal energy in the total of 82 countries is an increase from the 78 reported in 2010, 72 reported in 2005, 58 reported in 2000, and 28 reported in 1995. As in previous reports, an effort is made to quantify ground-source (geothermal) heat pump data which has grown at an annual rate of 8.6% in installed capacity and 10.2% in annual energy use over the past five years. An estimation of the installed thermal power for direct utilization by 2015 equals 70,329 MWt, almost a 45% increase over the 2010 data, growing at a compound rate of 7.7% annually with a capacity factor of 0.265. The thermal energy used is 587,786 TJ/yr (163,287 GWh/yr), a 38.7% increase over 2010, growing at a compound rate of 6.8% annually.

Electric Power Generation

The total installed capacity from worldwide geothermal power plants from 1995 to present is given in Tables 1 and 2 and in Figures 1 and 2.

In Table 3 data from all the countries currently generating geothermal electricity are presented, with the 2010 and the updated at 2015 values of installed capacity and the produced energy per year, the increment since 2010 both in absolute

Table 1. Total worldwide installed capacity from 1950 up to end of 2015 and forecasting to 2020.

Year	Installed Capacity MWe	Produced Energy GWh/yr
1950	200	
1955	270	
1960	386	
1965	520	
1970	720	
1975	1,180	
1980	2,110	
1985	4,764	
1990	5,834	
1995	6,832	38,035
2000	7,972	49,261
2005	8,933	55,709
2010	10,897	67,246
2015	12,635	73,549
2020	21,443 est.	

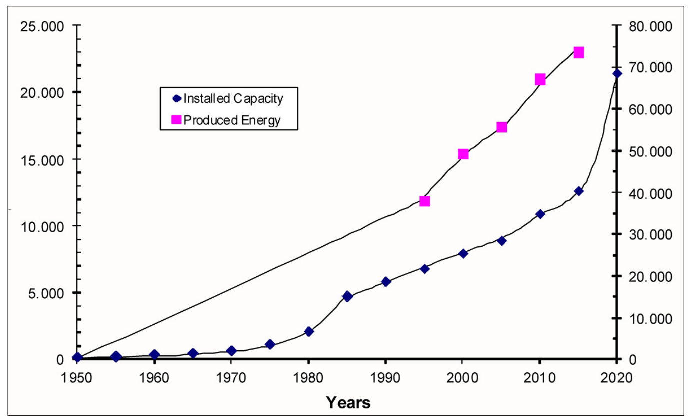

Figure 1. Installed electrical capacity from 1950 up to 2015 (MWe) and produced electricity from 1995 t0 2015 (GWh).

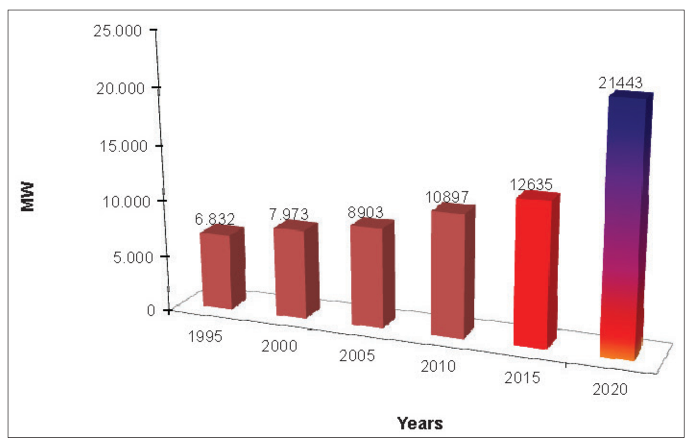

Figure 2. Installed electrical capacity to 2015 and project to 2020 (MWe).

Table 2. Total worldwide installed electrical capacity from 1995 up to end of 2015 and forecasting to 2020 by continent.

Continent	Installed in 1995	Energy in 1995	Installed in 2000	Energy in 2000	Installed in 2005	Energy in 2005	Installed in 2010	Energy in 2010	Installed in 2015	Energy in 2015	Forecast for 2020
	MWe	GWh	MWe	GWh	MWe	GWh	MWe	GWh	MWe	GWh	MWe
Europe	722	3,881	1,019	5,864	1,124	7,209	1,643	11,371	2,133	14,821	3,385
Africa	45	366	52	397	136	1,088	209	1,440	601	2,858	1,601
America	3,800	21,303	3,390	23,342	3,911	25,717	4,565	26,803	5,089	26,353	8,305
Asia	1,980	10,129	3,075	17,390	3,290	18,903	3,661	23,127	3,756	22,084	6,712
Oceania	286	2,353	437	2,269	441	2,792	818	4,506	1,056	7,433	1,440
TOTAL	6,832	38,032	7,973	49,261	8,903	55,709	10,897	67,246	12,635	73,549	21,443

Note: Guadelope (France), Kamchatka (Russia), and Turkey are included under Europe.

Table 3. Installed electrical capacity and produced electrical energy for 2010, 2015, and forecasting for 2020.

Country	Installed in 2010	Energy in 2010	Installed in 2015	Energy in 2015	Forecast for 2020	Increase since 2010			
	MWe	GWh	MWe	GWh	MWe	MWe	GWh	Capacity %	Energy %
Algeria					1				
Argentina					30				
Armenia					25				
Australia	0.1	0.5	1.1	0.5	20	1			
Austria	1.4	3.8	1.2	2.2	6				
Bolivia					40				
Canada					20				
Chile					150				
China	24	150	27	150	100	3		12%	
Costa Rica	166	1,131	207	1,511	260	42	380	25%	34%
Czech Republic					5				
Djibouti					50				
Dominica					10				
Ecuador					40				
El Salvador	204	1,422	204	1,442	300		20		
Ethiopia	7.3	10	7.3	10	50				
France	16	95	16	115	40		20		21%
Germany	6.6	50	27	35	60	20	-15	280%	-30%
Greece					40				
Guatemala	52	289	52	237	140				
Honduras					35				
Hungary					5				
Iceland	575	4,597	665	5,245	1,300	90	648	16%	14%
India					10				
Indonesia	1,197	9,600	1,340	9,600	3,500	143		12%	
Iran					5				
Italy	843	5,520	916	5,660	1,000	74	140	9%	3%
Japan	536	3,064	519	2,687	570	-16	-377	-3%	-12%
Kenya	202	1,430	594	2,848	1,500	392	1,418	194%	99%
Latvia					5				
Mexico	958	7,047	1,017	6,071	1,400	59	-976	6%	-14%
Montserrat					5				
Netherlands					5				
Nevis					35				
New Zealand	762	4,055	1,005	7,000	1,350	243	2,945	32%	73%
Nicaragua	88	310	159	492	200	72	182	82%	59%
Papua-New Guinea	56	450	50	432	70	-6	-18	-11%	-4%
Peru					40				
Philippines	1,904	10,311	1,870	9,646	2,500	-34	-665	-2%	-6%
Poland					1				
Portugal	29	175	29	196	60		21		12%
Romania			0.1	0.4	5	0.1	0.4		
Russia	82	441	82	441	190				
Slovakia					5				
Spain					40				
Switzerland					3				
Taiwan			0.1		1	0.1			
Thailand	0.3	2.0	0.3	1,2	1				
Turkey	91	490	397	3,127	600	306	2,637	336%	539%
UK					15				
USA	3,098	16,603	3,450	16,600	5,600	352		11%	
Total	**10,897**	**67,246**	**12,635**	**73,549**	**21,443**				

Table 4. Top five countries for installed electrical capacity in 2015.

Country	2010 MWe	2010 GWh	2015 MWe	2015 GWh
USA	3,098	16,603	3,450	16,600
Philippines	1,904	10,311	1,870	9,646
Indonesia	1,197	9,600	1,340	9,600
Mexico	958	7,047	1,017	6,071
New Zealand	762	4,055	1,005	7,000

Table 5. Top five countries for the absolute increase in MWe since WGC2010.

Country	MWe	GWh	% MWe	% GWh
Kenya	392	1,418	194%	99%
USA	352		11%	
Turkey	306	2,637	336%	539%
New Zealand	243	2,945	32%	73%
Indonesia	143		12%	

Table 6. Top five countries for the % increase in MWe since WGC2010.

Country	MWe	GWh	% MWe	% GWh
Turkey	306	2,637	336%	539%
Germany	20		280%	
Kenya	392	1,418	194%	99%
Nicaragua	72	182	82%	59%
New Zealand	243	2,945	32%	73%

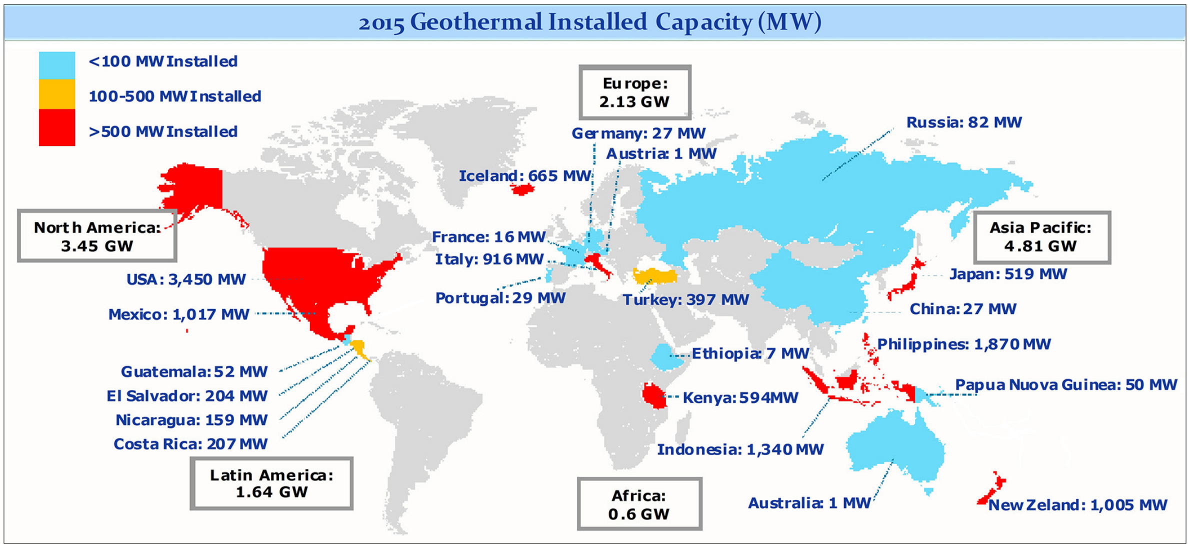

Figure 3. Worldwide installed capacity in 2015 (12.64 GWe). Note: Turkey and Russia are included under Europe.

terms and in percentage, and forecasting to year 2020 for the installed capacity. In Figure 3 a world map of the year 2015 installed capacity is presented.

Statistical Highlights for Electrical Generation — Top Five Rankings

The "Top Five Countries" for capacity and produce energy are shown in Table 4. New Zealand has replaced Italy (now 6th) since 2010.

The "Top Five Countries" for absolute value increase are highlighted in Table 5. Kenya, Turkey and New Zealand, after a period of stagnation, have had a recent surge in growth.

The "Top Five Countries" for percentage increase are shown in Table 6. Turkey's growth is mainly due to large installations, whereas Germany's growth is due to the installation of smaller units.

Plant Classification

We followed the standard plant classification with the classical definitions of binary, back pressure, single/double/triple flash and dry steam plant. In the pie charts of Figures 4, 5 and 6 the installed capacity in MWe, the produced energy in GWh and the total number of units for each category are presented.

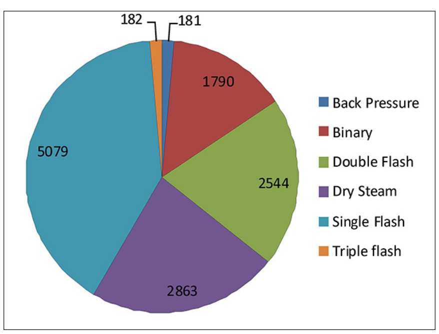

Figure 4. Installed electrical capacity in MWe for each plant type (total 12.64 GWe).

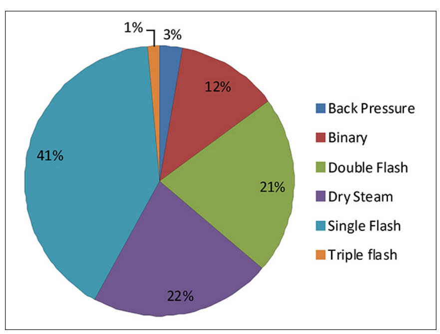

Figure 5. Produced energy in % from each plant type (73,549 GWh/yr).

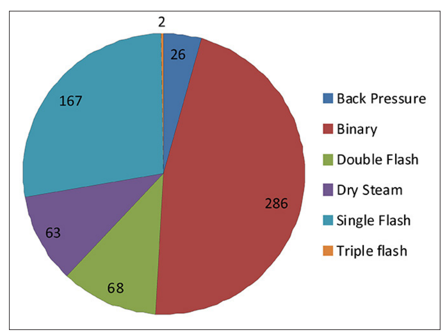

Figure 6. Number of units for each type (total 613).

The distribution per country and per continent of the individual plant characteristic along with the installed capacity are presented in Tables 7 and 8.

Table 7. Plant category per continent (Installed electrical capacity, MWe). Note: all numbers are rounded. Europe includes Guadeloupe (France), Russia and Turkey.

Table 8. Plant category per country (Installed electrical capacity, MWe).

Country	Back Pressure	Binary	Double Flash	Dry Steam	Hybrid	Single Flash	Triple Flash	Total
Australia		1						1
Austria		1						1
China		3	24			1		28
Costa Rica	5	63				140		208
El Salvador		9	35			160		204
Ethiopia		7						7
France		2	5			10		16
Germany		27						27
Guatemala		52						52
Iceland		10	90			564		665
Indonesia		8		460		873		1,340
Italy		1		795		120		916
Japan		7	135	24		355		520
Kenya	48	4				543		594
Mexico	75	3	475			466		1,019
New Zealand	44	265	356			209	132	1,005
Nicaragua	10	8				142		160
Papua New Guinea						50		50
Philippines		219	365			1,286		1,870
Portugal		29						29
Romania		0						0
Russia						82		82
Taiwan		0						0
Thailand			0					0
Turkey		198	178			20		397
USA		873	881	1,584	2	60		3,450
TOTAL	**181**	**1,790**	**2,544**	**2,863**	**2**	**5,079**		**12,640**

Note: all numbers are rounded. France includes Guadelope.

Continent	Back Pressure	Binary	Double
Africa	48	11	
Asia		236	52
Europe		268	27
Latin America	90	135	51
North America		873	88
Oceania	44	266	35
TOTAL	**181**	**1,790**	**25**

The average values per unit of the installed capacity and the produced energy are given in Table 9.

Table 9. Average electrical capacity and energy for each plant category (hybrid excluded).

TYPE	Average Energy (GWh/ unit)	Average Capacity (MWe/unit)
Binary	31	6.3
Back Pressure	76	7.0
Single Flash	179	30.4
Double Flash	231	37.4
Triple Flash	500	90.8
Dry Steam	253	45.4

Direct Utilization

Direct-use of geothermal energy is one of the oldest, most versatile and common forms of utilizing geothermal energy (Dickson and Fanelli, 2003). The early history of geothermal direct-use has been reviewed for over 25 countries in the *Stories from a Heated Earth – Our Geothermal Heritage* (Cataldi, et al., 1999), that documents geothermal use for over 2,000 years. The information presented here on direct applications of geothermal heat is based on country update papers published in the World Geothermal Congress 2015 (WGC2015) proceedings and covers the period 2010-2014. Papers from 70 countries and regions were received, 65 of which reported some geothermal direct-use with 17 additional countries added from other sources such as from WGC2010, WGC2005, European geothermal meetings and personal communications for a total of 82 countries – an increase of four countries from WGC2010 (Greenland, Madagascar, Pakistan, and Saudi Arabia). In the cases where data are missing or incomplete, the authors have relied on country update reports from the World Geothermal Congresses of 1995, 2000, 2005, and 2010 (WGC95, WGC2000, WGC2005, andWGC2010), as well as from three *Geothemics* publications (Lund and Freeston, 2001; Lund et al., 2005; and Lund et al., 2010), European Geothermal Congresses (2007 and 2013), and personal communications. Data from WGC2015 are also compared with data from WGC95, WGC2000, WGC2005, and WGC2010.

Direct Use Data Summary

Table 10 is a summary, by country, of the installed thermal capacity (MWt), annual energy use (TJ/yr and GWh/yr) and the capacity factors at the beginning of 2015. The total installed capacity, reported at the beginning of 2014 for geothermal direct utilization worldwide is 70,329 MWt, a 45.0% increase over WGC2010, growing at an annual compound rate of 7.7%. The total annual energy use is 587,786 TJ (163,287 GWh), indicating a 38.7% increase over WGC2010, and a compound annual growth rate of 6.8%. The worldwide capacity factor is 0.265 (equivalent to 2,321 full load operating hours per year), down from 0.28 in 2010, 0.31 in 2005 and 0.40 in 2000. The lower capacity factor and growth rate for annual energy use is due to the increase in geothermal heat pump installations which have a low capacity factor of 0.21 worldwide. The growth rates of installed capacity and annual energy use over the past 20 years are shown in Figure 7.

The growing awareness and popularity of ground-source (geothermal) heat pumps has had the most significant impact on the direct-use of geothermal energy. The annual energy use of these units grew 1.62 times at a compound rate of 10.3% compared to WGC2010. The installed capacity grew 1.51 times at a compound annual rate of 8.65%. This is due, in part, to better reporting and the ability of geothermal heat pumps to utilize groundwater or ground-coupled temperature anywhere in the world (see Figure 8). The five leading countries in terms of installed capacity (MWt) are: USA, China, Sweden, Germany and France, and in terms of annual energy use (TJ/yr) are: China, USA, Sweden, Finland, and Canada.

Table 10. Summary of direct-use data worldwide, 2015.

Country	MWt	TJ/yr	GWh/yr	Load Factor
Albania	16.23	107.59	29.89	0.21
Algeria	54.64	1699.65	472.25	0.99
Argentina	163.60	1,000.03	277.81	0.19
Armenia	1.50	22.50	6.25	0.48
Australia	16.09	194.36	53.99	0.38
Austria	903.40	6,538.00	1,816.26	0.23
Belarus	4.73	113.53	31.54	0.76
Belgium	206.08	864.40	24.01	0.13
Bosnia & Herzegovina	23.92	252.33	70.10	0.33
Brazil	360.10	6,622.40	1,839.70	0.58
Bulgaria	93.11	1,224.42	340.14	0.42
Canada	1,466.78	11,615.00	3,226.65	0.25
Caribbean Islands	0.10	2.78	0.77	0.85
Chile	19.91	186.12	51.70	0.30
China	17,870.00	174,352.00	48,434.99	0.31
Columbia	18.00	289.88	80.50	0.51
Costa Rica	1.00	21.00	5.83	0.67
Croatia	79.94	684.49	190.15	0.27
Czech Republic	304.50	1,790.00	497.26	0.19
Denmark	353.00	3,755.00	1,043.14	0.34
Ecuador	5.16	102.40	28.45	0.63
Egypt	6.80	88.00	24.45	0.41
El Savador	3.36	56.00	15.56	0.53
Estonia	63.00	356.00	98.90	0.18
Ethiopia	2.20	41.60	11.56	0.60
Finland	1,560.00	18,000.00	5,000.40	0.37
France	2,346.90	15,867.00	4,407.85	0.21
Georgia	73.42	695.16	193.12	0.30
Germany	2,848.60	19,531.30	5,425.80	0.22
Greece	221.88	1,326.45	368.49	0.19
Greenland	1.00	21.00	5.83	0.67
Guatemala	2.31	56.46	15.68	0.78
Honduras	1.93	45.00	12.50	0.74
Hungary	905.58	10,268.06	2,852.47	0.36
Iceland	2,040.00	26,717.00	7,422	0.42
India	986.00	4,302.00	1,195.10	0.14
Indonesia	2.30	42.60	11.83	0.59
Iran	81.50	1,103.12	306.45	0.43
Ireland	265.54	1,240.54	344.62	0.15
Israel	82.40	2,193.00	609.22	0.84
Italy	1,014.00	8,682.00	2411.90	0.27
Japan	2,186.17	26,130.08	7,258.94	0.38
Jordan	153.30	1,540.00	427.81	0.32
Kenya	22.40	182.62	50.73	0.26
Korea (South)	835.80	2,682.65	745.24	0.10
Latvia	1.63	31.81	8.84	0.62
Lithuania	94.60	712.90	198.04	0.24
Macedonia	48.68	601.11	166.99	0.39
Madagascar	2.81	75.59	21.00	0.85
Mexico	155.82	4,171.00	1,158.70	0.85
Mongolia	20.16	340.46	94.58	0.54
Morocco	5.00	50.00	13.89	0.32
Nepal	3.32	81.11	22.53	0.78
Netherlands	790.00	6,426.00	1,785.14	0.26
New Zealand	487.45	8,621.00	2,394.91	0.56
Norway	1,300.00	8,260.00	2,294.63	0.20
Pakistan	0.54	2.46	0.68	0.14
Papua New Guinea	0.10	1.00	0.28	0.32
Peru	3.00	61.00	16.95	0.64
Philippines	3.30	39.58	11.00	0.38
Poland	488.84	2,742.60	761.89	0.18
Portugal	35.20	478.20	132.84	0.43
Romania	245.13	1,905.32	529.30	0.25
Russia	308.20	6,143.50	1,706.66	0.63
Saudi Arabia	44.00	152.89	42.47	0.11
Serbia	115.64	1,802.48	500.73	0.49
Slovak Republic	149.40	2,469.60	686.05	0.52
Slovenia	152.75	1,137.23	315.93	0.24
South Africa	2.30	37.00	10.28	0.51
Spain	64.13	344.85	95.80	0.17
Sweden	5,600.00	51,920.00	14,423.38	0.29
Switzerland	1,733.08	11,836.80	3,288.26	0.22
Tajikistan	2.93	55.40	15.39	0.60
Thailand	128.51	1,181.20	328.14	0.29
Tunisia	43.80	364.00	101.12	0.26
Turkey	2,886.30	45,126.00	12,536.00	0.50
Ukraine	10.90	118.80	33.00	0.35
United Kingdom	283.76	1,906.50	529.63	0.21
United States	17,415.91	75,862.20	21,074.52	0.14
Venezuela	0.70	14.00	3.89	0.63
Vietnam	31.20	92.33	25.65	0.09
Yemen	1.00	15.00	4.17	0.48
GRAND TOTAL	**70,328.98**	**587,786.43**	**163,287.07**	**0.27**

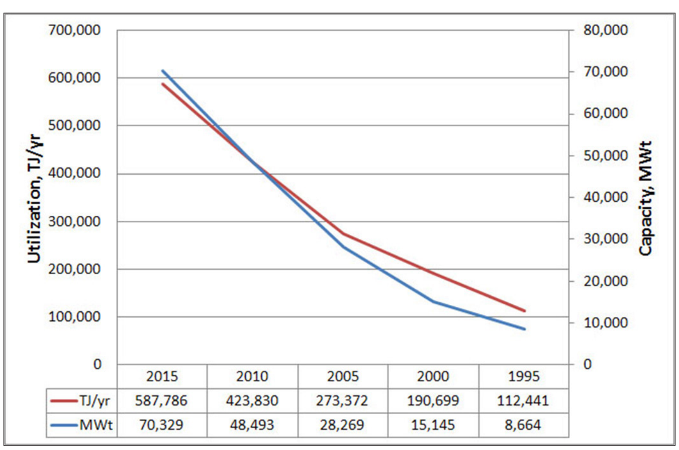

Figure 7. The installed direct-use geothermal capacity and annual utilization from 1995 to 2015.

In 1985, only 11 countries report an installed capacity of more than 100 MWt, By 1990, this number had increased to 14, by 1995 to 15, by 2000 to 23, by 2005 33 countries, and by 2010 to 36 countries. As of the end of 2014, there were also 36 countries reporting over 100 MWt.

The five countries with the largest direct-use (with heat pumps) installed capacity (MWt) are: China, USA, Sweden, Turkey and Germany accounting for 65.8% of the world capacity, and the five countries with the largest annual energy use (with heat pumps) are: China, USA, Sweden, Turkey and Japan accounting for 63.6% of the world use. However, an examination of the data in terms of land area or population shows that the smaller countries dominate, especially the Nordic ones. The "top five" then become for installed capacity (MWt/population): Iceland, Sweden, Finland, Norway, and Switzerland; and for annual energy use (TJ/yr/population): Iceland, Sweden, Finland, New Zealand, and Norway. The "top five" in terms of land area for installed capacity (MWt/area) are: Switzerland, Iceland, Netherlands, Sweden and Austria; and in terms of annual energy use (TJ/yr/area) are: Switzerland, Iceland, Netherlands, Sweden and Hungary. The largest percent increase in geothermal installed capacity (MWt) over the past five years was in: Thailand, Egypt, India, Korea (South) and Mongolia; and in terms of annual energy use (TJ/yr) over the past five years was in: Thailand, Egypt, Philippines, Albania, and Belarus. Most of these increases were due to geothermal heat pump installations and/or better reporting on bathing and swimming use.

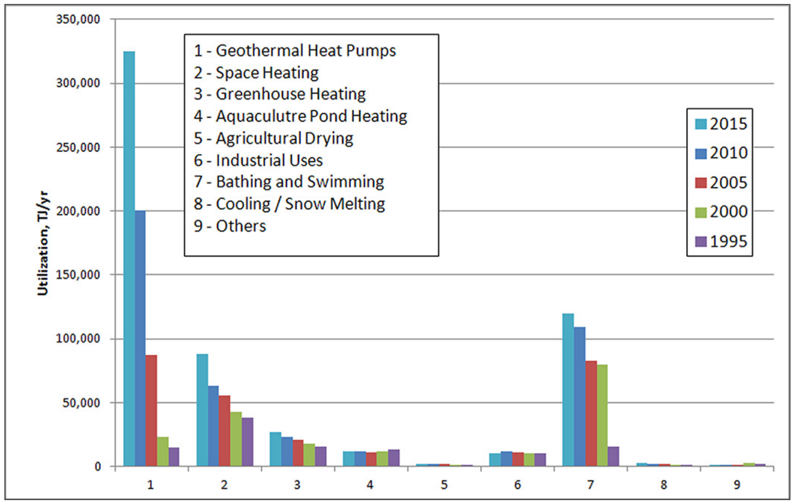

Figure 8. Comparison of worldwide direct-use geothermal energy in TJ/yr from 1995, 2000, 2005, 2010 and 2015.

Categories of Utilization

Table 11 divides the data from 1995, 2000, 2005, 2010 and 2015 among the various uses in terms of capacity, energy utilization and capacity factor. This distribution can also be viewed as bar charts in Figure 8. Figures 9 to 12 presents the 2015 data in pie-chart format as a percentage. An attempt was made to distinguish individual space heating from district heat, but this was often difficult, as the individual country reports did not always make this distinction. Our best estimate is that district heating represents 88% of the installed capacity and 89% of the annual energy use. Snow melting represents the majority of the snow melting/air-conditioning category. "Other" is a category that covers a variety of uses, details of which are not frequently provided, but is known to

Table 11. Summary of the various categories of geothermal direct-use worldwide for the period 1995-2015.

Capacity, MWt					
	2015	**2010**	**2005**	**2000**	**1995**
Geothermal Heat Pumps	49,898	33,134	15,384	5,275	1,854
Space Heating	7,556	5,394	4,366	3,263	2,579
Greenhouse Heating	1,830	1,544	1,404	1,246	1,085
Aquaculture Pond Heating	695	653	616	605	1,097
Agricultural Drying	161	125	157	74	67
Industrial Uses	610	533	484	474	544
Bathing and Swimming	9,140	6,700	5,401	3,957	1,085
Cooling / Snow Melting	360	368	371	114	115
Others	79	42	86	137	238
Total	**70,329**	**48,493**	**28,269**	**15,145**	**8,664**

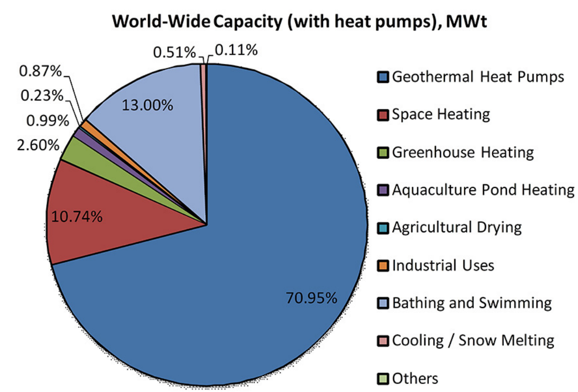

Figure 9. Geothermal direct applications worldwide in 2015, distributed by percentage of total installed capacity (MWt).

Table 11. Cont'd.

Utilization, TJ/yr					
	2015	**2010**	**2005**	**2000**	**1995**
Geothermal Heat Pumps	325,028	200,149	87,503	23,275	14,617
Space Heating	88,222	63,025	55,256	42,926	38,230
Greenhouse Heating	26,662	23,264	20,661	17,864	15,742
Aquaculture Pond Heating	11,958	11,521	10,976	11,733	13,493
Agricultural Drying	2,030	1,635	2,013	1,038	1,124
Industrial Uses	10,453	11,745	10,868	10,220	10,120
Bathing and Swimming	119,381	109,410	83,018	79,546	15,742
Cooling / Snow Melting	2,600	2,126	2,032	1,063	1,124
Others	1,452	955	1,045	3,034	2,249
Total	**587,786**	**423,830**	**273,372**	**190,699**	**112,441**

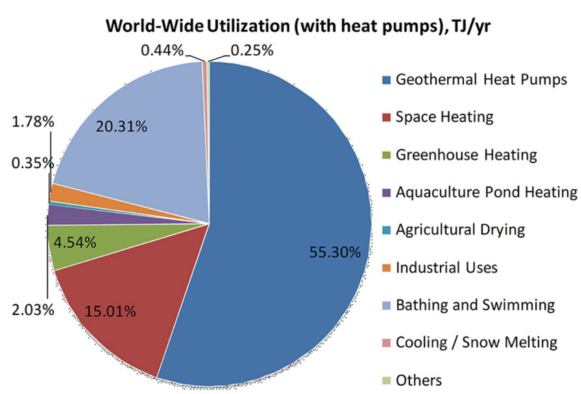

Figure 10. Geotherml direct applications worldwide in 2015, distributed by percentage of total annual energy used (TJ/yr).

Table 11. Cont'd.

Capacity Factor					
	2015	**2010**	**2005**	**2000**	**1995**
Geothermal Heat Pumps	0.207	0.19	0.18	0.14	0.25
Space Heating	0.370	0.37	0.40	0.42	0.47
Greenhouse Heating	0.462	0.48	0.47	0.45	0.46
Aquaculture Pond Heating	0.546	0.56	0.57	0.61	0.39
Agricultural Drying	0.400	0.41	0.41	0.44	0.53
Industrial Uses	0.543	0.70	0.71	0.68	0.59
Bathing and Swimming	0.414	0.52	0.49	0.64	0.46
Cooling / Snow Melting	0.229	0.18	0.17	0.30	0.31
Others	0.583	0.72	0.39	0.70	0.30
Total	**0.265**	**0.28**	**0.31**	**0.40**	**0.41**

include animal husbandry and carbonation of soft drinks. Figures 11 and 12 provide a similar pie-chart comparison, however, without the domination of geothermal heat pumps.

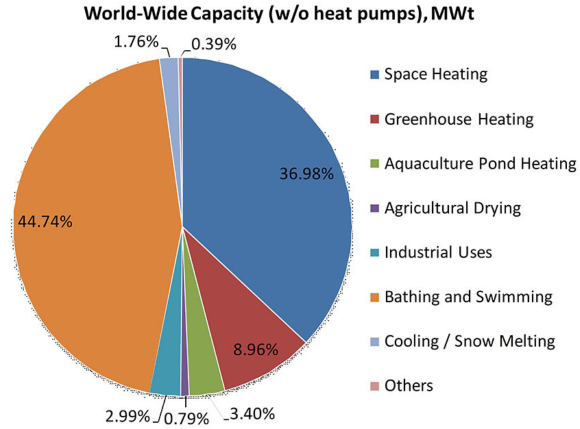

Figure 11. Geothermal direct applications worldwide in 2015 without geothermal heat pumps, distributed by percentage of total installed capacity (MWt).

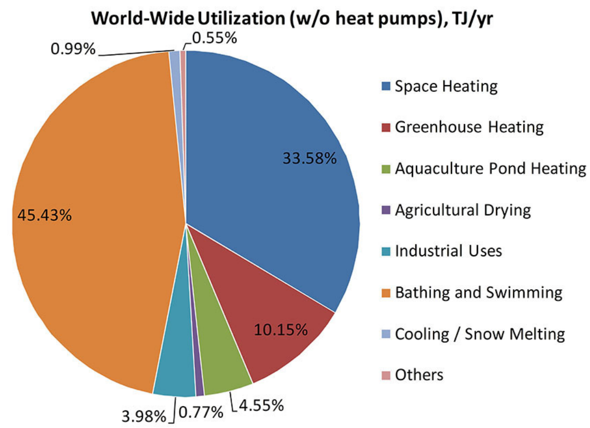

Figure 12. Geothermal direct applications worldwide in 2015 without geothermal heat pumps, distributed by percentage of total annual energy used (TJ/yr).

Geothermal Heat Pumps

Geothermal (ground-source) heat pumps have the largest energy use and installed capacity worldwide, accounting for 70.95% of the installed capacity and 55.30% of the annual energy use. The installed capacity is 49,898 MWt and the annual energy use is 325,028 TJ/yr, with a capacity factor of 0.21 (in the heating mode). Although, most of the installations occur in North American, Europe and China, the number of countries with installations increased from 26 in 2000, to 33 in 2005, to 43 in 2010, and to 48 in 2015. The equivalent number of installed 12 kW units (typical of USA and Western Europe homes) is approximately 4.16 million. This is a 51% increase over the number of installed units reported in 2010, and over three times the number of units reported in 2005. The size of individual units: however ranges from 5.5 kW for residential use to large units over 150 kW for commercial and institutional installations.

In the United State, most units are sized for peak cooling load and are oversized for heating, except in the northern states; thus they are estimated to average only 2000 equivalent full-load heating hours per year (capacity factor of 0.23). In Europe, most units are sized for the heating load and are often designed to provide the base load with peaking by fossil fuel. As a result, these units may be in operation up to 6000 equivalent full-load heating hours per year (capacity factor of 0.68), such as in the Nordic countries (especially in Finland). Unless the actual number of equivalent full-load hours was reported, a value of 2200 heating hours/year (and higher for some of the northern countries) was used for energy output (TJ/yr) calculations, based on a report by Curtis et al. (2005).

The energy use reported for the heat pumps was deduced from the installed capacity (if it was not reported), based on an average coefficient of performance (COP) of 3.5, which allows for one unit of energy input (usually electricity) to 2.5 units of energy output, for a geothermal component of 71% of the rated capacity [i.e. (COP-1)/COP = 0.71]. The cooling load was not considered as geothermal as in this case, heat is discharged into the ground or groundwater. Cooling, however, has a role in the substitution of fossil fuels and reduction in greenhouse gas emission and is included in later discussions.

The leaders in installed units are: United States, China, Sweden, Germany and France.

Space Heating

Space heating has increased 44% in installed capacity and in annual energy use over WGC2010. The installed capacity now totals 7,556 MWt and the annual energy use is 88,222 TJ/yr. In comparison, 88% of the total installed capacity and 89% of the annual energy use is in district heating (28 countries). The leaders in district heating in terms of annual energy use are: China, Iceland, Turkey, France, and Germany, whereas Turkey, USA, Italy, Slovakia and Russia are the major users in the individual space heating sector (a total of 28 countries).

Greenhouse and Covered Ground Heating

Worldwide use of geothermal energy used for greenhouses and covered ground heating increased by 19% in installed capacity and 16% in annual energy use. The installed capacity is 1,830 MWt and 26,662 TJ/yr in energy use. A total of 31 countries report geothermal greenhouse heating (compared to 34 from WGC2010), the leading countries in annual energy use being: Turkey, Russia, Hungary, China and Netherlands. Most countries do not distinguish between covered greenhouses versus uncovered ground heating, and only a few reported the actual area heated. The main crops grown in greenhouses are vegetables and flowers; however tree seedlings (USA) and fruit such as bananas (Iceland) are also grown. Developed countries are experiencing competition from developing countries due to labor cost being lower – one of the main costs of operating these facilities. Using an average energy requirement, determined from WGC2000 of 20 TJ/yr/ha for greenhouse heating, the 26,662 TJ/yr corresponds to about 1,333 ha of greenhouses heated worldwide – a 15.6% increase over 2010.

Aquaculture Pond and Raceway Heating

Aquaculture use of geothermal energy has increased over WGC2010, amounting to a 6.7% increase in installed capacity and a 2.7% increase in annual energy use. The installed capacity is 695 MWt and the annual energy use is 11,958 TJ/yr. Twenty-one countries report this type of use, the main ones in terms of annual energy use being USA, China, Iceland, Italy and Israel – the same as in 2010. These facilities are labor intensive and require well-trained personnel, which are often hard to justify economically, thus, the reason why the growth is slow. Tilapia, salmon and trout seem to be the most common species, but tropical fish, lobsters, shrimp and prawns, as well as alligators are also being farmed. Based on work in the United States, we calculate that 0.242 TJ/yr/tonne of fish (bass and tilapia) are required, using geothermal waters in uncovered ponds. Thus, the reported energy use of 11,958 TJ/yr represents an estimated equivalent of 49,413 tonnes of annual production, representing a 2.7% increase over 2010.

Agricultural Crop Drying

Fifteen countries report the use of geothermal energy for drying various grains, vegetables and fruit crops compared to 13 in 2010 and 15 in 2005. Examples include: seaweed (Iceland), onions (USA), wheat and other cereals (Serbia), fruit (El Salvador, Guatemala and Mexico), lucerne or alfalfa (New Zealand), coconut meat (Philippines), and timber (Mexico, New Zealand and Romania). The largest uses are in China, USA and Hungary. A total of 161 MWt and 2,030 TJ/yr are being utilized, an increase of 28.8 % and 24.2% respectively compared to WGC2010.

Industrial Process Heat

This is a category that has applications in 15 countries, the same as in 2010. These operations tends to be large and have high energy consumption, often operating year-around. Examples include: concrete during (Guatemala and Slovenia), bottling of water and carbonated drinks (Bulgaria, Serbia and the United States), milk pasteurization (Romania and New Zealand), leather industry (Serbia and Slovenia), chemical extraction (Bulgaria, Poland and Russia), CO_2 extraction (Iceland and Turkey), pulp and paper processing (New Zealand), iodine and salt extraction (Vietnam), and borate and boric acid production (Italy). The installed capacity is 610 MWt and the annual energy use is 10,453 TJ/yr, an 18% increase and a 12% decrease compared to WGC2010 respectively. As expected, because of almost year-around operation, heat use for the industrial processes has one of the highest capacity factors of all direct uses of 0.54, down from 0.70 in 2010. No reasons are given for the decrease in annual energy use and capacity factor; however, it may be due to more efficient operations and use of energy, or to fewer operating hours per year.

Snow Melting and Space Cooling

There are very limited applications in this area; the majority are pavement snow melting projects. Snow melting applications for streets and sidewalks operate in Iceland, Argentina, Japan, and the United States, and to a limited extent in Poland and Slovenia. An estimated 2.5 million square meters of pavement are heated worldwide, the majority of which is in Iceland (74%). A project in Argentina uses geothermal steam for highway snow melting in the Andes to keep a resort community open during the winter. In the United States, most of the pavement snow melting is on the Oregon Institute of Technology campus and in the City of Klamath Falls, Oregon, where it is part of the district heating system using the lower temperature return water in a heat exchanger with a glycol-water mixture. The power required varies from 130 to 180 W/m^2 (United States and Iceland). The installed capacity is 360 MWt and the annual energy use is 2,600 TJ/yr. Heat pumps in the cooling mode are not included as they only return heat to the subsurface, and thus do not use geothermal energy.

Bathing and Swimming

Data for this use are the most difficult to collect and quantify. Almost every country has spas and resorts that have swimming pools heated with geothermal water (including balneology – the treatment of diseases with water), but many allow the water to flow continuously, regardless of use (such as at night when the pool is closed). As a result, the actual usage and capacity figures may be high. In some cases where use was reported and no flows or temperature drops were known; in these cases 0.35 MWt and 7.0 TJ/yr were applied to estimate the capacity and energy use for typical installations. In other cases, 5 L/s and 10 °C temperature change were used (0.21 MWt) for the installed capacity and 3 L/s and 10 °C temperature change (4.0 TJ/yr) were used for the annual use, based on communications with the various country update authors. Undeveloped natural hot springs are not included.

In addition to the 70 countries (up from 67 in 2010 and 60 in 2005) that reported bathing and swimming pool use, we are also aware of development in Malaysia, Mozambique, Singapore and Zambia, although no information was made available. The installed capacity is 9,140 MWt and the annual energy use is 119,381 TJ/yr, up 36.4% and 9.1% respectively over 2010. We have also included the Japanese-style inns (onsens) that utilize hot spring water for bathing, as we included these figures in previous WGC reports. The largest reported annual energy uses are from China, Japan, Turkey, Brazil and Mexico.

Other Uses

This category includes 79 MWt and 1,452 TJ/yr, 88 and 52% higher compared to 2010, respectively. These values were reported in 13 countries, and include animal farming, spirulina cultivations, desalination and sterilization of bottles. The largest use is in New Zealand, where geothermal energy is used in irrigation, frost protection and a geothermal tourist park.

Direct Utilization Capacity Factors

Average capacity factors were determined for each country (Table 10) and for each category of use (Table 11). They vary from 0.09 to 0.99 for the countries and from 0.21 to 0.58 for the categories of use. The lower values usually refer to countries in which geothermal heat pump usage predominates, as indicated by the 0.21 in Table 11, whereas the higher numbers are for countries with high industrial use (New Zealand) or continuous operation of pools for swimming (Algeria, Caribbean Islands, Madagascar and Mexico).

The worldwide capacity factor dropped from 0.40 in 2000, to 0.31 in 2005, to 0.28 in 2010, to the current 0.265. Again, this is a result of the increase in geothermal heat pump usage. Capacity factors for the various categories of use remain approximately constant when compared to 2010, except for industrial uses which dropped from 0.70 to 0.54.

The capacity factor is calculated as follows: [(annual energy use in TJ/yr)/(installed capacity in MWt)] x 0.03171. This number reflects the equivalent percentage of equivalent full load operating hours per year (i.e., CF = 0.70 is 70% equivalent to 6,132 full load hours per year.

Summary

Worldwide Energy Savings From Electric Power and Direct Utilization

Geothermal, a domestic source of sustainable and renewable energy, can replace other forms of energy use, especially fossil fuels. For many countries, geothermal energy leads to a reduction in their dependence on imported fuel, and for all countries, it means the elimination of pollutants such as particulates and greenhouse gases. An attempt is made here to quantify the fossil fuel savings, using an efficiency factor of 0.35 if the competing energy is used to generate electricity and 0.70 if it is used directly to product heat, such as in a furnace.

Using the 264,776 TJ/yr for electricity generation and the 587,786 TJ/yr of energy consumed in direct geothermal applications by 2015 (total of 856,450 TJ/yr or 237,916 GWh/yr) (see Table 10), and estimating that a barrel of fuel oil contains 6.06 x 10^9 Joules, and that the fuel is used to produce electricity, the savings would be 404 million barrels of oil or 61 million tonnes of oil annually. If the oil were used directly to produce energy by burning it for heating, then these savings for direct-use only, would be 140 million barrels or 21 million tonnes. In saving in the cooling mode of geothermal heat pumps are considered, which is not geothermal, then this is equivalent to an additional annual savings of approximately 70 million barrels (10.5 million tonnes), of fuel oil, and 9.0 million tonnes of carbon pollution from burning fuel oil to produce electricity. This assumes that the annual energy used in cooling is approximately half that used in the heating mode. The above combined figures of 474 million barrels and 71.5 million tonnes of fuel oil equivalent (TOE) are summarized in Table 12.

Table 12. Woldwide savings in energy, carbon and greenhouse gases using geothermal energy including geothermal heat pump in the cooling mode (figures in millions) in terms of fuel oil (TOE = tonnes of oil equivalent).

	Fuel oil		**Carbon**	**CO_2**	**SO_x**	**NO_x**
	bbl	TOE	TOE	TOE	TOE	TOE
As electricity (all forms)	474	71.5	74.4	194.4	1.38	0.042
As direct heat (DU only)	175	26.2	22.9	74.1	0.51	0.015

Using figures developed by Lawrence Livermore Laboratory for the U.S. Department of Energy (Kasameyer, 1997) and by private consultant Goddard and Goddard (1990), the following savings would be realized for carbon, CO_2, SO_x, and NO_x. Compared to using electricity, the carbon savings would be 20.32 tonnes/TJ from natural gas, 86.81 tonnes/TJ for oil or 100.82 tonnes/TJ from coal for a total carbon production savings of 17.40, 74.35 or 86.35 million tonnes, respectively. Similarly, using 193 kg/MWh (53.6 tonnes/TJ), 817 kg/MWh (227.0 tonnes/TJ), and 953 kg/MWh (264.7 tonnes/TJ) for carbon dioxide emissions when producing electricity from natural gas, oil and coal, respectively, the saving in CO_2 emissions would be 45.90, 194.41, 226.70 million tonnes, respectively. The savings in SO_x and NO_x producing electricity from natural gas, oil and coal would be 0.0, 1.38 and 1.51 million tonnes of SO_x, and 13.98, 42.00, and 45.52 thousand tonnes of NO_x.

Wells Drilled for Geothermal 2010–2014

Approximately 2,218 well were drilled by 42 countries during the period 2010-2014 for both direct-use and electric power. Shallow heat pump wells are not included in these figures. This is a 6.2% increase over the period 2005-2009 (37 countries). The average was 53 wells per country, and the countries drilling more than 100 wells being: China, Turkey, USA, Kenya, India and New Zealand (in descending order). In terms of the types of wells, 48.8% were drilled for power generation, 38.7% drilled for direct utilization, 8.6% drilled as combined heat and power wells, and 3.9% drilled as research or gradient wells. The total depth drilled by the 42 countries was 9,534.5 km for an average of 4.30 km per well (over four times the depth drilled per well in 2005-2009). However, these are mostly wells drilled for power generation. The countries drilling more than 100 km during this period were: Hungary, China, Kenya, Turkey, United States, Mexico, Philippines and New Zealand (in descending order). The following are the regional allocations:

- 14.7% in Africa by 4 countries (327 wells)
- 19.2% in the Americas by 9 countries (426 wells)
- 48.4% in Asia by 8 countries (1074 wells)
- 12.6% in Europe by 19 countries (279 wells)
- 5.1% in Oceania by 2 countries (112 wells)

Person-Years of Professional Personnel Working in Geothermal 2010-2014

Approximately 34,000 person-years in 52 countries of professional effort was allocated to geothermal development (restricted to personnel with university degrees) during the period 2010-2014 for both direct-use and electric power (no distinction was made between the two). The average was 654 person-years per country over the five-year period (131 person-year/year/country). This is a 25% decrease from 2005-2009 (43 countries). The countries with more than 100 person-years/year are USA, China, New Zealand, Turkey, Iceland, Mexico, Belgium, Poland, Norway and South Korea (in descending order). The allocation of effort by category was: 10.8% by government, 21.9% by public utilities, 10.6% by universities, 1.7% by foreign consultants, 0.2% by contribution through foreign aid programs, and 54.8% by private industry. The following are the regional allocations:

- 0.8% in Africa by 5 countries (55.0 person-years/year)
- 36.4% in the Americans by 10 countries (2,475.0 person-years/year)
- 31.1% in Asia by 9 countries (2,115.5 person-years/year)
- 21.5% in Europe by 25 countries (1,466.5 person-years/year)
- 10.2% in Oceania by 3 countries (693.0 person-years/year)

Total Investment in Geothermal 2010-2014

Approximately US$ 20 billion was invested in geothermal energy by 49 countries during the period 2010-2014, for both direct-use and electric power, doubled the amount from 2005-2009 for 46 countries. The average was US$ 407 million per country, with countries investing over US$ 500 million (or US$ 100 million per year) being: Turkey, Kenya, China, Thailand, USA, Switzerland, New Zealand, Australia, Italy and South Korean (in descending order). In terms of categories of investment: 28.3% was for electric power utilization in 16 countries, 21.8% was for direct-use in 32 countries, 25.6% was for field development including production drilling and surface equipment in 32 countries, and 24.4% was for R&D including surface exploration and exploratory drilling in 48 countries. The following are the regional investments:

- 10.8% in Africa by 2 countries ($2,160 billion)
- 13.4% in the Americas by 9 countries ($2,669 billion)
- 44.0% in Asia by 9 countries ($8,765 billion)
- 19.9% in Europe by 27 countries ($3,953 billion)
- 11.9% in Oceania by 2 countries ($2,375 billion)

Conclusions

Electric Generation

The present value of 12.64 GWe is an important result, confirming the trend started in 2010, above the 10 GWe threshold toward a second exponential growing phase, mainly from the increase of medium-low temperature development projects through binary plants, and an important effort in developing economically viable projects worldwide. The short term forecasting for 2020 is a hope: the expected 21 GWe is based on an exponential forecast. Thus, it would be important to transform 8 GWe of paper-projects in real plants in the next five years. This challenge will be able to give to the entire geothermal community a clear signal of the possibility and the willingness of being one of the most important renewable energy players in the future electricity market.

We have evaluated (Bertani, 2003) the expected geothermal targets for year 2050:

- from hydrothermal resources of 70 GWe :
- 140 GWe in total (with EGS and other non-conventional resources)

If the target of 140 GWe is reached, it would be possible to produce from geothermal up 8.3% of total world electricity production, serving 17% of world population. Moreover, 40 countries (located mostly in Africa, Central/South America, Pacific) can be 100% geothermal powered). The overall CO_2 saving from geothermal electricity can be in around 1,000 million tons per year.

The estimated value of 21 GWe for 2020 is in line with the long term forecasting for standard hydrothermal fields.

Direct Utilization

As in 1995, 2000, 2005 and 2010 several countries stand out as major consumers of geothermal fluids for direct uses (China, USA, Japan, Iceland and Germany); however, in most countries development has been slow. This is not surprising as fossil fuels are a major competitor as well as the initial high investment costs of geothermal projects. Many countries have; however, been doing the necessary groundwork, conducting inventories and quantifying their resources in preparation for development when the economic situation is better and governments and private investors see the benefits of developing a domestic renewal energy source. This is true for many of the east African countries such as: Djibouti, Eritrea, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia, and Zimbabwe that have potential geothermal resources associated with the African Rift Valley. Countries where geothermal direct-use provides a significant contribution to their energy needs are summarized in Table 13. The distribution of geothermal use by continents of the world is shown in Table 14 indicating that Asia and Europe are the leaders by having 18 and 37 countries utilizing geothermal energy for direct-use applications.

Table 14. Distribution of Direct Geothermal Energy Utilization by Continent. *includes former CIS countries (Armenia, Belarus, Georgia, Russia and Ukraine), and Turkey.

Continent	# Countries	% MWt	% TJ/yr
Africa	8	0.2	0.3
Americas	16	27.7	16.9
Asia	18	35.8	43.8
Europe*	37	35.6	37.5
Oceania	3	0.7	1.5

Table 13. Significant Contributions of Direct-Use Geothermal Energy to a Country's Economy.

Iceland	90% of building heated
Japan	2000 onsens, 5000 public baths, 1500 hotels serving 15 million guests/year
Sweden	20% of building heated using geothermal heat pumps
Switzerland	90,000 geothermal heat pumps installed (~3 units/km^2)
Tunisia	244 ha of greenhouses heated
Turkey	90,000 apartment residences heated in 16 cities – approaching 30% of total units
USA	1.4 million geothermal heat pumps (7.0% annual growth)

With the increased interest in ground-source (geothermal) heat pumps, geothermal energy can now be developed anywhere, for both heating and cooling. They are now 70.9% of the installed capacity (MWt) and 55.3% of the annual energy use (TJ/yr) as illustrated in Figures 9 and 10. Low-to-moderate temperature geothermal resources are also being used in combined heat and power plant (CHP), where hot waters often with temperatures below 100 °C are first run through a binary (organic Rankine cycle) power plant then cascaded for space heating, swimming pools, greenhouses and/or aquaculture pond heating, before being injected back into the aquifer such as at Chena Hot Springs Resort in Alaska. CHP projects certainly maximize the use of the resource as well as improving the economics of the project, as has been shown in Iceland, Austria, and Germany, as well as on the Oregon Institute of Technology campus in Klamath Falls, Oregon, USA.

Key data and explanations were frequency missing from the WGC2015 country update reports used in this worldwide summary. Some data also appeared to be in error or misreported. We have attempted to correct for these errors by contacting the authors and/or by making estimates for the missing data, which has been pointed out in the relevant country summaries in Lund, et al., (2015).

Despite these discrepancies and the effort required to correct them, work on this review has proved useful, as it has allowed us to demonstrate that using low-to-moderate temperature geothermal resources in the direct heat applications, given the right conditions, is an economically feasible business, and can make a significant contribution to a country's or region's energy mix. As oil and gas supplies dwindle and increase in price, geothermal energy will become an even more economically viable alternative source of energy.

At the time of writing this report (April 2015), the cost of crude oil is around US$50/barrel and has been in the recent past over US$100/barrel. Thus, when geothermal energy becoming increasingly more competitive with fossil fuels and the environment benefits associated with renewable energy resources are better understood and accepted, development of this natural "heat from the earth" should accelerate in the future. This growth is well illustrated in Table 11 and Figures 7 and 8. An important task for all of us in the geothermal community is to spread the word on geothermal energy, its various applications, and the many environmental benefits that can accrue from its use.

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