Proceedings World Geothermal Congress 2015
Melbourne, Australia, 19-25 April 2015

Direct Utilization of Geothermal Energy 2015 Worldwide Review

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Keywords: Geothermal, 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 paper presents a review of the worldwide applications of geothermal energy for direct utilization, and updates the previous survey carried out in 2010. We also compare data from 1995, 2000 and 2005 presented at World Geothermal Congresses in Italy, Japan and Turkey, respectively (WGC95, WGC2000, and WGC2005). As in previous reports, an effort is made to quantify ground-source (geothermal) heat pump data. The present report is based on country update papers received from 70 countries and regions of which 65 reported some direct utilization of geothermal energy. Seventeen additional countries were added to the list based on other sources of information. Thus, direct utilization of geothermal energy in a 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. An estimation of the installed thermal power for direct utilization at the end of 2014 is used in this paper and 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), about 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. Energy savings amounted to 350 million barrels (52.5 million tonnes) of equivalent oil annually, preventing 46 million tonnes of carbon and 148 million tonnes of CO_2 being released to the atmosphere, this includes savings for geothermal heat pumps in the cooling mode (compared to using fuel oil to generate electricity). 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.

1. INTRODUCTION

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.

2. DATA SUMMARY

Table 1 is a summary, by country, of the installed thermal capacity (MWt), annual energy use (TJ/yr and GWh/yr) and the capacity factors to the end of 2014. The total installed capacity, reported through the end 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 Fig. 1.

Table 1. 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

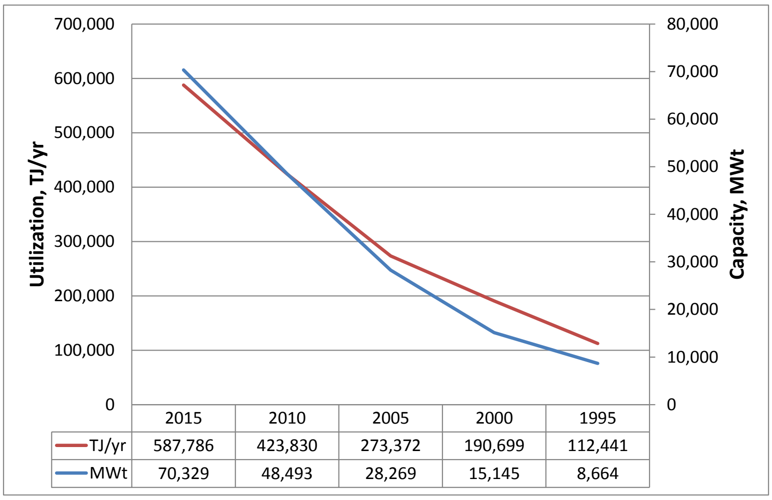

Fig. 1. The installed direct-use geothermal capacity and annual utilization from 1995 to 2015.

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 Fig. 2). 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.

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 or better reporting on bathing and swimming use.

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.

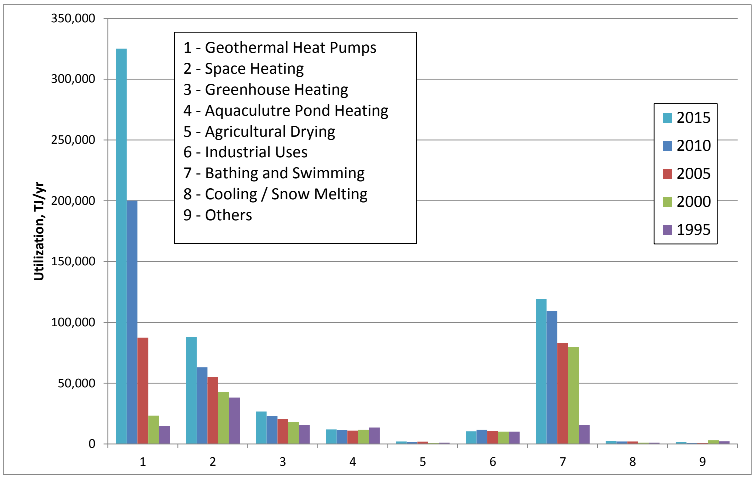

Fig. 2. Comparison of worldwide direct-use geothermal energy in TJ/yr from 1995, 2000, 2005, 2010 and 2015.

3. CATEGORIES OF UTILIZATION

Table 2 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 2. Figure 3 to 6 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 include animal husbandry and carbonation of soft drinks.

Table 2. Summary of the various categories of 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**

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**

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

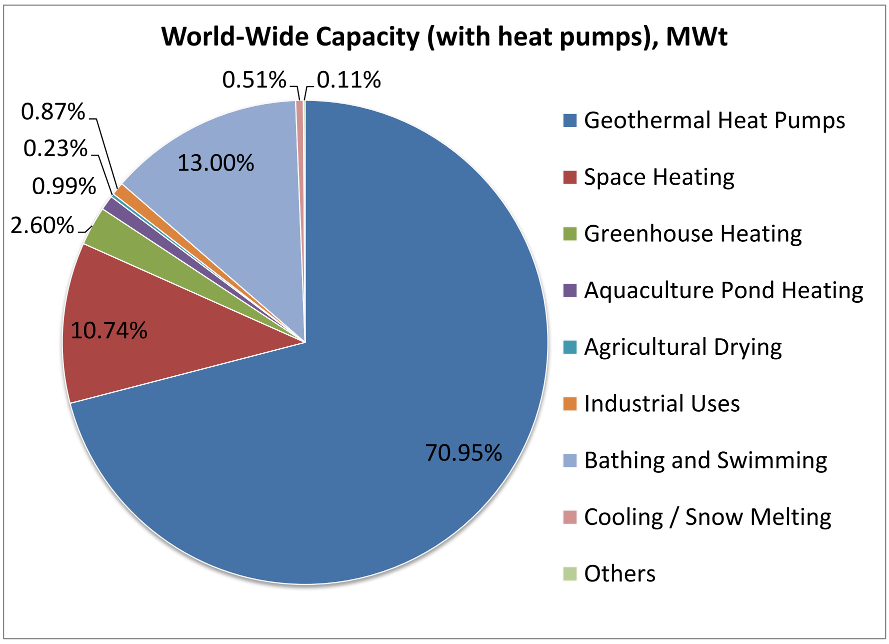

Fig. 3. Geothermal direct applications worldwide in 2015, distributed by percentage of total installed capacity (MWt).

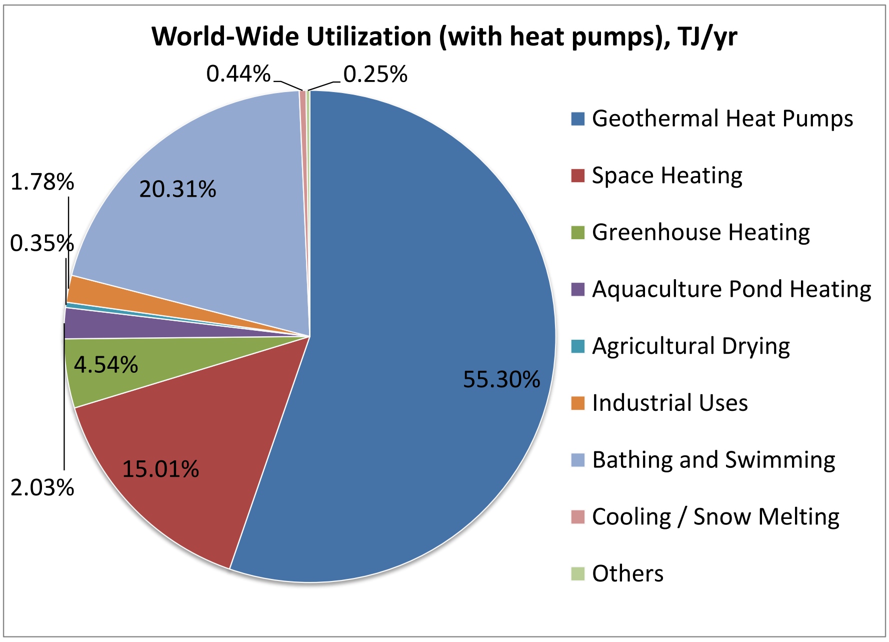

Fig 4. Geotherml direct applications worldwide in 2015, distributed by percentage of total energy used (TJ/yr).

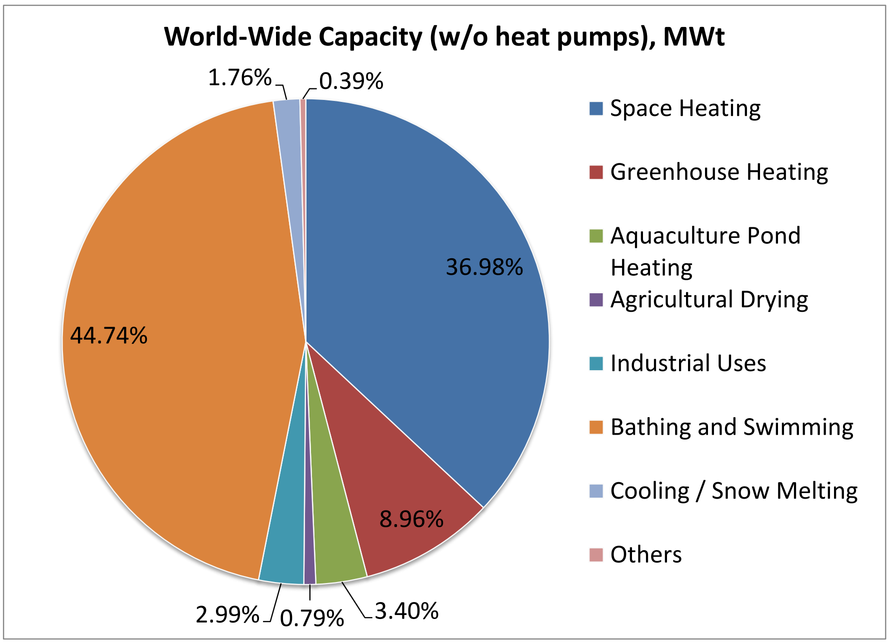

Fig. 5. Geothermal direct applications worldwide in 2015 without geothermal heat pumps, distributed by percentage of total installed capacity (MWt).

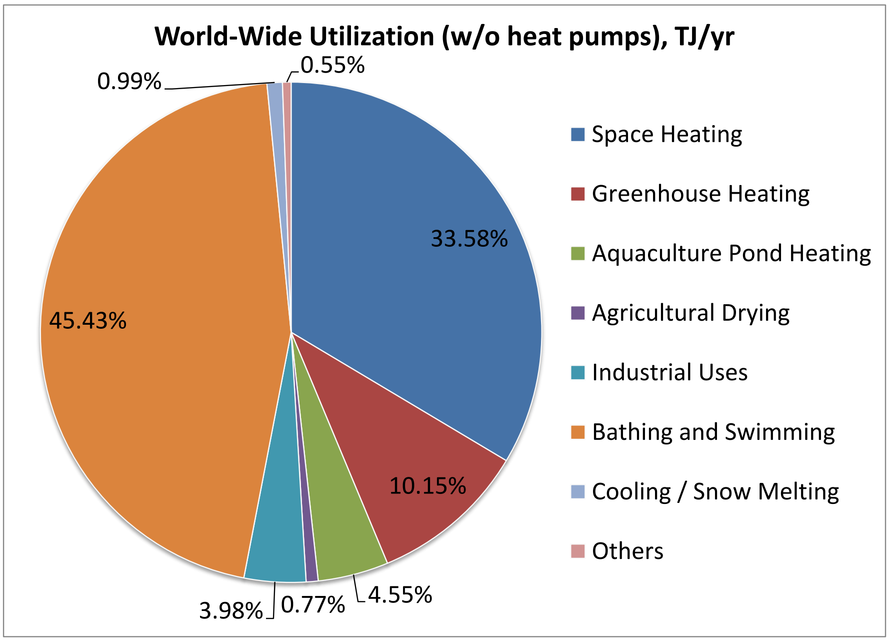

Fig. 6. Geothermal direct applications worldwide in 2015 without geothermal heat pumps, distributed by percentage of total energy used (TJ/yr)

3.1 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 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 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 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.

3.2 Space Heating

Space heat 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).

3.3 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.

3.4 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.

3.5 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.

3.6 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. 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 reason is 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.

3.7 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 during the winter, and 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.

3.8 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, 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.

3.9 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.

4. CAPACITY FACTORS

Average capacity factors were determined for each country (Table 1) and for each category of use (Table 2). 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 2, 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.

5. COUNTRY REVIEWS

5.1 Africa

5.1.1 Algeria.

There are more than 240 thermal springs in the country. The highest temperature recorded were 68°C for the western area (Tlemcenian dolomites), 80°C for the central area (carbonate formations), and 98°C for the eastern area (the sandstone Albian reservoir in the Sahara). The main utilizations of the geothermal waters in Algeria are balneology, space heating and greenhouse heating. Recently some new projects have been established for fish farming and agriculture, where the Algerian government gives financial support of 80% for such projects. A heat pump project was installed in a primary school (Sidi Ben Saleh) at Saida in NW Algeria for heating and cooling purposes. A similar project is planned in Khenchla and a binary-cycle geothermal power plant is also planned in Guelma. Recently some Tilapia fish farming projects started in Ghardaia and Ouargla prefectures. These projects utilize hot waters of the Albian aquifer of south Algeria. The individual uses of geothermal energy are 1.0 MWt and 13.05 TJ/yr for individual space heating; 0.08 MWt and 2.50 TJ/yr for air conditioning; 9.02 MWt and 279.1 TJ/yr for fish farming; 44.37 MWt and 1,400 TJ/yr for bathing and swimming; and 0.17 MWt and 5.0 TJ/yr for geothermal heat pumps. Since the original TJ number for air conditioning, and bathing and swimming gives an unrealistic capacity factor of 1.02, the authors (Lund and Boyd) have reduced these numbers. This gives a total for the country of 54.64 MWt and 1699.65 TJ/yr (Saibi, 2015).

5.1.2 Djibouti.

At present, there are no geothermal developments and/or utilizations in the country. However, it appears that the country has a large geothermal potential which could entirely meet the country's future power demand and attract foreign investors. The present geothermal prospects can be divided into four groups based on their geodynamic position. All are identified by surface manifestations such as fumaroles, hot springs, hydrothermal deposits and ground water anomalies. These include: 1) those in an active emerged rift; 2) those on sites of intense deformation (transform faults and rotation) in the vicinity of active ridges; 3) those located nearby and reaching the oceanic ridge; and 4) those located inland along grabens or on active transverse fractures (Moussa and Souleiman, 2015).

5.1.3 Egypt.

Direct utilization of thermal water in ancient Egypt goes back thousands of years, where Egyptians used warm water from hot springs for domestic uses. Warm lakes in the houses of wealthy people were developed for swimming and medical purposes. Some Papyrus writings are found in the western desert recording such images. Recently, some direct low-grade geothermal applications are now in use. The most common uses are for district heating, fish farming, agricultural applications and greenhouses. Some swimming pools have been constructed along the eastern coast of the Gulf of Suez. These pools are mainly used for touristic and medical purposes. Geothermal waters from hot springs are the main source for these pools. In the western desert of Egypt, greenhouses are heated with geothermal water such as at the oases of Baharia and Dakhla. District heating is also used in the winter. Unfortunately, no estimated of installed capacity and annual energy use is provided by the authors, as none were provided for WGC 2005 and 2010. Thus, the following estimates are made by J. Lund: three swimming pool/bathing locations are indicated – estimated at 4.0 MWt and 60 TJ/yr; one greenhouse location at 1.0 MWt and 10 TJ/yr; one location of space heating of 0.3 MWt and 3 TJ/yr; one district heating system at 1.5 MWt and 15 TJ/yr; for a total of 6.8 MWt and 88 TJ/yr (Lashin, 2015).

5.1.4 Eritrea.

No geothermal utilization is reported for the country (Yohannes, 2015).

5.1.5 Ethiopia.

No country update report was submitted from this country. Thus, the data from WGC2010 will be utilized. The report lists seven bathing and swimming facilities using geothermal energy at various hotels mainly in the Addis Abba area. These are estimated at 2.2 MWt and 41.6 TJ/yr (Lund, et al., 2010).

5.1.6 Kenya.

Direct-use of geothermal energy has not grown significantly since 2010 and greenhouse heating remains the leader with 50 ha heated for growing roses that are air-freighted daily to Europe and other world-wide locations. The installed capacity for these greenhouses is estimated at 16 MWt and annual energy use of 126.62 TJ/yr. Heat is only required normally from around 2:00 AM to 7:00 AM, but the heat also provides a dry environment that limits fungus growth. In addition pyrethrum drying is still being carried out at a plant constructed in the 1920s near Ebburu estimated at 1.0 MWt and 10 TJ/yr. At the Olkaria II power plant, the waste water is being piped to a swimming pool, locally referred to as “the blue lagoon”, estimated at 5 MWt and 40 TJ/yr. Changing rooms have also been built on site. The Lake Bororia Spa Resort has a pool at 0.4 MW and 6 TJ/yr. The total for the country is: 22.4 MWt and 182.62 TJ/yr (Omenda and Simiyu, 2015).

5.1.7 Madagascar.

The exploration for geothermal energy in the country is still at an early stage. In the last few years, researchers from the university evaluated the geothermal resources using geology, geochemical data analyses, and geophysical measurements. The preliminary results of this exploration indicate that about 130 natural geothermal outcrops have been identified. Direct heat use is one of the oldest, most versatile and also the most common form of utilization of geothermal energy. The commonest uses of geothermal energy in the country are for balneology, swimming, bathing and recreation. Today there are five thermal spas in the country developed for balneology, sports and recreations, and as tourist centers. Thermal waters are also bottled by three mineral water bottling companies. Bottling of mineral water is regulated by the Law on Concessions. A large hotel and rehabilitation center with a swimming pool is heated at Antsirabe Spa. A similar use is practiced in Ranomafana Namorona Spa near the Ranomafana National Park. Thermal springs at Bezaha Spa and Betafo Spa are used in conjunction with a rehabilitation center and a recreation center. Geothermal drinking water is also provided at these spas. The total geothermal use for the country is 2.814 MWt and 75.585 TJ/yr for bathing and swimming (Andrianaivo and Ramasiarinoro, 2015).

5.1.8 Malawi.

At present there is no geothermal utilization in the country; however the potential is great as the country is located within the East African Rift System, one of the hottest geothermal zones in the world. Six or seven groups of hot springs have been identified having potential for electricity generation. These are located in the northern half of the country and are thought to be sourced from porous sedimentary reservoirs at depth. At present, the country is dependent upon hydro generation, however, the country has suffered a serious power shortage due to droughts that has reduced the generation to as little as 50% of the installed capacity. Thus, geothermal is of interest as a reliable source of energy (Gondwe, et al., 2015).

5.1.9 Morocco.

Thermal water applications are mainly limited to balneology, swimming pools and bottling of potable water. The key application for developing geothermal energy use in Morocco is related to agriculture, mainly for greenhouse heating. The geothermal use in the country for bathing, swimming and balneology is estimated at 5 MWt and 50.0 TJ/yr (Barkaoui, et al., 2015).

5.1.10 Rwanda.

No geothermal development has taken place in the country to date. However, four prospects are being investigated using geophysical methods along with one exploratory well drilled at Karisimbi (Rutagarama, 2015).

5.1.11 South Africa.

The country is well endowed with thermal springs. More than 80 thermal springs with water temperature ranging from 25^{o}C to 71^{o}C have been reported. Around 29 of these springs have been developed for direct use, mainly at leisure and recreational resorts. During ancient times the thermal spring waters from Die Eiland (Letaba) and Soutini (Soulting) hot springs, were used for the production of salt. This is still practiced at Baleni (Soutini) in the northern part of Limpopo Province for ceremonial and health purposes. Recently, the thermal springs were evaluated with established criteria for each particular use. Potential uses examined included the use of the water for bottling, cosmetic uses, agricultural uses (greenhouse heating, irrigation, agricultural crop drying and mushroom farming, aquaculture (production of tilapia and spirulina), water mining, health and wellness, and specialized tourism. The estimate for bathing and swimming use of 23 thermal springs is 2.3 MWt for the installed capacity and 85.1 TJ for the annual energy use, however this gives an unrealistic capacity factor of 1.17, thus the authors (Lund and Boyd) reduce the value to 37 TJ/yr using a world-wide capacity factor of around 0.5 (Tshibalo, et al., 2015).

5.1.12 Tanzania.

There is currently no utilization of the geothermal resources in the country. However, there are some local informal uses such as using sinters for feeding animals and washing of animal hides. Most of the geothermal features are located in the Rift Valley and the common surface manifestations are in hot spring sites located in areas transected by faulting (Mnjokava, et al, 2015).

5.1.13 Tunisia.

No country update paper was submitted for Tunisia; however, a paper of geothermal development in the country was available. The use of geothermal energy in the country is limited to direct-applications because of the low enthalpy resources, which are located mainly in the southern part of the country. For thousands of years, geothermal water has been used in bathing, and many of the geothermal manifestations in the country have the name of Hammam or bath, which reflects the main use of geothermal water over the centuries. Now, most of the resources are utilized for irrigation or oases and heating of greenhouses. Today the cultivated area of greenhouse is 244 ha. Based on data from WGC2010, the total for greenhouses was 42.5 MWt and 335 TJ/yr, for bathing and swimming 0.9 MWt and 23 TJ/yr, and for others (mainly animal husbandry) was 0.4 MWt and 6 TJ/yr, for a country total of 43.8 MWt and 364 TJ/yr (Ben Mohamed, 2015).

5.2 The Americas

5.2.1 Central America and the Caribbean Islands

5.2.1.1 Eastern Caribbean Nations.

Geothermal phenomena in the 11 Eastern Caribbean islands comprise active and dormant volcanoes, fumaroles, hot spring, mud pots, and altered ground area. The reason for the existence of these thermal features is the westward subduction of the North Atlantic crustal plate beneath the Caribbean plate. Subsurface temperatures recorded in the region range from tepid to more than 290^{o}C as measured in a well drilled in 2013 on Montserrat. Since 2010, geothermal exploration and negotiations for the rights to explore have increased in the region. Three successful slim holes were drilled on Nevis, however, no further development has occurred. Also in 2010, the government of Dominica and Icelandic Drilling, Inc. initiated the drilling of three exploratory slim holes in the Wotton Waven district while in St. Lucia, the government signed a Memorandum of Agreement with UNEC Corporation for exploration and development in the Sulphur Springs regions. The Dominica drilling has confirmed the existence of a commercially viable resource with temperature up to 240^{o}C and a 10 MWe power plant for domestic use is planned. In 2013, two wells were successfully drilled and tested on Montserrat. Finally, negotiations for the rights to explore and develop geothermal resources began in 2013 in St. Vincent and in Grenada. Geothermal power production on Guadeloupe is discussed under France. Direct-use is limited to bathing or “balneology” at The Baths on Nevis Island, Ravine Claire and Malgretout on St. Lucia, at several small spas near Wotten Waven on Dominica and just outside Peggy’s Whim on Grenada, with a total installed capacity of 0.103 MWt and annual energy use of 2.775 TJ/yr (Huttrer and LaFleur, 2015).

5.2.1.2 Costa Rica.

At the end of the 1980’s a study of the country’s geothermal capacities was completed by the Instituto Coastarricense de Electricidad (ICE) in 1991, showing various possible zones of moderate and low temperature resources. However, the use of this type of resources is limited to low temperature forms in hotel pools dedicated to ecological tourism. These resorts and pools are located near Rincon de la Vieja Volcano, Miravalles Volcano, Arenal Volcano, and Turrialba Volcano. Local factors have discouraged the use of these resources, like the favorable climatic conditions and incipient industrial development of geothermal resources in the country. The main use of the geothermal resources is for electric power generation where 217.5 MWe is operating. The estimated installed capacity for direct-use is 1.0 MWt and the annual energy use is 21.0 TJ/yr (Sanchez-Rivera and Vallejos-Ruiz, 2015).

5.2.1.3 El Salvador.

No country update report was available for WGC2015 and no data were provided on direct utilization for WGC2010. However, based on a visit by one of the authors (Lund, 2008) revealed that there were some limited developments of greenhouse heating, fish farming, and fruit drying. During a tour of the Berlin geothermal field, samples of dried pineapples, apples, bananas, coconuts, etc. were made available as “Procesco de deshidratado Natural Geotermico: and called “Geo Fruit or Funda-Geo” which are processed in Berlin for local consumption. Based on recent evaluation, minimum values of 0.5 MWt and 10 TJ/yr is assumed for each of greenhouse heating and fish farming, 1.7 MWt and 21.1 TJ/yr for agricultural drying, and 0.66 MWt and 14.9 TJ/yr for swimming pools and sauna bath, for a total of 3.36 MWt and 56 TJ/yr.

5.2.1.4 Guatemala.

Geothermal energy in the past has been used for medicinal purposes, agriculture, and domestic use. The areas of Totonicapan, Quetzaltenango, and Amatitlan are popular tourist attractions known for their thermal bath houses and spas. These are estimated for a total of 0.21 MWt and 3.96 TJ/yr. The construction company, Bioteca, was the first to successfully apply a direct-use application of geothermal steam in the curing process of concrete products (Merida, 1999). In 1999, a fruit dehydration plant, Agroindustrias La Laguna was built to use hot water from a well in the Amatitlan geothermal field in the drying process. The company produces dehydrated pineapple, mango, banana, apple and chili peppers. Since, no paper was received for WGC2015 and no data for WGC2010, the data from WGC2005 will be use (Lund, et al., 2005). The concrete drying facility is reported at 1.6 MWt and 40.4 TJ/yr, and the fruit drying facility is reported at 0.5 MWt and 12.1 TJ/yr (Merida, 1999). The total for the country is thus, 2.31 MWt and 56.46 TJ/yr.

5.2.1.5 Honduras.

There is a potential market for direct uses in the country, such as cooling, industrial processes and bathing, especially considering that Honduras has a lot of activity by manufacturing and tourism companies. Also, due to the weather and the high temperature, cooling is needed in various setting, such as supermarkets and other industries and residential areas. In 2014, Honduras in collaboration with 4E-GIZ program has developed the project “Feasibility Study for the Development of Low and Medium Temperature Geothermal Resources for Industrial Processes” in order to promote the use of new alternatives for thermal power generation using geothermal resources of low and medium temperature. Potential sites were identified specifically in two areas in the northern part of the country (Valle de Sula and Sambo Creek). A number of swimming pools are reported using geothermal energy. These are estimated to have an installed capacity of 1.933 MWt and an annual energy use of 45 TJ/yr (Henriquez, 2015).

5.2.2 North America

5.2.2.1 Canada.

More than 140 thermal springs of temperature higher than 10°C have been identified in the Western Canadian Cordillera. Commercial exploitation of these natural hot springs in the provinces of Albert, British Columbia and Yukon as well as thermal water pumped from deep aquifers in Saskatchewan is taking place at fourteen locations to heat pools for bathing purposes. The hot springs have played an important role for the early development of tourism in the Canadian Rockies. The creation of Banff National Park in 1885, the first national park in Canada, is the result of a dispute about the right to develop hot springs. Commercial exploitation of the hot springs began in the 1880s, although First Nations people had used them for generations prior. Europeans initially visited Banff Hot Springs in 1882 and the first recorded visit at Radium Hot Springs was in 1841. Construction of bathhouses and hotels at Banff, Miette and Radium Hot Springs respectively began in 1886, 1913 and 1914. Original bathhouses have been modified, restored or reconstructioned and the hot springs pools are still operated today. Of the 13 commercial hot springs, two in Alberta, nine in British Columbia, one in Yukon Territory, and one is Saskatchewan, they have a total installed capacity of 8.780 MWt and annual energy use of 277 TJ/yr. The exploitation of shallow geothermal resources for geothermal heat pumps (GHP) is concentrated in southern Ontario and Quebec, but installations are present throughout the country. The average unit is estimated at 14 kW, the coefficient of performance of 3.5 and the full load operating hours annually as 3,000. From 1990 to date an estimated 120,000 units have been installed in the country with an installed capacity of 1,458 MWt and annual energy use of 11,338 TJ/yr (by the end of 2014). The residential section accounts for about 60% of the installed capacity with approximately 56% of the units are horizontal closed-loop and 24% are vertical closed-loop. A high growth rate of installations was experienced during 2006 to 2008, but severely decreased in 2010. The total for the country is then 1,466.78 MWt and 11,615 TJ/yr (Raymond, et al., 2015; and Thompson, et al., 2015).

5.2.2.2 Greenland (Kalaallit Nunaat).

Geothermal springs with a homeothermic source water temperature >2°C (homeothermic springs) can be found all over Greenland, however, warm springs >10°C are very rare. They are found primarily in Disko Island, West Greenland with a maximum temperature of 18°C, and on the east coast at a number of locations north and south of Scoresbysund. There the warmest geothermal springs are known, that is at Uunartoq Island in the vicinity of the town there are geothermal springs with temperatures between 34 and 38°C. The Greenland Glacier covers over 80% of the country and the majority of all hot springs and geothermal sites are believed to be ice covered. Recently, it has been pointed out that high heat flow below the glacier might in some areas contribute to the ice melt and consequently it has to be taken into account in planning deep ice drilling campaigns and climate reconstruction. Geothermal exploration in Greenland has mainly aimed at establishing the influence of the warm springs on the flora and fauna, which are noted for the large element of southern species. A limited investigation has been made into the possibility of geothermal utilization in Disko, West Greenland for space heating and power production. Currently, geothermal water is used in natural spas in one or two place (Uunartoq and Cape Tobin) for bathing, balneology and tourism with little economic return. These are estimated at 1.0 MWt and 21.0 TJ/yr (Hjartarson and Ármannsson, 2015).

5.2.2.3 Mexico.

Geothermal energy in the country is almost entirely used to produce electricity. Its direct uses are still under development and currently remain restricted to bathing and swimming facilities with recreational purposes and some with therapeutic uses (reported at 20 locations). Almost all of the resorts and pools have been developed and are operated by private investors. There are some facilities operated by federal, state or municipal governments, through their tourism offices or, in some cases, through federal institutions like the National Social Security Institute. Comision Federal de Electricidad (CFE) has developed some direct uses of geothermal resources at the Los Azufres geothermal field, including a wood-dryer, a fruit and vegetable dehydrator, a greenhouse and a system for heating of its offices and facilities in the field. The use of geothermal heat pumps is minimal and under developed, with no information available. The installed capacity and annual energy use for the various direct-use applications are 0.460 MWt and 4.397 TJ/yr for individual space heating; 0.004 MWt and 0.028 TJ/yr for greenhouse heating; 0.007 MWt and 0.067 TJ/yr for agricultural drying; and 155.347 MWt and 4,166.512 TJ/yr for bathing and swimming. The total for the country is then: 155.818 MWt and 4,171.004 TJ/yr (Guiterrz-Negrin, et al., 2015).

5.2.2.4 United States of America.

Geothermal energy is used for both electric power generation and direct utilization in the country. The direct utilization of geothermal energy includes the heating of pools and spas, greenhouses and aquaculture facilities, space and district heating, snow melting, agricultural drying, industrial applications and ground-source heat pumps. The largest application is ground-source heat pumps accounting for 88% of the annual energy use, with the next largest application being fish farming and swimming pool heating. Direct utilization (without heat pumps) has remained nearly static over the past five years with gains balancing loses; however, ground-source heat pumps are being installed at a 8% annual growth rate with 1.4 million units (12 kW size) in operation. A total of two new projects have come on line in the past five years; the addition to Boise State University to the city district heating system adding 60,000 m^2 of floor area; and a district heating system in Lakeview, Oregon connecting five schools, the local hospital and health care facility. In summary, when considering direct-use without geothermal heat pumps, the distribution of annual energy use is as follows: 34% for fish farming, 28% for bathing and swimming, 15% of individual space heating, 9% for greenhouse heating, 9% for district heating, 3% for agricultural drying, 2% for industrial process heating, <1% for cooling, and <1% for snow melting. The installation of new ground-source heat pumps are 60% in commercial and institutional buildings, and 40% in residential locations. Approximately 90% of the units are closed loop (ground-coupled) and the remaining open loop (water-source). Within the residential section, of the closed loops systems, approximately 30% are vertical and 70% horizontal, as the latter are cheaper to install. In the institutional and commercial section, 90% are vertical and only 10% horizontal, constrained by ground space in urban area. The current installed capacity and annual energy use for the various sections are: 139.89 MWt and 1,360.6 TJ/yr for individual space heating; 81.55 MWt and 839.6 TJ/yr for district heating; 2.31 MWt and 47.6 TJ/yr for air conditioning; 96.91 MWt and 799.8 TJ/yr for greenhouse heating; 141.95 MWt and 3,074.0 TJ/yr for fish farming; 22.41 MWt and 292.0 TJ/yr for agricultural drying; 15.43 MWt and 201.1 TJ/yr for industrial process heat; 2.53 MWt and 20.0 TJ/yr for snow melting; 112.93 MWt and 2,557.5 TJ/yr for bathing and swimming; and 16,800 MWt and 66,670 TJ/yr for geothermal heat pumps. This gives a total for the country of 17,415.91 MWt and 75,862.2 TJ/yr (Boyd, et al., 2015).

5.2.3 South America

5.2.3.1 Argentina.

The country continues to develop both their high enthalpy and low enthalpy resources, especially most recently in new thermal areas associated with sedimentary basins. This has allowed the development of therapeutic-recreational complexes that are generating new sources of revenue for the region. A number of new low enthalpy resources are being developed and put into production for potential direct-use applications. These include 10 areas in the provinces of Cordoba, Corrientes, Misiones and Buenos Aires that are under development and four areas in the provinces of Buenos Aires and Corrientes that are under production. Many of these projects are in close proximity to the large population centers of Buenos Aires and Gran Buenos Aires (more than 20 million inhabitants). Other developments are located in the Mesopotamia and the Pampa Humeda regions, mainly in the form of therapeutic recreational complexes. A total of 72 sites are reported to utilize geothermal water for direct-use ranging in temperature from 24 to 75^{o}C. Three sites are used for individual space heating, two for greenhouse heating, two for fish farming, one for snow melting, 67 for bathing and swimming and two for other uses (animal farming). No uses of geothermal heat pumps are reported. The installed capacity and annual energy use for the various applications are: 22.4 MWt and 50.0 TJ/yr for individual space heating; 21.48 MWt and 40.1 TJ/yr for greenhouse heating; 7.03 MWt and 13.1 TJ/yr of fish farming, 15.3 MWt and 44.64 TJ/yr for animal farming; 1.39 MWt and 31.6 TJ/yr for snow melting, and 96.0 MWt and 820.59 TJ/yr for bathing and swimming. The total for the country is 163.6 MWt of installed capacity and 1,000.03 TJ/yr for annual energy use (Pesce, 2015).

5.2.3.2 Brazil.

The Geothermal Laboratory of the National Observatory has compiled information on the main geothermal systems currently being exploited commercially in the country. These have been classified into groups based on their potential use, proximity to large urban centers and local climate characteristics. They are designate as BRT (Bathing, Recreations and Tourism), PIS (Potential for Industrial Use and Space Heating), and TDB (Therapeutic, Drinking and Bathing) groups. The concentration of the thermal and mineral springs is relatively high in southern and south-central Brazil (Vieira, et al., 2015). The total capacity of low temperature geothermal systems under economic exploitation is estimated at 360.1 MWt, while the annual energy use is estimate at 6,622.4 TJ/yr. The various direct-use applications are: 4.20 MWt and 77.0 TJ/yr for industrial wood processing plant; and 360.1 MWt and 6,545.4 TJ/yr for bathing and swimming (Vieira, et al., 2015).

5.2.3.3 Chile.

The Chilean Government is trying to promote the development on non-conventional energy sources (wind, solar and geothermal). Over 70 geothermal exploration concessions have been awarded by the Chilean Government to private companies, and exploration drilling has been conduction in at least nine of these areas. At two of these geothermal systems, Apacheta and Tolhuaca, the results of environmental impact studies have been submitted in advance of possible plans to develop these fields for geothermal power production. However, in Chile, geothermal resources have been traditionally used for recreational and touristic purposes. Direct-use in spas and swimming pools accounts for an installed capacity of 11.31 MWt with an annual energy use of 152.12 TJ/yr (assuming a 46% capacity factor). These values do not include about seven additional private thermal baths and hotels from which quantitative information is not available. For these, a rough estimate of capacity is 2.20 MWt and annual energy use of 27.30 TJ/yr (by J. Lund). In most cases, the thermal waters are collected from natural hot springs and piped to buildings and pools; only four spas have shallow wells that were drilled to extract geothermal water. The use of heat pumps in Chile began in 1996 when 51 units were installed in the southern part of the country. Approximately 70% of them are closed-loop (ground-coupled), and the rest are open-loop (water-source) systems. The installed heat pump capacity is 8.6 MWt and energy use of 34 TJ/yr, approximately 83% of the units are installed in commercial, industrial and institutional buildings; with only 17% in houses and apartments. The total geothermal direct-use for the country is then 19.91 MWt and 186.12 TJ/yr (Lahsen, et al., 2015).

5.2.3.4 Columbia.

The main hydrothermal systems in Columbia are related to volcanoes located in the Andrean Zone; mostly along the central and western cordilleras. The update of hot springs inventory has been carried out in phases in 2003 and from 2010 to 2014. About 300 hot springs have been registered. Samples of the liquid phase were collected from chemical and stable isotopes analysis. The hot springs located in the Andean Zone are likely related to hydrothermal systems of volcanoes. Discharge temperatures of the hot springs are between 94 and 95^{o}C with a pH of between 1.2 and 9.7. In consideration of the interest generated by the information on hot springs and other surface manifestations, a web application for public search was developed. The application includes general data on geographic and geological locations, in situ physicochemical variable measurements, images (photos and video), availability of spa infrastructure, paths, as well as chemical and isotope composition of the liquid and gas phases. The current utilization of the geothermal resources in Columbia is still limited to bathing for tourism purposes. About 40 localities in the departments of Cundinamarca, Boyaca, Norte de Santander, Antioquia, Caldas, Risaralda, Tolima, Cauca, Narino, Putumayo, Magdalena and Choco, have developed pools. The installed capacity based on limited information is estimated at 18 MWt and the annual energy use of 289.88 TJ/yr (Alfaro, 2015).

5.2.3.5 Ecuador.

In 2008, the Ecuadorian Government through MEER (Ministry of Electricity and Renewable Energy) re-started geothermal exploration aiming to develop the former INECEL (Instituto Ecuatoriano de Electrification) geothermal prospects for power production. MEER launched the Geothermal Plan for Electricity Generation, which described and prioritized 11 geothermal prospects countrywide. The Plan also included technical files for each prospect, preliminary TORs on Prefeasibility Studies for the first five prospects and general aspects to be taken into account for geothermal laws. The geothermal plan MEER is dedicated mainly for electrical use, but also looks into direct utilization. Today, utilization of geothermal resources in Ecuador is restricted to direct uses only, that is, for bathing resorts, balneology and swimming pools. The first use of space heating was at the private Termas Papallacta Spa Resort Hotel, but its use is irregular due to scaling problems. A heat exchanger has been designed for the resort using geothermal water from the hot springs. Also, several projects for direct use in fish hatchery await funding for development. A summary of most of the swimming pools using hot and warm springs has a total capacity of 5.157 MWt and annual energy use of 102.401 TJ/yr, which is the same as reported for WGC2010 (Beate and Urquizo, 2015).

5.2.3.6 Peru.

The first and older evidence of the utilization of geothermal heat in Peru was during the pre-Inca and Inca periods. These populations used the thermal water for their curative effects and for recreational purposes in the form of balneology. The oldest and best known is the "Baños del Inca" (Incas baths) in Cajamarca, formerly called "Baños de Pultumarca" (hot place), the name given because in these sources, the Inca Atahualpa used to take baths here for relaxation and recovery. The pre-Inca Caxamarca culture built an important city close to the hot springs that later became known as Baños del Inca. The place at that time consisted of some buildings that were one of the principal residences of the Caxamarca chiefs, who used the hot springs for healing and the worship of water. When the Incas conquered the Caxamarca culture the hot springs area became one of the principal residences of the Inca chief. Today, geothermal resources are located in areas of great tourist attraction, and have become an important source of economic development, as well as for the tourism industry. However, the utilization of these resources in Peru is still mostly limited to entertainment and balneology at places such as Baños del Inca in Cajamarca, Callejón de Huaylas in Huaraz, Churin in Lima, Calera in Arequip, and Aguas Calientes in Tacna. Today, the use of geothermal sources in balneology activities (hotels, spas and recreation) has increased in the country, from the simple and rustic local installations, to the construction of hotels and major recreational facilities. Thus, direct-use of geothermal resources are well known and more-or-less well developed, but as until now only non-official government entities have a complete inventory of these resources, and the thermal potential has not been estimated. The capacity and utilization of the geothermal resource for swimming, spas and balneology are not given in the paper, but based on estimates; the values are 3.0 MWt for the installed capacity and annual energy use of 61 TJ/yr (Cruz and Vargas, 2015).

5.2.3.7 Venezuela.

No report on the use of geothermal resources was made available for WGC2015. Personal communication with Urbani (2014) indicated that there has been no change since 2005. Thus, the figures of 0.7 MWt and 14 TJ/yr are estimated for several small spas in use (Lund, et al., 2005).

5.3 Asia

5.3.1 China.

Geothermal direct-use in the country has benefited from the requirement for energy conservation in buildings and reduction of CO_2 emissions. The fastest growing section is in the installations of geothermal heat pumps. In 2009, GHP accounted for 53.5% of the installed capacity and 51.9% of the annual energy use. Today, these numbers are 65.9% and 57.5% respectively. For geothermal direct-use excluding heat pump, the largest use was for bathing and medical treatment. Today the largest is for district heating with a 2.8 times increase over 2009. Geothermal space heating provides heat for 60.32 million m^2, with 19 million m^2 in Tianjin and 13.8 million m^2 in Hebei province. Hot springs have been used for bathing and medical treatment for many centuries. This industry is growing with new investors. The heating of greenhouses and aquaculture facilities is one of the main uses of geothermal resources. Greenhouses covering 30,000 m^2 with automatic control of temperature and humidity are becoming popular. Geothermal heat pumps have increased from heating area of 7.67 million m^2 in 2004, to 100.7 million m^2 in 2009, to 330 million m^2 in 2014. The largest concentration is in Shenyang where 22.48% of the China's capacity has been installed, followed by Beijing with 15.18%. In summary, district heating accounts for 2,946 MWt of installed capacity and 33,710 TJ of annual energy use; greenhouse heating for 154 MWt and 1,797 TJ/yr; fish farming for 217 MWt and 2,395 TJ/yr; agricultural drying for 95 MWt and 1,198 TJ/yr; industrial process heat for 169 MWt and 3,304 TJ/yr, bathing and swimming for 2,508 MWt and 31,637 TJ/yr; and geothermal heat pumps for 11,781 MWt and 100,311 TJ/yr. The total for the country is then, 17,870 MWt and 174,352 TJ/yr (Zheng, et al., 2015).

5.3.2 India.

To date the only direct-use of geothermal energy in the country is for bathing, swimming and balneology and in a few cases as a source of energy for cooking. Since 80% of electricity generation in India is spent for space cooling, a large amount of CO_2 can be saved using geothermal heat pumps. This use is currently being investigated. The increase in the annual geothermal use for balneology, bathing and swimming has gone from 2,545 TJ in 2010 to 4,152 TJ in 2014, with an installed capacity is 981 MWt. It is estimated that 5.0 MWt and 150 TJ/yr is used for cooking, which is included in the other category. Thus, the total for the country is 986 MWt and 4,302 TJ/yr. (Chandrasekharam and Chandrasekhar, 2015).

5.3.3 Indonesia.

There are no new applications of direct-use in the country as report for WGC2010. Direct-use development of geothermal spas and swimming pools have occurred over hundreds of years, along with 20th century development for washing and cooking. Today, direct-use has been developed for agriculture such as copra drying in Lahenong, Mataloko and Wai Rai Lampung, mushroom cultivation in Pengalengan, tea drying and pasteurization in Pengalengan, and for catfish growing in Lampung. Farmers at this latter operation report that the fish grow better in the geothermal fluid and freshwater mixture. Palm sugar is processed using 4 tonnes/hr of brine from the Lahendong geothermal power plant. A cocoa drying facility has also been developed close to the copra drying operations described above. No geothermal heat pump operations are report for the country. Based on data from 2001 (Lund and Freeston), the estimate usage for bathing and swimming are 2.3 MWt and 42.6 TJ/yr (Darma, et al., 2015).

5.3.4 Iran.

Swimming, spas and bathing at 189 locations are reported throughout the country, for an installed capacity of 81.306 MWt and annual energy use of 2,563.147 TJ/yr, however this gives an unrealistic capacity factor of 1.00, thus the authors (Lund and Boyd) reduced the value to 1,102 TJ/yr using the world-wide capacity factor of 0.41. No details are provided on locations of these facilities. Geothermal heat pumps are reported at nine locations for a total number of units of 11 with capacities from 5 to 21 kW.

The total installed capacity for heat pumps is reported at 0.191 MWt and annual energy use of 1.116 TJ/yr. The total for all uses in the country is 81.497 MWt and energy use of 1,103.116 TJ/yr (Porkhial and Yousefi., 2015).

5.3.5 Israel.

No country update report was received from this country. Thus, the data from WGC2010 will be utilized based on estimates from WGC2005. These include 27.6 MWt and 512.0 TJ/yr for greenhouse heating; 31.4 MWt and 989.0 TJ/yr for fish farming; and 23.4 MWt and 692 TJ/yr for bathing and swimming, giving a total for the country of 82.4 MWt and 2,193 TJ/yr (Lund, et al., 2010).

5.3.6 Japan.

No country update paper was available from Japan; however some data was provided by personal contact (Kasumi, 2014) indicating that there has been no change in direct utilization, except for a recent increase in geothermal heat pump installations. The direct-use of medium- and low-enthalpy geothermal water is mainly located in the areas around the high-enthalpy geothermal areas where hot spring resources are abundant. Otherwise, the use of shallow geothermal heat pump systems is available nationwide. Geothermal heat pumps are used for space heating and cooling, domestic hot water and snow melting. Many new systems have been installed in Hokkaido replacing old oil boilers. Approximately 84% of GHPs are closed loop, 15% open loop, and 1% using both systems. The estimated installed capacity is 100 MWt and annual energy use of 500 TJ/yr, based on extrapolations from 2012 data (62 MWt at that time). Bathing, mainly at Japanese-style inns (onsens) is very popular with the Japanese people and accounts for about 90% of the direct-use applications. Using data from WGC2010, the following applications are reported: 77.37 MWt and 969.49 TJ/yr for space heating, 36.92 MWt and 451.73 TJ/yr for greenhouse heating; 7.91 MWt and 141.86 TJ/yr for fish farming; 1.24 MWt and 30.92 TJ/yr for industrial applications; 45.76 MWt and 154.88 TJ/yr for air conditioning and 106.78 MWt and 361.39 TJ/yr for snow melting (based on assumptions for WGC2005 of a 30-70% split); and 1,810.19 MWt and 23,519.81 TJ/yr for bathing and swimming. This gives a total for the country of: 2,186.17 MWt and 26,130.08 TJ/yr (Yasukawa and Sasada, 2015).

5.3.7 Jordan.

The authors mention that thermal springs have been used for bathing and irrigation for many years. Recently several hotels (spas) were constructed at the thermal spring sites, for example Zarqa Ma'in spa. Generally, thermal water has various properties and differs in their temperature and curative ability. For example, thermal waters of Zara and Zarqa Ma'in springs are quite useful in treating osteon arthritis, degenerative disc and post traumatic problems. Thermal water of North Shuneh is good for cervical spondee losing while the thermal water of Afra and Burbeitta are quite good in treating degenerative disc and post traumatic problems. At present several farms producing tilapia exist in the country. For example, the Arab Fish Company farm consists of some 40 basins. It produces between 20 and 55 tonnes of tilapia per year. In winter, the temperature cannot be maintained at sufficient level to ensure the survival of the fingerlings and allow for the growth of the fish. Future plans are to use geothermal waters for greenhouse heating and refrigeration. Since no data were available the data from WGC2010 will be utilized based on estimates from 2001 (Lund and Freeston). It appears that at least six sites have installations for direct-use, mainly for bathing and swimming. These are 153.3 MWt and 1,540 TJ/yr (Saudi and Swariech, 2015).

5.3.8 Korea (South).

Direct-use of geothermal energy in the country has been quite active over the last five years, especially geothermal heat pump (GHP) installations. The rapid increase of GHP is mainly due to active government subsidizing programs for renewable energy development, but recently the number of installations without subsidy has also increased. There are several areas producing hot spring water with temperature higher than 60°C which circulates through deeply extended fractures in crystalline rocks. This hot water has been utilized for floor heating in the hot spring areas for more than 20 years. In addition, a small-scale district heating and greenhouse heating with hot spring water was started in 2008. 65% of the GHP installations are in office buildings, and 35% are for residential, agriculture, aquaculture and other uses. The COP in the heating mode is 3.73. It is estimated that over 7,000 GHP units have been installed in the country of which 75% are vertical closed loop, 16% are open loop (ground water), and 5.5% are horizontal closed loop installations. A summary of the various direct-uses are: 8.66 MWt and 53.43 TJ/yr for individual space heating; 2.21 MWt and 31.28 TJ/yr for district heating, 0.17 MWt and 1.33 TJ/yr for greenhouse heating, 32.56 MWt and 507.61 TJ/yr for bathing and swimming; and 792.2 MWt and 2,089 TJ/yr are for geothermal heat pumps. The total for the country are 835.8 MWt of installed capacity and 2,682.65 TJ/yr of annual energy use (Song and Lee, 2015).

5.3.9 Mongolia.

There are 43 geothermal areas in the country with many utilized for heating, bathing and medical purposes. National Sanatoriums utilized thermal waters via shallow (typically <100 m deep) wells at Tsenkher, Hujirt. Shargarljuut, Zart, Shivert, Khalzan uul, Eruu and Tsangaan Tal. Two types of geothermal applications are well developed in the country in the last decade. Those are the traditional sanatorium and the new technology of ground source heat pumps. Ground source heat pumps applications started in 2008. The traditional sanatorium and bathing are continuously developing in the country, for both local and foreign tourists. Many tourist camps have been established nearby the hot spring areas, and built hot pots and small pools for bathing and swimming. Ground source heat pumps have been established in public and private buildings throughout the country. A ground water system has been installed at the Corporate Nukht Hotel. Other systems have been established by the National Renewable Energy Center, a state owned enterprise. To date they have installed three ground source systems in public buildings, such as a school, dormitory and kindergarten, located in the Tuv province center about 45 km southwest of Ulaanbaator, the capital city. As summary of geothermal direct-use installations include installed capacity for bathing of 18.711 MWt, 0.685 MWt for space heating and 0.760 MWt for geothermal heat pumps. The annual energy uses include 294.96 TJ/yr for bathing, 21.30 TJ/yr for space heating, and 24.20 TJ/yr for geothermal heat pumps. The total for all applications are: 20.156 MWt of installed capacity and 340.46 TJ/yr of annual energy use (Dorj, 2015).

5.3.10 Nepal.

Geothermal energy is used only for bathing and swimming at the numerous hot springs throughout the country. The most popular hot spring in the country is Singa Tatopani located about 390 km west of Kathmandu. The pool can hold up to 100 people at a time, and more than 60,000 people from various parts of the country visit the spring every year mainly to cure for rheumatic and gastric diseases; but it is also used from recreational purposes. Another pool is in the Kodari geothermal area, which attracts people from various remote areas as well. During the winter season, bathing in the pond takes place 18 hours a day, with alternating shifts of three hours for male and female. Due to its popularity, the local community has improved the supporting infrastructure for meals and lodging. Improvements have been made at numerous other hot springs to make them a tourist destination. However, geothermal energy has remained a neglected area of renewable energy source, mainly due to lack of trained people and knowledge of the potential by the national and local governments. Lack of good road access and availability of investment has also been problems. However, many of these problems are being addressed which will encourage future direct-use developments. In summary, there are 25 hot springs that have been identified in the country where bathing, swimming and balneology takes place. These uses have an installed capacity of 3.316 MWt and annual energy use of 81.112 TJ/yr (Ranjit, 2015).

5.3.11 Pakistan.

The only direct-use of geothermal water in the country is from hot springs, mainly for bathing. Unfortunately, 90% of these spring waters are being wasted to the rivers and the sewer system. Two springs of Manghopir and Drig Road in Karachi are within the city limits and are being used in spas for bathing. A crocodile farm pool is using natural heated spring water from the Manghopir spring. There are also two residential houses in Islamabad and Lahore that are reported by the author utilizing geothermal water for heating/cooling, but no energy use is available. The summary of use for the country include for installed capacity of 0.509 MWt for bathing and 0.03 MWt for animal farming, and for annual energy use of 2.264 TJ/yr of bathing and 0.200 TJ/yr for animal farming. The total for the country is 0.539 MWt and 2.464 TJ/yr (Bukhari, 2015).

5.3.12 Philippines.

No details on the direct-use of geothermal energy are provided in the country update paper. Only two uses are mentioned in the tables: agricultural drying at the Palinpinon drying plant of 1 MWt and 17.34 TJ/yr (reported for WGC2010 as drying coconut meat and copra), and at the Manito drying plant of 0.63 MWt and 9.59 TJ/yr. However, both of these plants were reported as closed for economic reason in the report for WGC2010. Bathing and swimming at the Laguna Hot Springs and other resorts are reported as 1.67 MWt and 12.65 TJ/yr. This gives a total for the country 3.3 MWt and 39.58 TJ/yr of direct-use applications (Fronda, et al., 2015).

5.3.13 Saudi Arabia.

Some direct low-grade geothermal applications are now in operation in the country. These consist of swimming pools constructed in the Bani Malik-Jazan area. A recent governmental geothermal activity at Al Khouba hot springs – Jazan area was undertaken by the Saudi Ministry of Tourism and the local municipality consisting of two small projects. The purpose of these projects are to drill one shallow well that will hit the main fracture system of the hot springs at up to 75 m deep and pump and pipe the water to a high mountain area south of the hot springs. A number of swimming pools, medical therapy, spas and refreshment places are now under construction. It is also reported that geothermal energy is used in animal farming, most likely to heat pens, however, no details are provided. The energy use in the country consists of an installed capacity of 40 MWt for bathing and swimming and 4.0 MWt for animal farming, and respectively annual energy use of 138.89 TJ/yr and 14.0 TJ/y. It should be noted that the values for animal farming are estimated. The total for the country is 44.0 MWt and 152.89 TJ/yr for direct use applications (Lashin, et al., 2015).

5.3.14 Taiwan.

No information provided on direct-use applications in the country update paper (Yang, 2015).

5.3.15 Tajikistan.

No report was submitted from this country. Based on estimates made for WGC2010 (Lund, et al., 2010), the only use is for bathing and swimming at 2.93 MW and 55.40 TJ/yr.

5.3.16 Thailand.

There are over 1,800 hot spring manifestations in the country, exposed in the north and extended towards western and southern Thailand, with surface temperature range of 40 to 100^{o}C. In 1986 a pilot drying house was constructed in the Sankamphaeng geothermal field to experiment with curing and drying of tobacco, bananas, chili, garlic, maize, peanuts, etc. with positive results compared to using firewood and lignite. A similar drying facility was also constructed at the Fang geothermal field using the tail water from a small binary power plant at 77^{o}C which is still in operation. A cold storage plant was also constructed to test the cooling of lemons, onions and lichee. A third drying facility at the Maechan geothermal field is presently shut down due to maintenance and budget problems. Hot spring baths have been very popular in the country operated by the private sector as well as by local communities who are active in monitoring and preserving these hot springs. A total of 71 locations are reported, some as high as 20 MWt of installed capacity and 80 TJ/yr of utilization. Presently there are a number of geothermal heat pump facilities installed in the country, but the data is not available and can only be estimated. The estimated use for the country is 0.04 MWt and 0.3 TJ/yr for crop drying, 1.0 MWt and 12.0 TJ/yr estimated for geothermal heat pumps, and 127.470 MWt and 1,168.898 TJ/yr for bathing and swimming. This gives a total of 128.510 MWt and 1,181.198 TJ/yr for the country (Raksaskulwong, 2015).

5.3.17 Turkey.

Studies in the country have identified more than 225 geothermal field which can be useful at the economic scale, and about 2,000 hot and mineral water resources (springs and wells) which have temperatures ranging from 20 to 287^{o}C have also been documented. Up to now, nearly 1,200 geothermal exploratory, production and reinjection wells have been drilled in Turkey. At present there are 16 geothermal district heating systems in operation some using water as low as 40 to 45^{o}C, without the use of heat pumps. These systems serve 77,453 residences. Greenhouse applications have reached three million m^2 due to satisfaction with the various operations; however, development has slowed down in the last one to two years. There are six major greenhouse areas in the country, mostly in the west. Tomatoes are mostly grown in these greenhouses with the major markets of Russia (60%), Europe 20%, around 10% elsewhere internationally, and 10% sold domestically. 16 million local and 10,000 foreign visitors are benefiting from the balneological uses of geothermal water in Turkey, with investments growing in recent years. Geothermal heat pump installations have grown, with large installations in the Metro Meydan M1 Shopping Center/Istanbul; the Terme Maris Facility in Dalaman; The Titanic Hotel in Antalya; Antalya Terra city, and the Sabiha Gokcen Airport in Istanbul. In summary, the installed capacity and annual energy use for the various direct-use applications in the country are: 420 MWt and 4,635 TJ/yr for individual space heating, 805 MWt and 8,885 TJ/yr for district heating, 612 MWt and 11,580 TJ/yr for greenhouse heating, 1.5 MWt and 50 TJ/yr for agricultural drying, 1,005 MWt and 19,106 TJ/yr for bathing and swimming, and 42.8 MWt and 960 TJ/yr for geothermal heat pumps. The total for the country is then, 2,886.3 MWt of installed capacity and 45,126 TJ/yr for annual energy use (Mertoglu, et al., 2015).

5.3.18 Vietnam.

No country update report was received from this country. Thus, the data from WGC2010 based on estimates from 2005 (Lund, et al., 2005). These include the drying of bananas, coconuts and medicinal herbs at 0.5 MWt and 11.83 TJ/yr; production of salt at 1.4 MWt and 21.6 TJ/yr; and for balneology and medical treatment at 29.3 MWt and 58.9 TJ/yr. The total for the country is then estimated at 31.2 MWt and 92.33 TJ/yr.

5.3.19 Yemen.

No country update report was received from this country. Based on data from 2001 reported at WGC2010 (Lund and Freeston, 2001), 1.0 MWt and 15 TJ/yr is estimated for bathing and swimming.

5.4 Commonwealth of Independent States

5.4.1 Armenia.

No country update report was received nor was one received for WGC2005 or WGC2010. The data reported here is based on a report by Henneberger et al. (2000) and personal communication with Henneberger (2009). Geothermal water from an operating well is bottled and sold as mineral water, and also used to heat a nearby guesthouse. Two wells produce CO_2, one for a bottling plants and the other for a dry-ice factory. These wells also supply hot water to the Ankavan Sanatorium, a facility dedicated to the treatment of stomach ailments. Using number from Lund et al., (2005), it is estimated that the capacity is 1.0 MWt and use is 15 TJ/yr for bathing and swimming, and 0.5 MWt and 7.5 TJ/yr for individual space heating, for a country total of 1.50 MWt and 22.50 TJ/yr.

5.4.2 Belarus.

The first small geothermal heat pump system installed in the country was in 1997 for heating waterworks and sewage treatment buildings in the Minsk District. At present there are about 100 to 130 installations in the country. The exact number is not known, as there was no requirement to register the units with the Ministry of Natural Resources and Environmental Protection. The largest installation today is at the Greenhouse Complex “Berestye” in Brest. Fresh water is pumped from a sandstone layer through a 1,000 m deep borehole at 24^{o}C with a flow of 42 m^3/hr. Two heat pumps with a capacity of 505 kW each are used in the complex. In addition, several dozen small heat pumps systems are installed in private homes within and around the towns and cities of Brest, Gomel, Grodno, Minsk, Mogilev and Vitebsk, with a total capacity of 1.0 to 1.5 MWt. Most of the installations use cold groundwater taken from shallow boreholes at a temperature of 8 to 10^{o}C. Some use horizontal or vertical closed loop systems. Others utilize lake or river water. The estimated installed capacity is 6.307 MWt (of which 4.73 MWt are geothermal at a COP of 4.0). The annual energy use is 113.53 TJ/yr operating at 5,000 full load hours per year (Zui and Martynova, 2015).

5.4.3 Georgia.

The country has a high potential of geothermal resources, some of which has been in use since ancient times. The major areas of utilization are balneology resorts, local heating systems, the processing industry and greenhouses. No estimates were made for installed capacity and annual utilization, thus in correspondence with the authors, the following estimates are made: 13.57 MWt and 130.0 TJ/yr for individual space heating; 8.74 MWt and 83.0 TJ/yr for district heating; 20.27 MWt and 192 TJ/yr for greenhouse heating; 30.81 MWt and 290.0 TJ/yr for bathing and swimming; and 0.03 MWt and 0.16 TJ/yr for geothermal heat pumps. This gives a total for the country of 73.42 MWt and 695.16 TJ/yr with a load factor of 0.30 (Melikadze, et al., 2015).

5.4.4 Russia.

Direct use of geothermal resources is mostly developed in the Kuril-Kamchatka region, Dagestan and Drasnodar Krai, mainly for district and greenhouse heating. At present, 66 thermal water and steam-and hydrothermal fields have been exploited in the country. Approximately half of the extracted resource is used for space heating, a third for greenhouse heating and about 13% for industrial processing. There are also approximately 150 health resorts and 40 factories bottling mineral water. Heat pumps are at an early stage of development in Russia. Unfortunately, no specific data on direct-use applications was provided for this report, thus the data from WGC2010 will be utilized, assuming no changes since then. These estimates are based on personal communications with Svalova, 2010, data from Kononov and Povarov, 2005 and modified by Lund (2005). The breakdown of the various applications are: 16.5 MWt and 328 TJ/yr for individual space heating; 93.5 MWt and 1,857 TJ/yr for district heating; 160 MWt and 3,279 TJ/yr for greenhouse heating (estimated at 46.5 ha); 4 MWt and 63 TJ/yr of fish and cattle raising; 4 MWt and 69 TJ/yr for agricultural drying (wool washing, paper production and wood drying); 4 MWt and 63 TJ/yr for swimming and bathing; 25 MWt and 473 TJ/yr for industrial processing; and 1.2 MWt and 11.5 TJ/yr for geothermal heat pumps – mainly in Kamchatka, consisting of 100 units. The total for the country is then 308.2 MWt and 6,143.5 TJ/yr (Svalova and Povarov, 2015).

5.4.5 Ukraine.

No country update paper was submitted from this country. Thus, the estimates from WGC2010 will be utilized. According to a report from 2005, the direct-uses in the country included 3.5 MWt and 36.31 TJ/yr for individual space heating and 7.4 MWt and 82.5 TJ/yr for district heating, for a total of 10.9 MWt and 118.8 TJ/yr (Lund, et al., 2010).

5.5 Europe

5.5.1 Central and Eastern Europe

5.5.1.1 Albania.

Geothermal energy in the country consist mainly of low enthalpy resources. Natural springs and deep wells produced thermal water up to 65.5^{o}C. The two main uses of these low temperature resources are at wellness centers for balneology, bathing and swimming, and using geothermal heat pumps for heating and cooling. Examples of the wellness centers are Elbasani Llixha Spa located in central Albania, and Peshkopia Spa. The former is the oldest spa in the country where the springs have been used for over 2,000 years, whereas the latter is of modern construction as a balneological center. Potential uses of the geothermal heat being considered are to heat greenhouses for flowers and vegetables, for cultivation of micro-alga as spirulina, for aquaculture, and for chemical extraction such as iodine, bromine, and chlorine. Other areas of investigation include using deep abandoned oil and gas wells for extracting geothermal energy for greenhouse heating. In summary specific uses of geothermal energy include eight sites for bathing and swimming, with an installed capacity of 11.728 MWt and annual energy use of 84.33 TJ/yr; and seven locations using 138 installed geothermal heat pumps for heating and cooling, including schools and the Culture Palace and Twins Towers in Tirana with an installed capacity of 4.497 MWt and annual heating energy use of 23.26 TJ/yr. The total for the country is then: 16.225 MWt and 107.59 TJ/yr (Frasheri, 2015).

5.5.1.2 Bosnia and Herzegovina.

Early records show that the Romans used geothermal hot water in Illidža in 2400 B.C. The current direct use is implemented in 21 locations, with spas and recreation centers being the main users at 18 locations, followed by individual space heating at six locations and geothermal heat pumps being used at three spas. Two spas Kulaši and Gorni Šeher has been shut down. Of the 18 spas, six are public recreation centers where geothermal water is used only in open-air swimming pools during the summer season. Another four spas have both out-door and in-door swimming pools, the latter being open all year around. Thermal waters are used in one spa with radioactivity (Fojnica). Another spa has hyperalkaline water with pH of 11.75 (Laješljani). Individual space heating is used mainly at three spas, and with heat exchangers at six other locations. The average of this type of use is for about six months of the year, with sanitary water being heated during the entire year. There are dozens of geothermal heat pump installations in public and private facilities (health center, hotels, schools, businesses, etc.) as well as in family homes. It is estimated that there are about 100 buildings heated by geothermal heat pumps. In summary, individual space heating has an installed capacity of 9.94 MWt and 166.38 TJ/yr, bathing and swimming 12.78 MWt and 83.25 TJ/yr, and geothermal heat pumps 1.20 MWt and 2.70 TJ/yr. The total then, for the country is 23.92 MWt and 252.33 TJ/yr (Miošić, et al., 2015).

5.5.1.3 Bulgaria.

Direct-use of geothermal water in the country is for balneology, space heating and air-conditioning, greenhouse heating, ground-source heat pumps, direct thermal water supply, bottling of potable water and soft drinks and for some technological processes (oil, food and soft drinks production). The largest uses of the thermal water are for balneology and water supply, and within the former, two applications in balneology are dominant – relaxation and sanitary needs, and treatment and rehabilitation. Relaxation and sanitary needs are dominant at spa hotels located on mountain and seaside resorts. Greenhouses are currently in operation at six sites in southern Bulgaria. They cover an approximate area of 10 ha and produce vegetables and flowers for the local market. The applications of heat pumps has been growing over the past years, however, published data are lacking. These systems are used in family houses, block of flats, and office and industrial buildings in different regions of the country. GSHP use is estimated at 10.0 MWt and 47.30 TJ/yr for a capacity factor of 0.16. An innovated pilot system using CO_2 earth heat pipes has recently been installed to provide heating to an industrial building in Brani pole village. The installed capacity and annual energy use of each of the direct-use applications are: 3.3 MWt and 49.90 TJ/yr for space heating; 3.3 MWt and 49.96 TJ/yr for air conditioning; 1.65 MWt 25.45 TJ/yr for greenhouse heating; 65.69 MWt and 993.98 TJ/yr for bathing and swimming; 9.17 MWt and 57.83 TJ/yr for others (oil, food and soft drink production); and an estimated 10.0 MWt and 47.30 TJ/yr for geothermal heat pumps. The total for the country is 93.11 MWt for the installed capacity and 1,224.42 TJ/yr for the annual energy use (Bojadgieva, et al., 2015).

5.5.1.4 Croatia.

Geothermal energy in the country is mainly used in spas and recreation centers for bathing and swimming, and for space heating. There is no electricity production from geothermal energy, even though efforts are being made in this direction. There are 27 locations with direct-use development, most located in the Pannonian basin in the north eastern part of the country. Geothermal energy is also used to heat greenhouses in Bošnjaci, Krapinske Toplice and Sveta Nedjelja. Geothermal use for district heating is also reported, but no details are provided. The individual uses of geothermal energy are 31.99 MWt and 291.79 TJ/yr for individual space heating, 13.77 MWt and 8.61 TJ/yr for district heating, 7.53 MWt and 169.49 TJ/yr for greenhouse heating, 22.15 MWt and 172.1 TJ/yr for bathing and swimming, 4.50 MWt and 42.50 TJ/yr for geothermal heat pumps. The total for the country is then, 79.94 MWt and 684.49 TJ/yr (Kolbah, et al., 2015).

5.5.1.5 Czech Republic.

Thermal waters are used in spas, wellness centers and swimming pools. New thermal swimming pools are being constructed at many places. The most successful project using thermal water for balneological purposes is located at Poshlavky/Mosov in the southeastern part of the country in the Northern Vienna Basin. The most widespread use of geothermal is linked to the installation of various types of geothermal heat pumps for domestic (e. g. houses) and public use (e.g. education and administrative facilities). By the end of 2012, 46,000 heat pumps have been installed in the country of which approximately 18,000 are geothermal. All heat pumps are used mainly for domestic use (87%) providing heat capacity of 460 MWt and for public use (13%) which an installed heat capacity of 158 MWt. Larger geothermal heat pump installations are at Decin (3.28 MWt), AZ Tower in Brno (0.28 MWt) and Jeremenko water pit (0.091 MWt). Thermal water from a Svornost mine pit with considerable radon content is used for the Jachymov Spa. The three historical spas that are world-famous are Jansk Lazne with considerable radioactive elements; Karlovy Vary (Karlsbad) near Prague where the water is also used for drinking therapy; and Teplice, also with a high contact of radon. Recently developed spas include Vlke Losiny, Pasohlavky, Benesov nad Ploucnici, and Brna. No data are provided on spa and bathing energy use. Geothermal heat pumps are estimated at 300 MWt. Assuming an average COP of 3.5 and 2,200 full load operating hours per year, the annual energy use is estimated at 1,700 TJ/yr. Based on data from WGC2010, the estimated capacity for spas is 4.5 MWt with an annual energy use of 90TJ/yr. The total for the country is then 304.5 MWt and 1,790 TJ/yr (Lund, 1990 and Jirakova, et al., 2015).

5.5.1.6 Estonia.

No country update report was received from this country. Thus, the estimates from WGC2010 will be utilized. The geothermal direct-use is only for geothermal heat pumps, estimated at 4,874 units with an installed capacity of 63.0 MWt and using a COP of 3.5 and 2,200 full load operating hours annually, the use is 356 TJ/yr (Lund, et al., 2010).

5.5.1.7 Hungary.

Balneology is the earliest use of geothermal waters in the country. Hungary has world-famous spas in Budapest, Bük, Hajdúszoboszló, Harkány Héviz, Sárvár and Zalakaros. A total of 295 thermal wells and 132 natural springs produce water for sport and therapeutic purposes. In Hungary there are more than 70 ha of greenhouses and more than 250 ha of soil-heating plastic tents which use thermal waters. There are more than 50 examples of chicken, turkey, calf, pig and snail farms which use thermal water heating for their animal husbandry. In addition, there are 10 fish ponds near Szarvas and Györ which use low-temperature geothermal water to heat their ponds. Geothermal district heating began near balneology centers. These early examples include the Budapest Zoo and some apartment houses. In the late 1950s district heating projects were started in southeast Hungary. 23 locations use thermal waters for space and district heating. Hungary's largest operation geothermal-based district heating systems, fed 100% by geothermal, started daily operation in January 1, 2011 in Szentlörinc (SW-Hungary). It features an 1,800 m-deep well, with an outflow temperature of 87^{o}C and maximum yield of 25 l/s, coupled with a reinjection well. The heat capacity is 3 MWt, and the demand is 22,000 to 60,000 GJ. Of special interest are the two "super wells" in Miskolc-Mályi, a PannErgy Plc project. This project is the first "large-scale" project in Hungary, where geothermal-based district –heating system will feed several hundred apartments in the Avas housing estate in Miskolc, Hungary second largest city. The heat capacity is 55 MWt and the heat demand is 695,000 to 1,100,000 GJ. Geothermal water has also been used in secondary oil production since 1969. A total of 88 wells are used to produce thermal and drinking water, since the shallow aquifers are contaminated. Shallow geothermal using heat pumps has increased considerably from 2000 to 2010, but has stopped since due to the economic crises. The estimated number of installed units is more than 4,000. The typical size range for residential use is 10 to 14 kW. The installed capacity and annual energy use for the various applications are: 33.02 MWt and 326.05 TJ/yr for individual space heating, 153.56 MWt and 1,700.26 TJ/yr for district heating, 271 MWt and 3,024.12 TJ/yr for greenhouse heating, 6 MWt and 61.51TJ/yr for fish farming, 4 MWt and 31.34 TJ/yr for animal farming, 25 MWt and 297.13 TJ/yr for agricultural drying, 19 MWt and 220.62 TJ/yr for industrial process heat, 352 MWt and 3,912.03 TJ/yr for bathing and swimming, and 42 MWt and 695 TJ/yr for geothermal heat pumps. The total for the country is then 905.58 MWt and 10,268.06 TJ/yr (Toth, 2015).

5.5.1.8 Latvia.

No country update paper was submitted from this country. Thus, the estimates from WGC2010 will be utilized. The following uses were reported in 2005: 0.53 MWt and 9.50 TJ/yr for balneology; 0.23 MWt and 6.44 TJ/yr for fish farming; 0.38 MWt and 8.90 TJ/yr for individual space heating; 0.17 MWt and 4.75 TJ/yr for district heating; and 0.321 MWt and 2.22 TJ/yr for geothermal heat pumps (10 units installed). The total for the country is then 1.631 MWt and 31.81 TJ/yr (Lund, et al., 2010).

5.5.1.9 Lithuania.

The use of geothermal energy for district heating started in Klaipeda in 2000 on the Baltic coast. The absorption heat pumps use a lithium bromide solution. Low-temperature geothermal heat is extracted from water in the Devonian aquifer. The plant operating capacity is given as 35 MWt of which 13.6 MWt is from geothermal (installed geothermal capacity is 18 MWt). The plant is still solving difficulties with injection and struggling with the market – as it only operates during the heating season. The number of small-scale ground-source heat pumps in the country is growing. At present there are 5,500 installations, mainly by private companies. New construction of the logistics Center "Wurth Lithuania" included a 140 kW heating and cooling system using heat pumps. The installed capacity of small scale heat pumps is 76.6 MWt and annual energy use of 678.8 TJ/yr, and for the Klaipeda plant 18 MWt and 34.1 TJ/yr for a total of 94.6 MWt and 712.9 TJ/yr (Zinevicius, et al., 2015).

5.5.1.10 Macedonia.

The utilization of thermal waters in the country consists of seven geothermal projects and six spas. In Istibanja (Vinica) 6 ha of greenhouses are heated with geothermal energy and peaked with heavy oil boilers. Funded by Austrian and Dutch grants the greenhouse produces roses for export. At Kocani (Podlog), the largest geothermal project in the country, "Geoterma", consists of 18 ha of greenhouses and space heating of public buildings in the center of town. The paper industry, vehicle parts industry and rice drying projects have been shut down. At Bansko the "Strumica" project has been shut down, however, one company is heating greenhouses, and providing heat to the hotel Car Samuil, and the rest house/rehabilitation facility for children Spiro Zakov. At Smokvica (Gevhelija) formerly the largest geothermal system in the country, now provides heat to 10 ha of greenhouse of which 6 ha are glass houses, and 4 ha are plastic house. At Negorci (Gevgelija) spa, reconstruction of the heating system has been completed and now all the hotel and therapeutic facilities are heated with geothermal energy. Ground-source heat pumps are becoming more popular, with the current estimate of 200 units in operation. The current installed capacity for individual space heating is 0.84 MWt and annual energy use of 6.6 TJ/yr, for district heating 42.55 MWt and 518.37 TJ/yr, for greenhouse heating 2.79 MWt and 61.14 TJ/yr and for geothermal heat pumps 2.50 MWt and 15.0 TJ/yr. The total for the country is then 48.68 MWt and 601.11 TJ/yr (Popovsak-Vasilevska and Armenski, 2015).

5.5.1.11 Poland.

During 2010-2014 geothermal energy was used in several localities mainly for heating, bathing and swimming and the use of geothermal heat pumps. Over the past five year the total installed geothermal capacity and heat sales have increased, resulting mainly from additional heat sales in the Podhale region, relaunch of a plant in Stargard Szczecinski, opening of a new heating plant in Poddebice and additional geothermal heat pump installations. Six geothermal district heating plants are operational: in the Podhale region (since 1994), in Pyrzyce (since 1996), in Mszczonow (since 1999), in Uniejow (since 2001), in Stargard Szczecinski (since 2012, re-opened after closure in 2008), and in Poddebice (since 2013). Geothermal bathing and swimming facilities are available at eleven health resorts. Many of them have a long history of use while three recent ones just received formal health resort status. The geothermal heat pump sector has been characterized by a very moderate growth for many years, but has increased in recent years. The number of geothermal heat pumps (water/water, water/brine, horizontal and vertical closed loop) is estimated at least at 35,000 units. The largest installation in the country is at Szczecin municipality with an installed capacity of 2.6 MWt consisting of 240 vertical bore holes each at 52 m depth. The number of applications with the installed capacity and annual energy use are: 5.0 MWt and 60 TJ/yr for individual space heating; 82.2 MWt and 573.0 TJ/yr for district heating; 0.3 MWt and 0.5 TJ/yr for industrial process heat; 1.00 MWt and 8.7 TJ/yr for snow melting; 10.34 MWt and 100.4 TJ/yr for bathing and swimming; and at least 390 MWt and 2,000 TJ/yr for geothermal heat pumps. This gives a total for the country of 488.84 MWt and 2,742.6 TJ/yr (Kepinska, 2015).

5.5.1.12 Romania.

Due to economic difficulties, only a few new geothermal projects were completed during the last five years. New projects are a district heating system using open loop heat pumps, and one geothermal project for bathing and swimming. Also, some existing district systems were expanded. Some greenhouses have been closed during this period. The main direct uses of geothermal heat in the country are for district heating and individual space heating, and health and recreational bathing. In a few places geothermal energy is also used for greenhouse heating (about 10 ha), fish farming (a few farms), industrial processing, and drying. In areas where the available wellhead temperature is low, the geothermal water is only used for health and recreational bathing (i.e. Felix spa), or for fish farming, depending upon the chemical composition of the fluid. Higher temperatures and in larger communities, geothermal water is first used for district heating, some industrial processes, and then part of the depleted water used for bathing and/or fish farming, the rest being reinjected. The market for ground-source heat pumps began in the late 1990s, and is now developing quite well. There are over 2,000 large borehole heat exchangers ranging from 70 to 125 m in depth. Many of these applications are open loop systems requiring large water flows that are not always available. Thus, in the last few years the larger applications are using closed loop systems that are more common for commercial buildings. Since there is no central authority keeping track of geothermal heat pump installations, based on limited information, the estimated installed capacity is about 40 MWt and the annual energy use is 140 GWh (480 TJ/yr). The installed capacity and annual energy use for the various applications are: 29.63 MWt and 207.28 TJ/yr for individual space heating; 78.31 MWt and 616.17 TJ/y for district heating; 15.69 MWt and 80.49 TJ/yr of greenhouse heating; 4.78 MWt and 9.50 TJ/yr for fish farming; 6.32 MWt and 12.70 TJ/yr for agricultural drying; 3.75 MWt and 6.84 TJ/yr for industrial process heat; 66.65 MWt and 492.34 TJ/yr for bathing and swimming. The total for the country including geothermal heat pumps is then 245.13 MWt and 1,905.32 TJ/yr (Bendea, et al., 2015).

5.5.1.13 Serbia.

The commonest use of geothermal energy in the country is the traditional ones: balneology and recreation. Today, there are 59 spas in Serbia that use thermal water for balneology, sport and recreation. Geothermal energy is also used for space heating as well as for agriculture and industrial processes, but only on a limited scale. In Vranjsak Spa thermal waters with temperature of 96^{o}C have been used for 40 years for heating the rehabilitation center through a heat exchanger, and then for heating greenhouses where flowers are grown, downstream of the spa. A large hotel and rehabilitation center with a swimming pool is heated with thermal water in Kursumlijska Spa. In Niska Spa, heat pumps with a capacity of 6 MWt use 25^{o}C water for heating the rehabilitation center. Thermal waters are used at the Sijarinska Spa for heating the hotel and recreation center. At the Ribarsak Spa thermal water at 44^{o}C are passed through a heat exchanger from a well heating the rehabilitation center, and a second well at 48^{o}C is used for balneotherapy. Thermal water at Lukovska Spa is used for heating the hotel and for balneotherapy. A project has been completed for geothermal direct use at Debrc for drying wheat and other cereals, and for space heating. Many other geothermal projects are either in the planning stages or under construction. In 1990, due to the economic and political situation in the country the development of geothermal projects has been curtailed with many of them closed. However, after the year 2000, there has been renewed interest in direct-use geothermal projects in the country. The current utilization of geothermal energy by category in terms of installed capacity and annual energy use are: 32.899 MWt and 525.385 TJ/yr for district heating (21 locations); 12.850 MWt and 191.209 TJ/yr for greenhouse heating (7 locations); 1.653 MWt and 22.924 TJ/yr for fish farming (1 location); 3.947 MWt and 85.854 TJ/yr for animal farming (3 locations); 0.967 MWt and 26.868 TJ/yr for agricultural drying (1 location); 52.238 MWt and 861.759 TJ/yr for bathing and swimming (59 locations), and 11.090 MWt and 88.479 TJ/yr for geothermal heat pumps (715 installed units ranging from 10 to 40 kW – vertical (2 %) and water-source units (98%)). The total for the country is then, 115.644 MWt and 1802.478 TJ/yr (Oudech and Djokic, 2015).

5.5.1.14 Slovak Republic.

Geothermal wells are located mostly in the intra-mountain depressions or in lowlands bordering the Slovak territory in its southern part. Today, 27 hydrogeothermal areas or structures have been identified in the country. Geothermal waters were proved by 171 geothermal wells with depths of 9 to 3,616 meters. Three new wells were drilled and put into operation in the last five years. The first geothermal district heating plant with a capacity of 8 MWt was put on line in Galanta in 1996. Geothermal waters are also widely used for recreational purposes, mostly in very popular aquaparks in many places in Slovakia. A total of 38 localities use geothermal water for recreational purposes, mainly in swimming pools. Space heating, greenhouses and fish farming also use geothermal waters in the country. Geothermal waters in Sered and Sals are used for district heating, waters in Besenova and Vyhe for bathing, and for greenhouse heating in Nesvady. Other uses include heating of hotels, sport hall, and in Novaky-Kos it is utilized for heating of miner’s dressing rooms and air heating in the brown coal mine. A total of 61 locations throughout the country use geothermal water for heating. The individual applications for installed capacity and annual energy use include: 16.6 MWt and 367.1 TJ/yr of individual space heating, 16.2 MWt and 198.1 TJ/yr for district heating, 15.4 MWt and 224.7 TJ/yr of greenhouse heating, 11.9 MWt and 271.0 TJ/yr for fish farming, 87.7 MWt and 1,395.2 TJ/yr for bathing and swimming, and 1.6 MWt and 13.5 TJ/yr for geothermal heat pumps. The total for the country is then 149.4 MWt and 2,469.6 TJ/yr (Fendek and Fendekova, 2015).

5.5.1.15 Slovenia.

In the country, geothermal energy is estimated to currently supply direct heat uses and geothermal (ground-source) heat pumps (GSHP). Space heating is implemented in 19 locations, predominately at thermal spas and resorts using heat exchangers (e.g. Moravske, Toplice, Banovci, and Terme Lendava), or geothermal heat pumps (e.g. Cerkno, Hotel Diana in Murska Sobota). During the last five years space heating with geothermal energy was introduced at several localities: Radenci, Mala Nedelja, Ptuj, Maribor, Bled and at Dobova (Paradiso). The heating of domestic (sanitary) hot water is included at nine locations. There are 18 thermal spas and health resorts, and an additional nine recreation centers (four of which are part of a hotel), where swimming pools with a surface area of about 45,500 m^2 and volume of 61,200 m^3 are heated by geothermal water directly or indirectly through heat exchangers or geothermal heat pumps. There are three geothermal district heating systems in the country. In Murska Sobota the residential area (300 flats with 16,000 m^2) and a new theater are heated geothermally. In Lendava a large number of public buildings (mainly schools) and blocks of flats are heated under a private authority. District heating on a small scale is used in the village Benedikt where a few public buildings (50,000 m^2) have been heated since 2010. Sidewalk snow melting has recently been installed in Lendava. Air conditioning (cooling) of hotel spaces using geothermal is reported at three locations. A total of 13.5 ha of greenhouses at four locations are heated with geothermal energy. Tomatoes, orchids, exotic fruit are grown in these houses. The industrial use at Vrhnika by the Leather Industry Co. went into bankruptcy and is no longer in operation. The various uses of geothermal energy are: 27.0 MWt and 297.2 TJ/yr of individual space heating, 3.72 MWt and 23.5 TJ/yr for district heating, 1.57 MWt and 23.1 TJ/yr for air conditioning, 15.7 MWt and 130.3 TJ/yr for greenhouse heating. 0.03 MWt and 0.23 TJ/yr for snow melting, 17.3 MWt and 140.1 TJ/yr for bathing and swimming, other uses of 1.43 MWt and 21.5 TJ/yr (heating of sanitary hot water), 0.36 MWt for industrial installed capacity, however, since the plant is not operating, there is no annual energy use, and geothermal heat pumps of 85.64 MWt and 501.3 TJ/yr for geothermal heat pumps. The total for the country is then 152.75 MWt and 1,137.23 TJ/yr (Rajver, et al., 2015).

5.5.2 Western Europe

5.5.2.1 Austria.

Balneology use of thermal water has a very long tradition in Austria dating back to the Roman times (e.g. Baden west of Vienna, Warmbad Villach, federal county Carinthia, and Bad Gastein, federal county Salzburg). At these locations natural warm springs are utilized, with the highest temperature of 47°C at Bad Gastein. In the 1970s some abandoned oil exploration wells were used for the production of thermal waters that were used at the spa resorts Loipersdorf and Waltersdorf in the Styrian Basin. The economic success of these resorts boosted several exploration and drilling projects. Today a total of 27 spas are based on successful geothermal drillings, which were built after 1970 and represent a major economic factor in the region. Geothermal district heating projects are operating at nine locations in the country: Altheim, Geinberg, Simbach on the Inn/Braunau on the Inn, Obernberg, St. Martin on the Innkreis, Ried on the Innkreis, Haag on the Hausruck, Bad Blumau and Bad Waltersdorf. In addition, there are geothermal greenhouse projects and industrial operations at Geinberg. In the period of 2010 to 2014, five deep geothermal boreholes were drilled for a total length of 15.6 km. A district heating scheme was established at Ried on the InnKreis in Upper Austrian Molasse Basin. Ground-source heat pumps have shown a steady increase since 2010. The number of units based on DHE is estimated at 70,000 having a capacity of 840 MWt and 4,990 TJ/yr. The total installed capacity for district heating is 50.4 MWt and the annually energy use is 1,255 TJ/yr; for greenhouse heating 1.8 MWt and 29 TJ/yr; for bathing and swimming 10 MWt and 247 TJ/yr; and for industrial 1.2 MWt and 17.0 TJ/yr, for a total, including heat pumps, of 903.4 MWt and 6,538 TJ/yr (Goldbrunner, 2015).

5.5.2.2 Belgium.

In general, geothermal energy has been growing slowly in Belgium over the last five years, mainly in the form of geothermal heat pumps or ground-source heat pumps (GSHP). However, shallow geothermal installations have been increasing at a faster rate than deep geothermal energy. Shallow geothermal installation development is expected to grow more rapidly as energy obligations for new buildings and renovations are steadily strengthened. In addition, a minimal share of renewable energy use is obligated to start in 2014. Differences in deep geothermal development between the regions, depends on the geological situations, but also on the legislative and regulatory environment. GSHP comprise by far the greatest proportion of geothermal applications in Belgium. Many new medium to large building in the public sector are now equipped with GSHP. The total number of GSHP is expected to increase from 13,085 in 2010 to 22,613 in 2015, with total installed capacity increasing from 157 MWt to 198.7 MWt and annual energy use is now 756.4 TJ/yr. The majority (estimated at 80%) of applications are Borehole Thermal Energy Storage Systems (BTES), and only 5% Aquifer Thermal Energy Storage (ATES), and the remaining 15% horizontal loop systems. Geothermal water is used directly in several district heating systems and for waste water treatment as part of heat cascading system. For district heating the installed capacity is 7.526 MWt and the annual energy use 94.987 TJ/yr; and for waste water treatment 0.581 MWt and 12.977 TJ/yr. The total for the country including GSHP is 206.8 MWt and 864.4 TJ/yr (Loveless, et al., 2015).

5.5.2.3 Denmark.

The country has three geothermal plants with deep wells producing heat for district heating. Other projects are at different levels of maturation. The first geothermal heating plant started production in Thisted in 1984 and now has a capacity of 7 MWt (75 TJ/yr) from 43°C saline water from the Gassum reservoir at 1.25 km depth. A plant in Copenhagen at 14 MWt (180 TJ/yr) operating from 74°C saline water from a well at 2.6 km depth started production in 2005 from the Bunter Sandstone reservoir. The latest plant, at up to 12 MWt (100 TJ/yr) using 48°C saline Gassum formation water from 1.2 km depth, started production at Sønderborg in 2013. The plants have one production and one injection well producing heat from the sandstone reservoirs through heat exchanger and/or Lithium-bromine based absorption heat pumps. The driving heat primarily comes from biomass boilers for heat and/or combined heat and power production. Shallow geothermal is mainly used for domestic heating via arrays of closed loops about one meter depth in combination with heat pumps. Closed loop boreholes to around 150 m depth are also beginning to be used for domestic heating, both for single houses, for smaller collective networks, and for heating large office buildings. Borehole Thermal Energy Storage (BTES) for seasonal storage of heat is applied in a test plant at the district heating network in Brædstrup. Few installations use a groundwater aquifer for heating, cooling or seasonal storage (ATES). The number of small ground source heat pumps extracting shallow geothermal heat has been assessed to around 27,000 with an installed capacity of 320 MWt and annual energy use of 3,400 TJ/yr. The total for the country is then 353 MWt and 3,755 TJ/yr (Røgen, et al., 2015).

5.5.2.4 Finland.

No country update paper was received from this country, thus the geothermal direct-use is estimated from a paper presented at the European Geothermal Congress 2013, and then extrapolated to 2015 (Kallio, 2013). Finland has had a large growth in the number of heat pump installed starting from 2005 with less than 100,000 to 540,000 in 2013. The strongest growth has taken place in air-source heat pumps, but geothermal heat pumps have had a large increase with a record 72% in 2012. Today over half of new residences utilize heat pump technology and an increasing number of office buildings and shopping center are using geothermal heat pumps for heating and cooling. There is a clear trend toward large geothermal heat pumps installations, but still domestic installation are the fastest growing market with >50% of new residences using these systems. The largest installation is in the Logistics Center in the southern part of Finland with 150 bore-hole heat exchangers, each 300 m deep (total 45,000 m). This energy field/installation has been provided by an advanced real-time fiber optic monitoring system designed by the Geological Survey of Finland GTK. There were 90,000 geothermal heat pump units in operation by the end of 2012 and 130,000 units projected by 2015. Approximately 13,000 new units were installed in 2012. By 2015 the expected investment in shallow geothermal heat pump system will be 1,000 million Euros (1,250 million US$). The number of full load hours annually is estimated at 3,340 with an average COP of 3.0. For 2015 the estimated production will be 4.0 to 5.0 TWhr/year (14,400 to 18,000 TJ/yr), with an installed capacity of 1,560 MWt (using an average unit size of 12.0 kW). Using a capacity factor of 3,340/8760 = 0.38, the estimated production is around 18,000 TJ/yr.

5.5.2.5 France.

Geothermal energy has been used in the country for a variety of applications over a long period, especially since the two 1970s oil crises. Many geothermal direct-use applications have been commissioned since 1961, and most of the wells drilled in the early 1980s, especially in the Paris sedimentary basin and in Aquitaine. There has been renewed interest in direct-use applications since 2007 in the Paris basin. The development of ground-source heat pumps is a more recent effort, but is still weak; however, the market for heating office buildings and collective public housing is flourishing. The total number of geothermal heat pump units installed is estimate at 163,000 with an average size of 12.33 kW. The use of geothermal heat is expected to increase six-fold between 2006 and 2020, thanks to the use of ground-source heat pumps as well as geothermal district heating. The development of geothermal heat projects has been boosted by the implementation of a renewable heat fund. The new fund, created in 2009, aims at increasing the number of projects using renewable energy for industry, collective housing and commercial buildings, with about €1.2 billion allocated to cover all renewable energies for the 2009-2013 period. In the Paris basin 37 doublets or triplets comprising 50 plants for district heating are operating in the Dogger aquifer, with an installed thermal power of 278.5 MWt, and annual energy use of 4311.8 TJ/yr. Some also supply heat to greenhouses and fish farms. New geothermal direct-use operations have been realized in the Paris basin since 2007, such as a new doublet for converting the district heating of the Orly Parisian airport to renewable energy, producing 36 GWh per year. In other basins such as Aquitain, Auvergne, Centre, Languedoc, and Lorraine, 16.7 MWt and 137.6 TJ/yr are utilized for bathing and swimming, 18.4 MWt and 183.4 TJ/yr for fish farming, 5.8 MWt and 53.5 TJ/yr of district heating, 8.2 MWt and 123.4 TJ/yr of greenhouse heating, and 9.5 MWt and 157.2 TJ/yr for individual space heating for a total of 58.6 MWt and 655.1 TJ/yr for these areas. The total for direct use is all of France by individual application are: 2,010 MWt and 10,900 TJ/yr for geothermal heat pumps; 9.5 MWt and 157.2 TJ/y for individual space heating; 284.1 MWt and 4,365.4 kJ/yr of district heating; 8.2 MWt and 123.4 TJ/yr for greenhouse heating; 18.4 MWt and 183.4 TJ/yr for fish farming and 16.7 MWt and 137.6 TJ/yr for bathing and swimming. The total for the country is 2,346.9 MWt and 15,867 TJ/yr (Vernier, et al., 2015).

5.5.2.6 Germany.

The most common deep geothermal utilization in the country using thermal water with temperatures over 20°C from wells over 400 m depth are district heating plants or combined heat and power plant (CHP), thermal spas and space heating. District heating systems typically use doublets for the production and injection well, while spas usually use a single well. Three deep borehole heat exchangers are in operation in the country at Arnsberg (Nordrhein-Westphalen) with a total depth of 2,835 m for heating a spa; at Prenzlau (Brandenburg) 2,786 m, used for district heating; and at Heubach (Hessen) providing heat for industry at a depth of 773 m. In 2014, the total installed capacity – which includes auxiliary heat sources such as peak load boilers in addition to the geothermal sources – reached about 650 MWt of which the geothermal share is 258.6 MWt. The 19 district heating and combine plants (not including deep borehole heat exchangers) accounted for the largest portion of the total geothermal capacity at about 208 MWt. All together, the installed capacity of the deep geothermal heat uses in the country shows a considerable increased from about 160 MWt in 2010 to 260 MWt in 2014. Heat production by deep geothermal utilization rose from 716 GWh to 925 GWh for the same period. Heat pumps for heating and cooling of residential houses and office buildings are widespread in the country. Common systems are horizontal heat collectors or borehole heat exchangers (brine/water systems), and groundwater systems with extraction and injection well(s) (water/water systems). Direct expansion heat pumps with horizontal collectors and heat pipes used as borehole heat exchangers have their small market niche. The use of foundation piles or other concrete building parts in contact with the ground as heat exchangers (“energy piles”) is increasing in areas with poor subsoil stability. Typical installed capacities of heat pumps used in residential houses are about 10 kW for brine/water and about 14 kW for water/water systems. Heat pump systems in office buildings reach capacities of several 100 kW. The largest heat pump installation in the country is running in an office building in Duisburg and has a heating capacity of over 1.0 MWt. There are 21 large geothermal heat pump systems installed in the country. The total number of heat pumps of all types (including air-source units) reached about 555,000 in 2013 and produced around 7.5 TWh of renewable heat. Brine/water systems are about 85% of those installed. In summary, there is 3.4 MWt capacity and 20.8 TJ/yr energy use for individual space heating; 208.1 MWt and 1,909.4 TJ/yr for district heating; 47.1 MWt and 1,401.1 TJ/yr for bathing and swimming, 2,590.0 MWt and 16,200 TJ/yr for geothermal heat pumps. This gives a total of 2,848.6 MWt and 19,531.3 TJ/yr for the country (Weber, et al., 2015).

5.5.2.7 Greece.

High enthalpy geothermal resource appears to be confined in the active South Aegean volcanic arc, with a proven potential exceeding 250 MWe in the islands of Milos and Nisyros. Low enthalpy geothermal fields (<100^{o}C) are numerous in Greece, most of which are located in the basins in Northern Greece, as well as in many of the Aegean Islands. Present data indicate that the proven low enthalpy in the country exceeds 100 MWt. A small share of this potential is currently exploited mainly for greenhouse heating and balneological uses. The total installed capacity of direct-use applications is over 220 MWt, exhibiting a modest increase of 65% over data present at WGC2010. Geothermal heat pumps exhibit the largest share (>65% of the installed capacity), followed by bathing and swimming and greenhouse heating. Direct applications (without GHPs) remained rather static over the past few years; however there were some new facilities, while others were closed, mostly for reason unrelated to geothermal energy. On the other hand, ground-source heat pumps were being installed at a 25% average annual growth rate over the past five years, with over 850 installations recorded in the country: 61% are open loop, 30% closed vertical loop, and 9% closed horizontal loop systems. Open-loop geothermal heat pump systems are used for soil heating for off-season asparagus cultivation, now exceeding 20 ha. The majority of greenhouses are located in the north of the country and about 70% are glass covered. Currently, there are 26 greenhouse heating units using geothermal energy covering about 25.6 ha. Tomatoes, sweet peppers, and cucumbers appear to be the main crops, with cut flowers and potted plants also being raised. Two spa facilities (Traianoupolis in Trace and Nea Appolonia close to Thessaloniki) are heated with low enthalpy geothermal water. Space heating is also provided to a hotel in Milos. A novel tomato dehydration plant started operation in 2001 near Neo Erasmio where more than 140 tonnes of "sun dried" tomatoes have been produced. Geothermal aquaculture projects have been in place in Greece since the late 1990s and include the heating of fish wintering ponds (Mediterranean seabass and gilt-head sea bream) and the cultivation of spirulina in raceways. More than 60 spas and bathing centers in the country use thermal waters for both therapeutic purposes and/or for recreation. There are also more than 25 outdoor swimming pools using geothermal water. Current installations include 1.65 MWt and 17.8 TJ/yr for individual space heating, 33.93 MWt and 335 TJ/yr of greenhouse heating, 7.62 MWt and 59.8 TJ/yr for fish farming, 0.28 MWt and 1.79 TJ/yr of agricultural drying, 43 MWt and 260 TJ/yr for bathing and swimming, 0.4 MWt and 4.06 TJ/yr for other uses, 135 MWt and 648 TJ/yr for geothermal heat pumps, producing a combined total for the country of 221.88 MWt and 1,326.45 TJ/yr (Andritsos, et al., 2015).

5.5.2.8 Iceland.

Utilization of geothermal energy has played a major role in the energy supply of the country for many years. The country's geological characteristics related to its location on the Mid-Atlantic Ridge have endowed the country with an abundant supply of geothermal resources. The share of geothermal energy in the primary energy supply of Iceland is about 68%. The utilization of geothermal water for house heating and other direct uses started early in the twentieth century. Space heating is by far the most important direct utilization, covering 90% of all energy used for house heating in the country. Other sectors of direct use are for swimming pools, snow melting, industrial applications, greenhouse heating and fish farming. About 30 separate geothermal district heating systems are operated in towns and villages in the country and additionally some 200 small systems in rural areas. These smaller systems supply hot water to individual farms or group of farms as well as summerhouses, greenhouses and other uses. The Reykjavik district heating system is the largest in the country, serving over 200,000 people or about 67% of the Icelandic population, and about 100% of the population of the city. There are about 175 swimming pools in the country of which 150 are geothermally heated. Most of the pools are open all year, and serve recreational purposes and for swimming lessons. Many are located outdoors. Geothermal snow melting covers around 1,200,000 m^2, mostly in the capital city. The largest industrial use of geothermal heat is the seaweed drying plant Thorverk, located in west Iceland. Other industrial applications include heat to produce salt from the ocean. Commercial liquid carbon dioxide is produced from the Heidarendi geothermal field. Geothermal energy has been used for about 35 years for drying fish. CO_2 emissions from a power plant are used to produce methanol to blend with gasoline to fuel cars. Geothermal heating of greenhouses started in 1924, which today, covered about 194,000 m^2, including glass houses and plastic tunnels. Fish farming produces about 7,000 tons annually on 70 fish farms, mainly arctic char and salmon. Geothermal heat pumps are used mainly in Akureyri to supplement the district heating system in northern Iceland. The summary of the various direct-use applications are for installed capacity and annual energy use are: district heating of 1,515 MWt and 29,400 TJ/yr; greenhouse heating of 45 MWt and 660 TJ/yr; fish farming of 85 MWt and 2,230 TJ/yr; industrial process heat of 70 MWt and 910 TJ/yr; snow melting of 195 MWt and 1,900 TJ/yr; bathing and swimming of 90 MWt and 1,600 TJ/yr; and geothermal heat pumps of 5 MWt and 17 TJ/yr. The total for the country is then 2,040 MWt and 26,717 TJ/yr (Ragnarsson, 2015).

5.5.2.9 Ireland.

Geothermal energy in the country is dominated by using low temperature resources for space heating with geothermal heat pumps. The slow but steady increase in the number of heat pump units installed accounts from 177 MWt installed in the last five years. The recent difficult economic situation and the end of the dedicated financial support for domestic ground source heat pumps has resulted in fewer systems being installed during this period, with the main deployment due to large scale open and closed loop ground source systems with individual capacities of up to 2.0 MWt in size. Since the initial exploration drilling in the southern margin of the Dublin Basin, the deep geothermal energy sector has progressed very slowly. Despite encouraging results from 2D seismic reflection surveys at the Newcastle project and planning for the first deep geothermal electricity plant being granted in late 2010, the lack of subsidies and holdup of the implementation of legislative framework for licensing deep geothermal resources exploration and development has stalled this work. The current installed capacity for geothermal heat pumps is 265.54 MWt and annual energy use of 1,240.54 TJ/yr. The majority of this is from individual space heating, but some is used for air conditioning (3%) and for bathing and swimming (<1%) (Pasquali, et al., 2015).

5.5.2.10 Italy.

Utilization of geothermal resources in Italy for direct application dates back to prehistoric times and developed intensively during the Roman Antiquity (3rd B.C. to 5th A.D.). It declined notable from the 6th through the 12th centuries A.D., but started to grow again from the 13th century onward, reaching a peak in the early 20th century with the production of boron compounds at Lardarello. In this period of over 3,000 years, the most intensive development of geothermal direct-use was for thermal balneology during the Roman period and from 1850 to 1920 for the exploitation of hydrothermal materials. From 1950 through 2000, almost

325 MWt of direct uses were installed in Italy with spa use and thermal balneology as the major applications. After 2000, other direct uses, especially ground-source heat pumps, stared to grow. Today, not considering geothermal heat pumps, space heating is the main direct-use application counting for about 41% of the energy use. This is followed by bathing and swimming at 32% and aquaculture at 19%. Heat pumps will continue to be the main growth for direct-use. The current uses in terms of installed capacity and annual energy use are: individual space heating at 67 MWt and 517 TJ/yr, district heating at 68 MWt and 589 TJ/yr, greenhouse heating at 69 MWt and 574 TJ/yr, fish farming at 121 MWt and 1932 TJ/yr, industrial process heat at 14 MWt and 107 TJ/yr, bathing and swimming at 418 MWt and 3,463 TJ/yr, and geothermal heat pumps at 257 MWt and 1500 TJ/yr, for a total of 1,014 MWt and 8,682 TJ/yr (Conti, et al., 2015).

5.5.2.11 Netherlands.

The first use of geothermal energy in the country started in the early 1980s with shallow geothermal applications. Initially, the objective was cooling and seasonal storage of energy for space heating in winter. The focus in the 1980s was on larger scale applications (buildings such as offices rather than individual homes), and that in the Netherlands shallow aquifers can be found almost everywhere, many new utility buildings started using groundwater wells to store and extract thermal energy. The first attempt to develop deep geothermal energy in the period 1980 – 2000 was basically both unsuccessful and costly. At the beginning of this century the setting started to change. Heat and cold storage applications and the rate of implementation increased spectacularly – even with modest government support. The renewed interest led to the implementation of the first deep projects, mostly for the heat demand of greenhouses. By the end of 2013, geothermal development is still in a fairly early development state, though heat and cold storage is thought to be a mature technology. In 2013 these system supplied 830 GWh and the nine deep geothermal plants supplied 268 GWh. In 2014 four new deep geothermal doublets were in the process of drilling, testing, and/or starting production. Today, there are a total of 2,300 geothermal heat pump units in operation operating 2,000 full load hours annually. The uses of geothermal energy by category in the country are: 100 MWt and 1,426 TJ/yr for greenhouse heating; and 690 MWt and 5,000 TJ/yr for geothermal heat pumps. Thus, the total for the country is 790 MWt and 6,426 TJ/yr (van Heekeren and Bakema, 2015).

5.5.2.12 Norway.

The major geothermal activity in Norway is the utilization of geothermal heat pumps (GHP). In Norway, the main uses of energy in households, is for space heating. Depending on winter temperatures, the proportion of energy used for heating varies from 40 to 50 percent of a household’s stationary energy consumption. One of the major sources of increased energy efficiency in household space heating in recent times is the increased use of heat pumps during the last decade. Now, over a quarter of Norwegian households own a heat pump, approximately 90% of which are air-to-air systems. Of the geothermal heat pumps, more than 90% utilize energy from boreholes in crystalline rocks by use of borehole heat exchangers (BHE). The Norwegian standard system is a 50 to 350 m deep borehole of 115 mm (casing 139 mm) diameter with a single 40 mm U-tube installed. Most of the BHE are kept open without grouting. There is a trend towards deeper BHEs consisting of a 500 m deep single U-tube which have been successful in delivering heat since 2011. Some of the BHE fields established recently have boreholes of 300 m depth. There has been an increase in GHP for larger buildings after a new building code with strict requirements for energy efficiency was introduced in 2007 and revised in 2010. There are 17 large GHP systems installed in the country. These new energy performance requirements are expected to cut the need for energy for heating purposes by around 25%. Some locations in Norway utilize groundwater resources in superficial deposits. The largest underground thermal energy storage system (UTES) in Norway is at the Oslo’s Gardermoen international airport. This UTES system has been in operation since the airport opened in 1998 and comprises an 8 MW heat pump, coupled to 18 wells at 45 m depth, nine for extraction of groundwater and nine for re-injection. All these systems use ground or groundwater temperatures in the 6 to 8°C range. The total installed capacity for GHPs is 1,300 MWt and an annual energy use of 8,260 TJ/yr (Midttømme et al., 2015).

5.5.2.13 Portugal.

Direct-use applications on the Mainland and Azores are restricted to small district heating operations, greenhouse heating and many balneological applications located near existing hot springs. Two main district heating systems are found on the mainland, at Chaves in northern Portugal and at S. Pedro do Sul in central Portugal. The former consists of swimming pools, two hotels and the Thermal Bath. They use a well of 100 m depth and temperature of 70°C. The latter site is the main Portuguese spa along with the heating to two hotels and room in the spa using 69°C water. Only a single greenhouse facility is still in operation at S. Pedro do Sul (Vau) in the central mainland. This operation produces tropical fruits (mainly pineapples). The greenhouse operation at S. Miguel, Azores operated by the INOVA Institute is no longer in operation. About 24 baths/spas are in operations, which are quite popular for health, well-being and touristic purposes. New investigations are being carried out for future development of spas in the Azores. A small number of ground-source heat pumps have been installed, of which 13 are registered. Larger uses include at the Superior School of Technology of Setubal, the GROUNDMED installations for offices and laboratories in Coimbra city, and a third system is installed in Sines Tecnopolo - Business Innovation Center at Sines City. A summary of the individual applications for installed capacity and annual energy use include: 4.90 MWt and 95.3 TJ/yr for district heating; 1.00 MWt and 12.4 TJ/yr for greenhouse heating; 14.3 MWt and 280.5 TJ/yr for bathing and swimming; and an estimated 15.0 MWt and 90 TJ/yr for geothermal heat pumps. This gives a total of 35.2 MWt and 478.2 TJ/yr for the entire country (Carvalho, et al., 2015).

5.5.2.14 Spain.

The country has been slow in developing their geothermal potential. To date the only geothermal developments are for direct-use applications. Very low temperature systems (<30°C) have been utilized for geothermal heat pumps, both open (groundwater) and closed (ground-coupled) systems. The higher temperature systems (>30°C) have been developed for space heating, spas and swimming pools, and for greenhouse heating. Current estimates foresee that these types of applications will experience little increases. In addition, it is estimated that from 2015 onward, several heating and cooling network projects (geothermal district heating and cooling) may be launched. The estimate installed capacities and annual energy uses for the various direct-use applications are: 3.52 MWt and 76.26 TJ/yr for individual space heating, 14.93 MWt and 94.42 TJ/yr for greenhouse heating, 2.59

MWt and 52.50 TJ/yr for bathing and swimming, and 43.087 MWt and 121.67 TJ/yr for geothermal heat pumps, for a total for the country of 64.13 MWt and 344.85 TJ/yr (Arrizabalaga et al., 2015).

5.5.2.15 Sweden.

Geothermal energy in Sweden is dominated by low temperature, shallow systems for direct-use. The vast majority of installed geothermal energy systems are ground source heat pumps (GSHP) for space heating and domestic hot water heating for single family buildings. About 20% of the Swedish buildings use GSHP. The market for larger shallow geothermal energy systems for residential as well as non-residential buildings has been expanding during the last few years. The Lund deep geothermal plant is the largest geothermal heat pump installation in Sweden. The two heat pumps deliver 21 and 27 MWt of heat respectively, providing a net of 200 GWh annually. The vast majority of the Swedish shallow geothermal energy systems are vertical boreholes in hard rock. The typical shallow geothermal energy extraction system is a groundwater filled vertical closed loop GSHP system. The heat pump is typically electrically driven and is used for both space heating and domestic hot water heating. About 20 to 25% of all shallow geothermal systems are horizontal ground loops in soft ground material. Indications are that there are currently some 500,000 ground source heat pumps installed in Sweden, of which about 10,000 are open groundwater or surface water heat pump systems. Shallow geothermal systems are also used in district heating networks, providing some 0.65 TWh/year to these networks. Large Aquifer Thermal Energy Storage (ATES) and Borehole Thermal Energy Storage (BTES) are used in the commercial and institutional sectors. The total geothermal heat pumps systems used in the country are 5,600 MWt of installed capacity and 51,920 TJ/yr of annual energy use (Gehlin, et al., 2015).

5.5.2.16 Switzerland.

Direct use of geothermal energy has had a long tradition in the country and is very successful. The oldest utilizations are the still popular thermal spas, which can be found in the midlands but also in the alpine region. Geothermal heat pumps applications have been for more than a century an unabated success story with annual growth rates of up to 12%. The deployment of shallow geothermal energy applications is mainly restricted by water protection regulations, but not constrained by its natural potential. Geothermal heat pump systems for space heating provide the main part of heat production – about 3.06 TWh. Of this 86% come from systems with borehole heat exchangers (2,626.1 GWh). The remaining heat pump-based utilization is made up by groundwater systems (367.3 GWh), geostructures (33.6 GWh), deep aquifers (18.85 GWh), tunnel water (6.5 GWh) and deep borehole heat exchangers (2.2 GWh). Geothermal heat pumps installation providing both heating and cooling are growing steadily. In 2013, the total drill-length of borehole heat exchangers was about 2,600 km, with a density of 3 standard 12 kW units per km^2, the highest worldwide. Direct heat use without heat pumps is applied mainly to thermal bathing (228.7 GWh), and a doublet system for district heating (2.4 GWh) in Riehen near Basle. The temporary decline in direct-heat generation in 2011 was due to the reconstruction of the heating station in Riehen. At the tunnel of "Lötschberg" a big part of the geothermal heat (2 GWh) is used directly for fish farming at Troopenhaus Frutigen. Tunnel water that drains from the surrounding rock zones produces a considerable amount of warm water that flows towards the portals. Water with a temperature of up to 50^{o}C can be utilized for space heating, greenhouses, balneology, fish farming, etc. In summary, the various geothermal applications in terms of installed capacity and annual energy use are: district heating 1.60 MWt (estimated) and 8.64 TJ/yr; fish farming 2.00 MWt (estimated) and 7.2 TJ/yr; bathing and swimming 27.48 MWt and 823.32 TJ/yr; and geothermal heat pumps (including district heating, and tunnel water) at 1,702.00 MWt and 10,997.64 TJ/yr. This gives a total for the country of 1,733.08 MWt and 11,836.80 TJ/yr (Link, et al., 2015).

5.5.2.17 United Kingdom.

The City of Southampton Energy Scheme remains the only significant exploitation of low enthalpy geothermal energy in the UK. The scheme was started in the early 1980s, with the construction of a district heating system starting in 1987. The project has since evolved and expanded to become a combine heat and power scheme for 3,000 homes, 10 schools and numerous commercial buildings. The hot springs at Bath have long been a tourist attraction among the Roman architecture of the ancient city. The baths, together with four adjacent buildings, underwent major refurbishments and were re-opened in 2008. There are currently plans to use the heat from the Bath hot springs to supply a new underfloor heating system for Bath Abbey. During 2011, a geothermal borehole was drilled in the center of Newcastle-upon-Tyne on a brownfield site that is to be developed for university, commercial and residential buildings heating. In 2012 the Irish company, GT Energy announced that it was working with major utilities on a proposal to develop deep geothermal heat project in Manchester and several other UK cities. A deep co-axial heat exchanger will be installed in 2014 at 1,800 meter depth in Cornwall. The use of ground-source heat pumps have been slow, however, multiple units have been installed in the last 15 years estimated at 22,000 units installed to date. Examples of large GSHP installations include the King's Mill Hospital in Mansfield (~5MW closed loop lake installation); a mixed office/commercial development next to St. Paul's Cathedral in London (~2.4 MW combination of thermal piles and open loop); and, Churchill Hospital at Oxfored, the largest closed loop borehole installation to date in the UK (~3 MW). The current installed capacity and annual energy use for the various applications include: 2.76 MWt and 72.5 TJ/yr for district heating, 1.0 MWt and 34.0 TJ/yr for balneology, and 280 MWt and 1,800 TJ/yr for ground source heat pumps. The total for the country is then 283.76 MWt and 1,906.5 TJ/yr (Batchelor, et al., 2015).

5.6 Oceania

5.6.1 Australia.

The country's only geothermal district heating system at Portland in Victoria, remains decommissioned since 2006 for a variety of reason included environmental (surface discharged of the fluid). However, it may be recommissioned in 2014 or 2015. One of the main areas of interest for development of direct-use geothermal is around the City of Perth in Western Australia where the resource is being developed for swimming, an aquatic center and for heating schools. At Robe in South Australia, barramundi (an edible tropical freshwater fish) is being raised in tanks using water from a well at 29^{o}C. An additional barramundi farm using geothermal water is located at Weribee using 28^{o}C fresh water. At Warmamool a meat processing facility uses geothermal water for washing down and sterilizing the industrial facility. A number of spas and resorts are using geothermal water, most notably are a resort at Warmambool where space heating of 122 rooms and domestic hot water heating is provided; and Peninsula Hot Spring on the Mornington Peninsula near Melbourne attracts 420,000 visitors annually and has 228 full time and part time staff. It uses 46^{o}C water to heat a number of indoor and outdoor pools. If its commercial growth pattern over the past nine year continues, it will become the largest tourism attraction in Victoria in 3-5 year time. There at least 17 locations in the country where geothermal waters are using for bathing and swimming. A unique one is Dalhousie Springs, a group of over 60 natural artesian springs located in Witjira National Park on the western fringe of the Simpson Desert in northern South Australia. For tens of thousands of years, the Arrente People (indigenous language group) has managed the water resources in a harmonious and sustainable way to provide water, food, life and connection on an important traditional travel path. The geothermal ground-source heat pump sector in the country appears to be on the verge of a rapid period of growth. The largest installation is in the Geoscience Australia building in Canberra, with the 2,500 kW of thermal power provided to 210 heat pumps. A new project being proposed is using geothermal heat pumps of an 800-block housing estate near Blacktown in Sydney's west side. A summary of the individual uses of geothermal direct-use in terms of installed capacity and annual energy use is: 2.3 MWt and 43.5 TJ/yr for fish farming; 11.29 MWt and 138 TJ/yr for bathing and swimming; and an estimated 2.50 MWt and 12.86 TJ/yr for geothermal heat pumps, for a country total of 16.09 MWt and 194.36 TJ/y (Beardsmore, et al., 2015).

5.6.2 New Zealand.

Interest and use of geothermal heat pumps (both ground- and water-sourced) is accelerating in the country. The geothermal heat pump industry is in its infancy but is finding niche markets in areas of high end housing or facilities where there is greater demand for heating and cooling such as airports, libraries, swimming pools, residential care facilities and hospitals. One of the significant areas where geothermal development is occurring is in Christchurch which suffered major damage in the September 2010 and February 2011 earthquakes. These quakes destroyed much of the central business district and rebuilding is underway. This rebuilding of the central business district has enabled distributed energy nodes (district energy hubs) to be established. Some of these will use open source geothermal groundwater based energy technology to supply about 90% of the energy load to a node with the peak 10% topped up from other sources. Direct geothermal energy use in the country is dominated by Norske Skog Tasman (NST) pulp and paper mill at Kawerau. Prior to 2013 this one site accounted for half of the total New Zealand direct geothermal heat use. With the reducing global consumption of newsprint, one of the two paper production lines was closed at the beginning of 2013. Several new industrial developments are using geothermal energy directly. In 2010 a tissue mill owned by Svenska Cellulosa Aktiebolget at Kawerau converted from natural gas steam production to clean steam production using geothermal steam and energy to run it reboiler steam generation equipment. The Miraka milk drying factory, located on land above the Mokai geothermal field, commenced operating in August 2011. The plant also uses reboiler technology to produce clean process steam from geothermal steam. The installed capacity and energy use of the various applications are: 9.32 MWt and 69.0 TJ/yr for geothermal heat pumps; 31 MWt and 289 TJ/yr both for individual space heating and for district heating (the division is estimated); 24 MWt and 366 TJ/yr for greenhouse heating; 17 MWt and 196 TJ/yr for fish farming; 0.13 MWt and 2 TJ/yr for animal farming; 284 MWt and 5,043 TJ/yr for industrial processing; 58 MWt and 1,375 TJ/yr for bathing and swimming; and 33 MWt and 992 TJ/yr for others (irrigation, frost protection, geothermal tourist park). This gives a total for the country of 487.45 MWt and 8,621 TJ/yr (Carey, et al., 2015).

5.6.3 Papua New Guinea.

Geothermal resources on the island of Lihir are exploited to generate electricity for the gold mines. On New Britain Island, low-enthalpy heat is used to boil megapod eggs and megapods (a local fowl) use the hot ground to incubate their eggs, which are then harvested by the locals. Hot springs on the north end of the island are used for bathing by the locals. Based on estimates from WGC2010, the current direct-use is estimated for bathing and swimming at 0.1 MWt and 1.0 TJ/yr (Lund, et al., 2010).

6. ENERGY SAVINGS

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 587,786 TJ/yr of energy consumed in direct geothermal applications by 2015 (see Table 1), and estimating that a barrel of fuel oil contains 6.06 x 109 Joules, and that the fuel is used to produce electricity, the savings would be 280 million barrels of oil or 42 million tonnes of oil annually. If the oil were used directly to produce energy by burning it for heating, then these savings would be 140 million barrels or 21 million tonnes. The actual savings are most likely somewhere in between these two values. Note that 280 million barrels is about three days of worldwide oil consumption.

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 8.60, 36.80 or 42.74 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 31.51, 133.46, 155.63 million tonnes, respectively. The savings in SO_x and NO_x producing electricity from natural gas, oil and coal would be 0.0, 0.81 and 0.88 million tonnes of SO_x, and 8.16, 24.51, and 26.57 thousand tonnes of NO_x. If heat were produced by burning these fuels, the carbon, CO_2, SO_x and NO_x saving would be half of these values. Again, the actual savings would be somewhere in between these values since a mix of fossil fuels would be used for heating and electricity generation.

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 figures are summarized in Table 3.

Table 3. 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	350	52.5	45.8	148.3	1.02	0.031
As direct heat	175	26.2	22.9	74.1	0.51	0.015

7. 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). 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)

8. 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)

9. 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)

10. CONCLUDING REMARKS

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 4. The distribution of geothermal use by continents of the world is shown in Table 5 indicating that Asia and Europe are the leaders by having 18 and 32 countries utilizing geothermal energy for direct-use applications.

Table 4. Significant Contributions of Direct-Use Geothermal Energy to a Country's Economy.

Iceland	90% of building space heating
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 the total units
USA	1.4 million geothermal heat pumps (7.0% annual growth)

Table 5. Distribution of Direct Geothermal Energy Utilization by Continent.

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

*includes CIS countries (Armenia, Belarus, Georgia, Russia and Ukraine)

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 3 and 4. 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^{o}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. 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 this paper.

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 (November, 2014), the cost of crude oil is around US$75/barrel and has been in the recent past over US$100/barrel, and natural gas prices are also on the rise. 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 2 and Figures 1 and 2. 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.

ACKNOWLEDGEMENT AND DEDICATION

The authors would like to acknowledge and dedicate this paper to three past worldwide leaders of the direct utilization of geothermal energy: Paul J. Lienau, USA (1937 – 2008) – co-founder of the Geo-Heat Center and its first Director; Kiril Popovski, Macedonia (1943-2010) – founder and director of the International Summer School on Direct Application of Geothermal Energy under IGA; and Derek Freeston, New Zealand (1929-2010) – co-founder of the Geothermal Institute at the University of Auckland under UNDP, and he was also the co-author of the direct use summaries for WGC2000, WGC2005 and WGC2010. They, as the early promoters and pioneers of direct-use geothermal energy, are sorely missed.

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