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Direct Utilization of Geothermal Energy 2020 Worldwide Review

John W. Lund[1] and Aniko N. Toth[2]

[1]Geo-Heat Center, Oregon Institute of Technology, Klamath Falls Oregon, USA

[2]Ana-Geo Ltd., Miskolc, Hungary

john.lund@oit.edu, aniko@tothgeo.com

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ABSTRACT

This paper presents a review of the worldwide applications of geothermal energy for direct utilization and updates the previous survey carried out in 2015. We also compare data from WGC1995, WGC2000, WGC2005, WGC2010, and WGC2015 presented at World Geothermal Congresses in Italy, Japan, Turkey, Indonesia and Australia. As in previous reports, an effort is made to quantify geothermal (ground-source) heat pump data. The present report is based on country update papers received from 62 countries and regions reporting on their direct utilization of geothermal energy. Twenty-six additional countries were added to the list based on other sources of information. Thus, direct utilization of geothermal energy in a total of 88 countries is an increase from 82 in 2015, 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 2019 is used in this paper and equals 107,727 MWt, a 52.0% increase over the 2015 data, growing at a compound rate of 8.73% annually. The thermal energy used is 1,020,887 TJ/yr (283,580 GWh/yr.), a 72.3% increase over 2015, growing at a compound rate of 11.5% annually. The distribution of thermal energy used by category is approximately 58.8% for geothermal (ground-source) heat pumps, 18.0% for bathing and swimming (including balneology), 16.0% for space heating (of which 91.0% is for district heating), 3.5% for greenhouse heating, 1.6% for industrial applications, 1.3% for aquaculture pond and raceway heating, 0.4% for agricultural drying, 0.2% for snow melting and cooling, and 0.2% for other applications. Energy savings amounts to 596 million barrels (81.0 million tonnes) of equivalent oil annually, preventing 78.1 million tonnes of carbon and 252.6 million tonnes of CO_2 from being released to the atmosphere. This includes savings for geothermal heat pumps in the cooling mode, compared to using fuel oil to generate electricity. Since it is almost impossible to separate direct-use from electric power generation for the following, they are combined: approximately 2,647 wells were drilled in 42 countries, 34,500 person-years of effort were allocated in 59 countries, and US $22.262 billion invested in projects by 53 countries.

1. INTRODUCTION

Direct utilization (direct-use) of geothermal energy is one of the oldest, most versatile and most 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), which documents geothermal use for over 2,000 years. The information presented here on direct applications of geothermal heat is based on country update papers submitted to the World Geothermal Congress 2020 (WGC2020), published in the proceedings and covers the period 2015-2019. We solicited papers from 113 countries and regions, of which 62 reported having geothermal uses, with 26 countries added from other sources, such as from other World Geothermal Congresses and personal communications-- for a total of 88 countries, an increase of 6 countries from WGC2015. Other countries were also contacted, but unfortunately did not respond or are only exploring for geothermal and have not developed any utilization as of 2019: Bangladesh, Comoros, Daghestan, Djibouti, Eritrea, Fiji, Libya, Malta, Pakistan, Panama, Rwanda, Sri Lanka, Sudan, Tanzania, Uganda, United Arab Emirates, Uruguay, Vanuatu, Zambia and Zimbabwe. Where data are missing or incomplete, the authors have relied on country update reports from previous World Geothermal Congresses, as well as from four *Geothermic* publications (Lund and Freeston, 2001, Lund et al., 2005, Lund et al., 2011, and Lund and Boyd, 2015), European Geothermal Congresses, 2007, 2013, and 2019), and personal communications. Data from WGC2020 are also compared with data from the previous World Geothermal Congresses.

2. DATA SUMMARY

Table 1 summarizes by region and continent the installed thermal capacity (MWt), the annual energy use (TJ/yr and GWh/yr), and the capacity factors through 2019. Table 1A in the Appendix is a similar summary by individual countries. The total installed capacity, reported to the end of 2019 for geothermal direct utilization worldwide is 107,727 MWt, a 52.0% increase over WGC2015, growing at an annual compound rate of 8.7%. The total annual energy use is 1,020,887 TJ (283,580 GWh), indicating a 72.3% increase over WGC2015 and a compound annual growth rate of 11.5%. The worldwide capacity factor is 0.300 (equivalent to 2628 full load operating hours per year), an increase from 0.265 in 2015 and 0.28 in 2010, but a decrease compared to 0.31 in 2005 and 0.40 in 2000. The recent higher capacity factor and growth rate for annual energy use is due to the increase in geothermal heat pump installations even though they have a low capacity factor of 0.245 worldwide. The growth rates of installed capacity and annual energy use over the past 30 years are summarized in Fig. 1.

The growing awareness and popularity of geothermal (ground-source) heat pumps have had the most significant impact on the direct-use of geothermal energy reported in 58 countries or regions, up from a reported 48 in 2015. The annual installed capacity grew 1.54 times at a compound rate of 9.06%. The annual energy use of these units grew 1.84 times at a compound rate of 12.92% compared to WGC2015. This is due, in part, to better reporting and the ability of geothermal heat pumps to utilize groundwater or ground-coupled temperatures anywhere in the world (see Fig. 2). The five leading countries for geothermal heat pumps in terms of both installed capacity (MWt) and annual energy use (TJ/yr): China, USA, Sweden, Germany, Finland, and in terms of annual energy use are: China, USA, Sweden, Germany and Finland (see Table 7). An estimated 6.46 million units are installed worldwide, with also the leaders accounting for 77.4% of these units.

The five countries with the largest direct-use (with geothermal heat pumps) installed capacity (MWt) are: China, USA, Sweden, Germany and Turkey, accounting for 71.1% of the world capacity and five countries with largest annual energy use with geothermal heat pumps (TJ/yr) are: China, USA, Sweden, Turkey and Japan, accounting for 73.4% 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" for installed capacity (MWt/population) then become Iceland, Sweden, Finland, Switzerland and Norway; and for annual energy use (TJ/yr/population) Iceland, Sweden, Finland, Norway and New Zealand (see Table 3). The "top five" in terms of land area for installed capacity (MWt/area) are Switzerland, Netherlands, Iceland, Sweden and Austria; and in terms of annual energy use (TJ/yr/area) the leaders are: Switzerland, Iceland, Sweden, Hungary and Austria (see Table 4). The largest percentage increase in geothermal installed capacity (MWt) over the past five years was in Iceland, Hungary, France, Egypt and Australia; and in terms of annual energy use (TJ/yr) over the past five years was in Spain, Yemen, Australia, Kenya and Georgia (see Table 5). Most of these increases were due to geothermal heat pumps installations or better reporting on bathing and swimming use. In 1985, only 11 countries reported 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, to 33 by 2010, to 36 by 2015, and by 2020 to 38 countries.

The five countries with the largest direct-use, without geothermal heat pumps, in installed capacity (MWt) are: China, Turkey, Japan, Iceland and Hungary, accounting for 76.0% of the world capacity. The five countries with the largest annual energy use (TJ/yr), without geothermal heat pumps, are: China, Turkey, Japan, Iceland and New Zealand, accounting for 76.5% of the world use (see Table 6).

Table 1: Summary of direct-use data worldwide by region and continent, 2019

Region/Continent (#countries/regions)	MWt	TJ/year	GWh/year	Capacity Factor
Africa (11)	198	3,730	1,036	0.597
Americas (17)	23,330	180,414	50,115	0.245
Central America and Caribbean (5)	*9*	*195*	*54*	*0.687*
North America (4)	*22,700*	*171,510*	*47,642*	*0.24*
South America (8)	*621*	*8,709*	*2,419*	*0.445*
Asia (18)	49,079	545,019	151,394	0.352
Commonwealth of Independent States (5)	2,121	15,907	4,419	0.238
Europe (34)	32,386	264,843	73,568	0.259
Central and Eastern Europe (17)	*3,439*	*28,098*	*7,805*	*0.259*
Western and Northern Europe (17)	*28,947*	*236,745*	*65,762*	*0.259*
Oceania (3)	613	10,974	3,048	0.568
Total (88)	**107,727**	**1,020,887**	**283,580**	**0.300**

Table 2: Worldwide leaders in the direct-use of geothermal energy including geothermal heat pumps.

MWt		TJ/year	
China	(40,610)	China	(443,492)
United States	(20,713)	Unites States	(152,810)
Sweden	(6,680)	Sweden	(62,400)
Germany	(4,806)	Turkey	(54,584)
Turkey	(3,488)	Japan	(30,723)

Table 3: Worldwide leaders in the direct-use of geothermal energy in terms of population(per1,000).

MW/population		TJ/population	
Iceland	(7.00)	Iceland	(99.10)
Sweden	(0.67)	Sweden	(6.22)
Finland	(0.42)	Finland	(4.23)
Switzerland	(0.26)	Norway	(2.34)
Norway	(0.21)	New Zealand	(2.12)

Table 4: Worldwide leaders in the direct-use of geothermal energy per land area (per 100 km²).

MWt		TJ/year	
Switzerland	(5.32)	Iceland	(32.62)
Netherland	(4.14)	Switzerland	(32.18)
Iceland	(1.93)	Sweden	(13.86)
Sweden	(1.48)	Hungary	(11.94)
Austria	(1.31)	Austria	(10.30)

Table 5: Worldwide leaders in the direct-use of geothermal energy in terms of the largest increase (%)

MW/population		TJ/population	
Ukraine	(18,642)	Ukraine	(4,181)
Spain	(748)	Spain	(1,040)
Australia	(487)	Yemen	(567)
Yemen	(400)	Australia	(339)
China	(127)	Kenya	(330)

Table 6: Worldwide leaders in the direct-use of geothermal energy without geothermal heat pumps

MWt		TJ/year	
China	(14,160)	China	(197,281)
Turkey	(3,480)	Turkey	(54,413)
Japan	(2,407)	Iceland	(33,590)
Iceland	(2,368)	Japan	(29,958)
Hungary	(952)	New Zealand	(9,729)

Table 7: Worldwide leaders in the installation and use of geothermal heat pumps

MWt		TJ/year	
China	(26,450)	China	(246,212)
United States	(20,230)	United States	(145,460)
Sweden	(6,680)	Sweden	(62,400)
Germany	(4,400)	Germany	(23,760)
Finland	(2,300)	Finland	(23,400)

3. CATEGORIES OF UTILIZATION

Tables 8, 9 and 10 divide the data from 1995, 2000, 2005, 2010, 2015 and 2020 among the various uses in terms of capacity (MWt), energy utilization (TJ/yr) and capacity or load factor (C.F.). This distribution can be viewed as a bar chart in Fig. 2 for the top 6 energy uses. An attempt was made to distinguish individual space heating from district heating, but this was often difficult, as the individual country reports did not always make this distinction. Our best estimate is that district heating represents 91% of the installed capacity and 59% of the annual energy use. Snow melting represents the majority (>90%) 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, cultivation of spirulina, and carbonation of soft drinks.

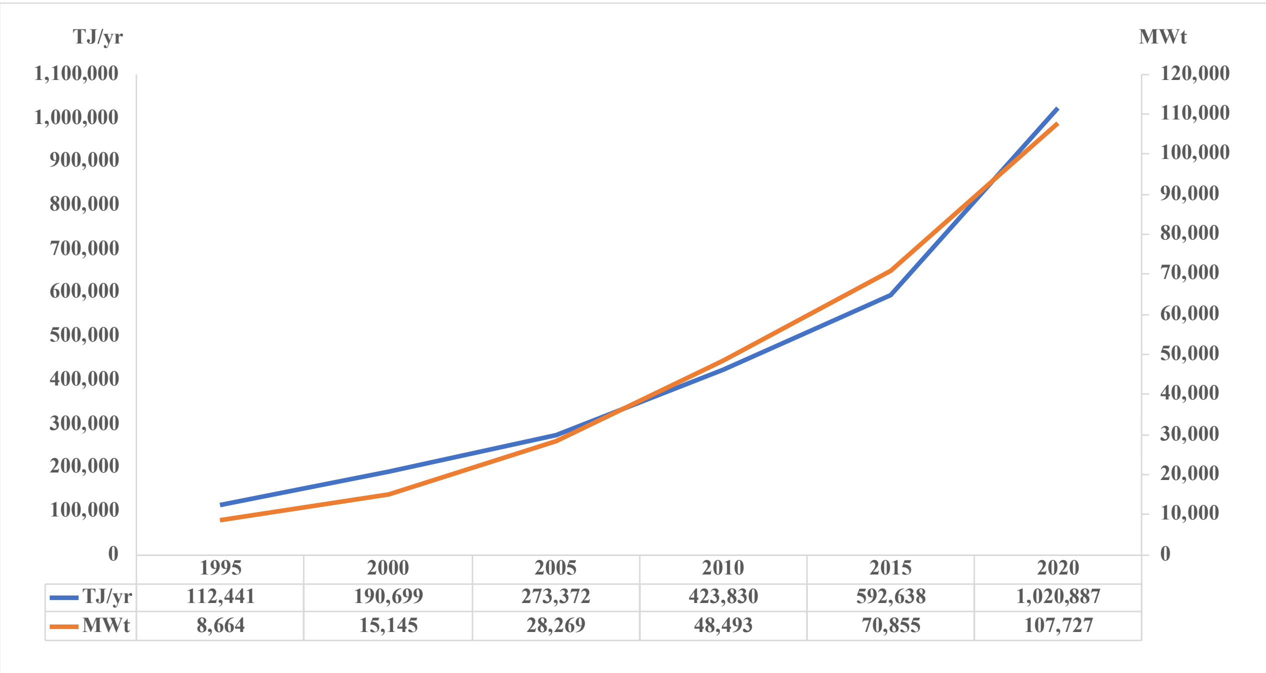

Fig.1 The installed direct-use geothermal capacity and annual utilization from 1995-2020.

3.1 Geothermal heat pumps

Geothermal (ground-source) heat pumps have the largest geothermal use worldwide, accounting for 71.6% of the installed capacity and 59.2% of the annual energy use. The installed capacity of 77,547 MWt and the energy use is 599,981 TJ/yr, with a capacity factor of 0.245 in the heating mode. Although most of the installations occur in North America, Europe and China, the number of countries with installations increased from 26 in 2000, to 33 in 2005, to 43 in 2010, to 48 in 2015 and to 54 in 2020. The equivalent number of installed 12 kW units (typical of USA and Western European homes) is approximately 6.46 million. This is a 54% increase over the number of installed units reported in 2015, and over twice the number of units reported in 2010. 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 States, 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 2,000 equivalent full-load heating hours per year (capacity factor of 0.23). In Europe, most units are sized for the heating load and are often designed to provide the base load with peaking by fossil fuels. However, some of these units may be in operation up to 3,000 equivalent full-load heating hours per year (capacity factor of 0.34), such as in the Nordic countries (especially in Finland). Unless the actual number of equivalent full-load heating hours was reported, a value of 2,200 hours/year, and higher for some of the northern countries, was used for energy output (TJ/yr) 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 in this case, as heat is discharged into the ground or ground-water. Cooling, however, has a role in the substitution of fossil fuels and reduction in greenhouse gas emission and, thus is included in later discussion.

The leaders in installed units (MWt) are: China, United States, Sweden, Germany and Finland accounting for 77.4% of these units, and the leaders in energy produced (TJ/yr) are also: China, United States, Sweden, Germany and Finland accounting for 83.5% of the output (see Table 7).

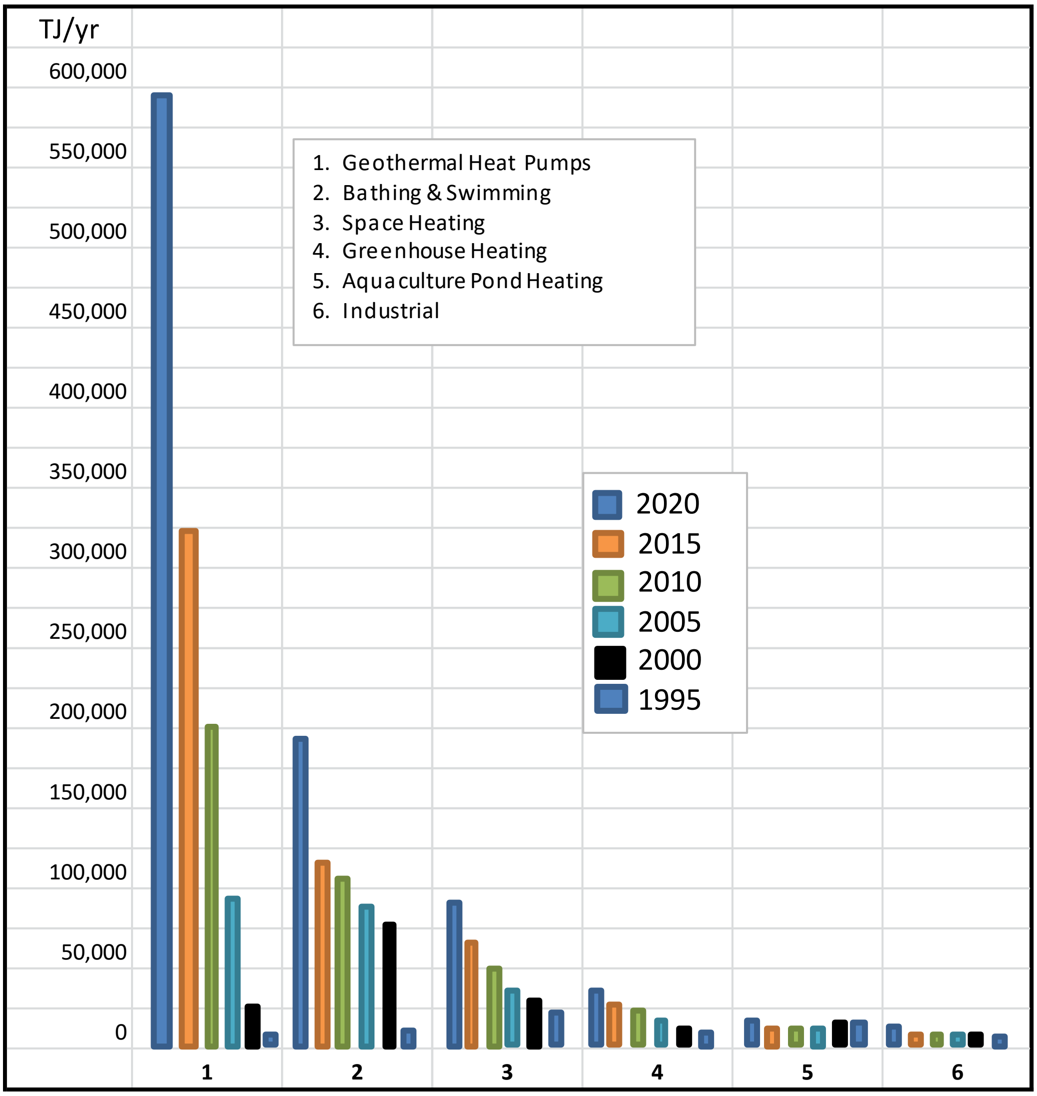

Fig. 2. Comparison of worldwide direct-use of geothermal energy in TJ/yr from 1995, 2000, 2005, 2010, 2015 and 2020.

3.2. Space heating

Space heating, including individual space heating and district heating, has increased 68.0% in installed capacity and 83.8% in annual energy use over WGC2015. The installed capacity now totals 12,768 MWt and the annual energy use is 162,979 TJ/yr. In comparison 91% of the installed capacity and 91% of the annual energy use is in district heating (29 countries). The leaders in district heating in terms of both capacity and annual energy use are China, Iceland, Turkey, France and Germany, whereas in the individual space heating sector in installed capacity (MWt) the leaders are Turkey, Russia, Japan, United States, and Hungary. In annual energy use (TJ/yr), the leaders are Turkey, Japan, Russia, the United States, and Switzerland, a total of 29 countries. These five leaders account for about 90% of the world's total use in district heating and about 75% of the world's individual space heating.

3.3. Greenhouses and covered ground heating

Worldwide use of geothermal energy for greenhouse and covered ground heating increased by 24% in installed capacity and 23% in annual energy use. The installed capacity is 2,459 MWt and 35,826 TJ/yr in energy use. A total of 32 countries report geothermal greenhouse heating (compared to 31 from WGC2015), with the leading countries in annual energy use (TJ/yr) being Turkey, China, Netherlands, Russia and Hungary, accounting for about 83% of the world's total. Most countries do not distinguish between greenhouse vs. 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, cacti and fish in ponds (USA), along with fruit such as bananas (Iceland) are also grown. Covered ground heating has been reported in Iceland (vegetables) and Greece (asparagus), using geothermal heat pumps. Since labor is one of the major costs in this sector, developing countries have a competitive advantage when compared with more developed countries. Using the average energy requirement determined from WGC2000 of 20 TJ/yr/ha for greenhouse heating, the 35,826 TJ/yr corresponds to about 1,791 ha of greenhouses heated worldwide – a 23.4% increase over 2015.

3.4. Aquaculture pond and raceway heating

Aquaculture use of geothermal has increased over WGC2015, amounting to a 36.5% increase in installed capacity and 13.5% increase in annual energy use. The installed capacity is 950 MWt and the energy use 13,573 TJ/yr. Twenty-one countries report this type of use, the main ones in terms of annual energy use being China, United States, Iceland, Italy and Israel – the same countries reported in WGC2015, accounting for 92% of the annual use. Like greenhouses, these facilities are labor intensive and require well trained personnel. As this is often difficult to justify economically, growth is slow. Tilapia, salmon, bass and trout seem the most common species cultivated, but tropical fish, lobsters, shrimp and prawns, as well as alligators, are also being farmed. Two of the main alligator-raising facilities are in the United States: in Idaho where they are raised for their meat and hides, and in Colorado as a tourist attraction. Based on work in the United States, it is estimated that 0.242 TJ/yr/tonne of fish (bass and tilapia) are required using geothermal water in uncovered ponds. Thus, the reported energy use of 13,573 TJ/yr. represents an estimated equivalent of 56,087 tonnes of annual production, representing a 13.5% increase over 2015. It should be noted that if the fish are raised in covered ponds, say by a greenhouse, the energy requirements would be about half. However, very few covered ponds are known to be in use.

3.5. Agricultural crop drying

Fifteen countries reported the use of geothermal energy for drying various grains, vegetables and fruit crops, the same number as in 2015. Examples include: seaweed (Iceland), onions (USA), wheat and 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 users are China, France, Hungary, United States and Japan, accounting for 94% of the world's use. A total of 257 MWt and 3,529 TJ/yr are utilized, an increase of 59.6% and 73.8% respectively compared to WGC2015.

3.6. Industrial process heat

This is a category with applications in 14 countries, one less than in 2015. These operations tend to be large and have high energy consumption, often operating year-round. Examples include: concrete curing (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 852 MWt and the energy use is 16,390 TJ/yr, an increase of 38.8% and 56.8% respectively, compared to WGC2015. As expected, because of almost year-round operation, heat for the industrial processes have one of the highest capacity factors of all direct-uses at 0.610, up from 0.540 for WGC2015, but down from 0.699 for WGC2010 and 0.712 for WGC2005. No reasons are given for the decrease in capacity factor; however, it may be due to more efficient operations and energy use, or fewer operating hours per year. The leaders in energy use (TJ/yr) are: China, New Zealand, Iceland, Russia and Hungary, accounting for 98% of the use.

3.7. Bathing and swimming

These are the most difficult data to collect and quantify. Almost every country (53 of 88) has spas and resorts with swimming pools heated by geothermal water, including balneology, the treatment of diseases with water, but many never regulate the water flow, even at night when the pool is closed. Some countries do not keep track of pool use. As a result, the actual usage and capacity figures may be off by as much as 20%. Where no flow or temperature drop was reported, estimates of 0.35 MWt and 7.0 TJ/yr were applied for capacity and energy use. In other cases, 5 L/s and 10^{o}C temperature change were used for the installed capacity of 0.21 MWt, and 3 L/s and 10^{o}C temperature change were used for the annual use of 4.0 TJ/yr based on communications with various country update authors. Undeveloped natural hot springs are not included.

In addition to the 53 countries (70 reported in 2015, 67 in 2010, and 60 in 2005) that reported bathing and swimming pool use, there are known installations in Denmark, France, Mozambique, Nicaragua, Singapore, and Zambia for which no information was available. The total installed capacity is 12,253 MWt and the energy use is 184,070 TJ/yr, up 35.1% and 53.9% respectively over 2015. We have also included the onsens (hot pools) at Japanese-style inns that utilize hot spring water for bathing, as we included these figures in previous WGC reports. The largest reported annual energy uses for bathing and swimming are from China, Japan, Turkey, Brazil, and Mexico, accounting for 79.5% of the annual use.

3.8. Snow melting and space cooling

The very few applications in this area mostly consist of snow melting projects for pavement. Snow melting applications for streets and sidewalks operate in Iceland, Japan, Argentina, United States, and Slovenia, and to a limited extent in Poland and Norway. An estimated 2.5 million square meters of pavement are heated worldwide, the majority in Iceland (74%). A project in Argentina uses geothermal steam for highway snow melting in the Andes to keep a resort community open during the winter. In the United States, most of the pavement snow melting is used on the Oregon Institute of Technology campus and in the City of Klamath Falls, where it is part of the district heating system using the lower temperature return water in a heat exchanger with a glycol-water mixture to melt snow on sidewalks and bridge decks. The power required varies from 130 to 180 W/m^2 (United States and Iceland). The installed capacity for snow melting is 415 MWt and the energy use is 2,389 TJ/yr, a slight decrease over WGC2015.

Space cooling (air conditioning) is used in seven countries with Bulgaria being the leader followed by Brazil, Australia, Slovenia, Algeria, Albania and India for a total of 19.9 MWt and 200.1 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. However, their numbers are included in later discussions since they replace the use of fossil fuels.

The total for both uses is: 434.9 MWt and 2,589.1 TJ/yr.

3.9. Other uses

This category includes 106 MWt and 1,950 TJ/yr 34.2 and 35.4% higher respectively compared to 2015. These values are reported in 14 countries, which include animal husbandry, spirulina cultivation, desalination and sterilization of bottles. The largest use is in New Zealand, where it is used in irrigation, frost protection and a geothermal tourist park, followed by Japan (cooking) and Kenya (boiling water).

4. CAPACITY FACTORS

Average capacity factors were determined for each country (Appendix Table A1) and for each category (Table 2). They vary from 0.07 to 1.00 for the countries and from 0.189 to 0.610 for the categories of use. The lower value usually refers to countries in which geothermal heat pumps usage dominates (Belgium, Denmark, Egypt, Netherlands, Saudi Arabia and Ukraine) whereas the higher numbers are for countries with high industrial use (New Zealand), or continuous operation of pools for swimming (Algeria, Eastern Caribbean Islands, Iran, Kenya, Madagascar and Mexico). Snow melting/cooling is also low with a capacity factor of 0.189 due to low use.

The worldwide capacity factor increased from 0.265 for WGC2015 to 0.300 for WGC2020, but was nearly the same for WGC2010, and decreased from WGC2005, WGC2000 and WGC1995. These variations are due to various factors, but mainly the increase in geothermal heat pumps, space heating and bathing and swimming uses.

The capacity factor (CF) is calculated as follows: [(energy use in TJ/yr)/(installed capacity in MWt)] x 0.0317. This number reflects the equivalent percentage of equivalent full load operating hours per year (i.e., if the CF = 0.70 then this is equivalent to 6,132 full load operating hours per year (8760 x 0.70)).

Table 8: Summary of MWt for various categories of direct-use for the period 1995-2020.

Utilization	Capacity MWt					
	2020	**2015**	**2010**	**2005**	**2000**	**1995**
Geothermal heat pumps	77,547	50,258	33,134	15,384	5,275	1,854
Space heating	12,768	7,602	5,394	4,366	3,263	2,579
Greenhouse heating	2,459	1,972	1,544	1,404	1,246	1,085
Aquacultural pond heating	950	696	653	616	605	1,097
Agricultural drying	257	161	125	157	74	67
Industrial uses	852	614	533	484	474	544
Bathing and swimming	12,253	9,143	6,700	5,401	3,957	1,085
Cooling/snow melting	435	360	368	371	114	115
Other	106	79	42	86	137	238
Total	**107,727**	**70,885**	**48,493**	**28,269**	**15,145**	**8,664**
% increase in 5 years	52.0	46.2	71.5	86.7	74.8	

Table 9: Summary of TJ/year for various categories of direct-use for the period 1995-2020.

Utilization	Utilization TJ/year					
	2020	2015	2010	2005	2000	1995
Geothermal heat pumps	599,981	326,848	200,149	87,503	23,275	14,617
Space heating	162,979	88,668	63,025	55,256	42,926	38,230
Greenhouse heating	35,826	29,038	23,264	20,661	17,864	15,742
Aquacultural pond heating	13,573	11,953	11,521	10,976	11,733	13,493
Agricultural drying	3,529	2,030	1,635	2,013	1,038	1,124
Industrial uses	16,390	10,454	11,745	10,868	10,220	10,120
Bathing and swimming	184,070	119,611	109,410	83,018	79,546	15,742
Cooling/snow melting	2,589	2,596	2,126	2,032	1,063	1,124
Other	1,950	1,440	955	1,045	3,034	2,249
Total	**1,020,887**	**592,638**	**423,830**	**273,372**	**190,699**	**112,441**
% increase in 5 years	72.3	39.8	55.0	43.4	69.6	

Table 10: Summary of capacity factors for various categories of direct-use for the period 1995-2020.

Utilization	Capacity Factor					
	2020	2015	2010	2005	2000	1995
Geothermal heat pumps	0.245	0.206	0.192	0.180	0.140	0.250
Space heating	0.405	0.370	0.371	0.401	0.417	0.470
Greenhouse heating	0.462	0.467	0.478	0.467	0.455	0.460
Aquacultural pond heating	0.463	0.545	0.559	0.565	0.615	0.390
Agricultural drying	0.435	0.400	0.415	0.407	0.445	0.532
Industrial uses	0.610	0.540	0.699	0.712	0.684	0.590
Bathing and swimming	0.473	0.415	0.518	0.487	0.637	0.310
Cooling/snow melting	0.189	0.229	0.183	0.174	0.296	0.310
Other	0.584	0.578	0.721	0.385	0.702	0.300
Total	**0.300**	**0.265**	**0.277**	**0.307**	**0.399**	**0.412**

5. COUNTRY REVIEWS

5.1. Africa

5.1.1. Algeria

The main utilizations of geothermal waters in Algeria are balneology, space heating and greenhouse heating. A successful project of fish farming product in the Sahara is a good example of the geothermal water use, with hot water temperature of 60°C. Eighteen greenhouses covering a total surface of 7,200 m^2 are heated by the 57°C Sahara geothermal waters. A heat pump project was installed in a primary school (Sidi Ben Saleh) at Saiada in NW Algeria for heating and cooling purposes. The various uses of geothermal direct-use are: 2.0 MWt and 26 TJ/yr for individual space heating, 1.2 MWt and 5.0 TJ/yr. for greenhouse heating, 15.0 MWt and 300.5 TJ/yr for fish farming, 58.3 MWt and 1955.4 TJ/yr. for swimming and bathing, 0.5 MWt and 3.2 TJ/yr for air conditioning, and 0.7 MWt and 85 TJ/yr for geothermal heat pumps, for a total of 77.7 MWt and 2,375.1 TJ/yr with a capacity factor of 0.969 (Ait Ouali, et al., 2020).

5.1.2. Burundi

Direct geothermal utilization is reported in the town of Mugara, in the Rumonge district, where a spa is used for balneology and bathing. People from all over the country visit this spa for bathing and tourism. With the development of tourism in Mugara, other economics activities have been created, such as hotels and a small market. Transportation to this area is provided for tourist and other visitors. Swimming pools and bathing are estimated at 0.35 MWt and 7.0 TJ/yr (Wakana, 2019).

5.1.3. Egypt

Direct utilization of thermal waters in ancient Egypt goes back thousands of years, with Egyptians using warm water from hot spring for domestic uses. The wealthy developed warm ponds for swimming and medical purposes, as was recorded by some papyrus documents discovered in the western desert. Some direct low-grade geothermal applications are now in use in Egypt, in the form of district heating, fish farming, agricultural applications and green houses. Some swimming pools have been constructed along the eastern coast of the Gulf of Suez. These thermal pools are mainly used for touristic and medical purposes. The majority of the green houses in the western desert of Egypt (Baharia and Dakhla oases), use thermal waters. District heating is also used in the winter. A total of 12 sites report the use of geothermal energy, 7 sites using it for bathing and swimming, and 5 sites using it for other uses (cooking). The estimated use is 44.0 MWt and 152.9 TJ/yr.

5.1.4. Ethiopia

Direct use applications in Ethiopia are limited to bathing and swimming. A number of resorts, hotels and parks have been utilizing hot water and steam for bathing in swimming pools and for balneological purposes in the Addis Abba area. The energy used for these direct utilizations was estimated for WGC2015 and is still assumed to be current. The estimates for swimming and bathing are 2.2 MWt and 41.6 TJ/yr (Lund, et al., 2010; Solmon, et al., 2019).

5.1.5. Kenya

The main geothermal use sites in the country are at the Eburru geothermal field, where a pyrethrum dryer built in 1939 dries pyrethrum flowers and grains, in the Oserian Greenhouse heating installation in Naivasha where the world's largest geothermally heated greenhouse grows roses for world export (shipping one million roses/day), and in the Olkaria Spa and bath, which uses waste water from the Olkaria II geothermal power plant. The country totals are: 5.3 MWt and 185 TJ/yr for greenhouses, 0.3 MWt and 9.9 TJ/yr for agricultural drying, 0.2 MWt and 6.5 TJ/yr for fish farming, 8.7 MWt and 275.5 TJ/yr for bathing and swimming, and 4.0 MWt and 125.5 TJ/y. for other uses (laundromat and milk processing), for a total of 18.5 MWt and 602.4 TJ/yr (Omenda, et al. 2019).

5.1.6. Madagascar

Madagascar currently has five thermal water spas, used for balneology, sports, recreation, and as tourist centers. Thermal waters are also bottled by three mineral water bottling companies, and regulated by the Law on Concessions. A large hotel and rehabilitation center with a swimming pool is heated at the Antsirabe Spa. A similar use is practiced at Ranomafana Namorona Spa near the Ranomafana National Park. Thermal springs in Bezaha Spa and in Betafo Spa are used at the rehabilitation and recreation center. Drinking water out of taps is used for disease prevention. Utilized water for relaxation, sanitary needs and prevention has the highest share in balneology. The total for bathing and swimming is: 2.814 MWt and 75.585 TJ/yr (Andrianaivo, 2019).

5.1.7. Malawi

Direct use of geothermal energy in Malawi has not been fully developed. Notable uses are for bathing in Nkhotakota, where bathrooms have been constructed. The rest are used more for informal uses, such as for bathing and cassava curing. Only air source heat pumps have been recorded for space heating and cooling at Protea Ryalls Hotel, although there may be one other heat pump installation. It is claimed that geothermal is being used for fish farming, but the Department of Energy Affairs and the Department of Geological Surveys could not confirm this. It is currently estimated that 0.1 MWt and 2 TJ/yr are for geothermal heat pumps, 0.1 MWt and 2 TJ/yr for agricultural dryings, and 0.35 MWt and 7.0 TJ/yr for bathing and swimming, for a total of 0.55 MWt and 11.0 TJ/yr (Gondwe, et al., 2019)

5.1.8. Morocco

As no paper was received from Morocco, we will use data from WGC2015, assuming nothing has changed. Thermal waters applications are mainly for balneology, swimming pools and bottling of potable water. The key application for developing geothermal energy use in the country is related to greenhouse heating; however, none is reported at this date. The geothermal use for bathing and swimming is estimated at 5 MWt and 50.0 TJ/yr (Barkaoui, et al., 2015).

5.1.9. Nigeria

There are sites where the recreational centers were developed on the basis of well- known geothermal springs, categorized as geothermal direct use examples in Nigeria. These are Ikogosi Warm Spring Resort in Ikogosi town, Ekiti State (SW Nigeria) and Wiki Spring Resortin in Yankari National Park, Bauchi State (NE Nigeria). The Ikogosi warm spring has a temperature of about 70°C at the source and 37°C after meeting a water stream from another cold spring. There is a swimming pool filled with the water from the spring as well as accommodation facilities for tourist in the resort. The Wikki warm spring has a temperature of 32°C, with a swimming area for the tourists fed by the source in a nearby cave. The Wikki spring is one of many attractions in the resort, along with the area's wildlife, forest, and remnants of a more primitive lifestyle. Besides the water temperature, another attractive quality of the Ikogosi and Wikki warm springs are their acclaimed curative power, widely-believed to have positive therapeutic effects. That, together with the area's natural beauty, attracts many tourists to the resorts. It is estimated that 0.7 MWt and 14 TJ/yr are the capacity and use of geothermal energy in the country for bathing and swimming (Kwaya, M. Y., Kurowska, E., 2019).

5.1.10. South Africa

Geothermal utilization in South Africa is confined to direct uses. During ancient times the thermal spring waters from Die Eiland (Letaba) and Soutini (Soulting) hot springs were used for salt production. This is still practiced at Baleni (Soutini) in the northern part of Limpopo Province for ceremonial and health purposes. During the 19th and early 20th centuries, thermal springs were very popular and visited for their alleged medicinal properties. This use waned over time, and currently the most popular use is leisure and recreation. Those thermal springs, with a relatively low flow rate and located far from established transport networks or in former 'tribal areas' or 'homelands', have either fallen into disrepair or were never developed. Application of a rating scale also showed that the majority of thermal spring waters, barring those in the Western Cape, have unacceptably high concentrations of fluorine and are not suitable for consumption. Despite the non-conformity of water for recreational use at some resorts (due to high fluoride levels), the small amount of water ingested during recreational activities such as swimming should not pose a hazard. However, even those springs which were fit for consumption violate South African National Bottled Water Association (SANBWA) standards, and thus are unsuitable for bottling. A total of 23 sites have been reported as using geothermal waters for swimming and bathing. These have a capacity of 2.3 MWt and use of 85.1 TJ/yr (Tshibalo AE, Olivier J and Nyabeze P. 2019).

5.1.11. Tunisia

No country update paper was received from Tunisia, thus this report is based on data from WGC2015, assuming little has changed since then. The use of geothermal energy in the country is limited to direct applications because of the low enthalpy resources, located mainly in the south. For thousands of years, geothermal water has been used in bathing. Many of the geothermal manifestations in the country are called *Hammam* or bath, reflecting the main use of geothermal water over the centuries. The government's policy in the beginning of the 1980's was oriented toward oasis development, and supplying geothermal water for irrigation. Therefore, boreholes are mostly operated to complement oasis irrigation after the water is cooled in atmospheric cooling towers. Water cooler than 40-45°C is generally used directly for oasis irrigation. Most resources are currently utilized for irrigation of oases and heating of greenhouses. The government started using geothermal energy for greenhouse farming in 1986, then considered a promising and economically feasible application, by planting one ha in the southern part of the country. The results of this experiment were encouraging, and thus the cultivated areas have now increased to 244 ha. Based on data from WGC2010 and WGC2015, 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) 0.4 MWt and 6 TJ/yr for a country total of 3.8 MWt and 364 TJ/yr (Ben Mohamed, 2015).

5.2. Asia

5.2.1. China

Geothermal direct-use in the country has benefited from the State requirements for energy conservation in buildings and the reduction of CO_2 emissions. The fastest growing sector is the installation of geothermal heat pumps (GHP). In 2009, GHP accounted for 53.5% of the installed capacity and 51.9% of the annual energy use. Today, these numbers are 65.1% and 55.5%, respectively. For geothermal direct-use after heat pumps, the largest uses were for individual space heating and for bathing and medical treatment, at 20.4% and 19.6% of the annual energy use. Geothermal space heating exceeds 150 million square meters, with a growth rate of 10% per year. Tianjin, south of Beijing, has the largest use of space heating, heating 25 million square meters, accounting for 6% of the city's central heating. It is expected that by 2020, by extracting 6.4 million m^3 per year, the heating area will reach 35 million square meters. In Beijing, 3.36 million square meters are heated with geothermal energy, including in the city, the international airport, a large sub-center, and the Winter Olympic venues. In Xiong County, Hebei Province, 4.6 million square meters are geothermally heated, meeting the needs of more than 9% of the area's winter heating, and creating China's first heating "smoke-free city".

The development and utilization of hot springs mainly concentrate on three areas. Firstly, medical and recuperation aspects, as modern medical research shows that hot springs have therapeutic effects on dozens of diseases, especially the cure rate of skin diseases. It is estimated that a total of 60% of the thermal fields are used for bathing. Industrial, agricultural and fishery uses are in second place. A good example of this use category is found in Beijing, where many plants are planted annually to use the heat and water from hot springs. Here, 20 km^2 are devoted to growing vegetables, along with 70 kinds of special flowers and 8 million flowers grown in greenhouses. China's use of hot springs for aquaculture has spread to over 47 geothermal fields in more than 20 provinces, with about 300 farms and 5.5 million m^2 of fish ponds. The third and final use is that of leisure tourism. Hot springs are used for tourism almost everywhere in China, especially in recent years, with developers' projects involving hot springs, hot spring culture, hot spring resorts and hot spring towns.

The use of geothermal (ground-source) heat pumps has developed rapidly in China, with an average annual growth rate of more than 20%. According to incomplete statistics, by the end of 2019 the buildings using geothermal heat pumps have reached 500 million m^2. As an example, in 2018, more than 1,300 heat pump projects were completed in Beijing, heating an area of 50.97 million square meters, which replaces 65,000 million tonnes of fossil fuels and reduces air pollution. Other examples include Beijing's Daxing International airport, providing heating and cooling to 2.57 million square meters of building area, and a sub-center of Beijing City that has installations which provide heating and cooling to 3 million square meters of floor space.

China now has seven geothermal district heating projects, with many greenhouse, agricultural drying, industrial and bathing/swimming projects. Geothermal heat pump projects are found in more than eight areas in China. For district heating 7,011 MWt and 90,650 TJ/yr. are used, for greenhouse heating, 346 MWt and 4,255 TJ/yr, for fish farming 482 MWt and 5,016 TJ/yr, for agricultural drying 179 MWt and 2,145 TJ/yr, for Industrial process heat 395 MWt and 8,221 TJ/yr, for bathing and swimming 5,747 MWt and 86,993 TJ/yr., and for geothermal heat pumps 26,450 MWt and 246,212 TJ/yr, for a total of 40,610 MWt and 443,492 TJ/yr (Tian, et al., 2020).

5.2.2. India

Up until recently, India's only direct-use applications were bathing, swimming and balneology (and to a lesser extent cooking), all used more frequently since 2015. More recently, private commercial establishments began installing GHP for space cooling to save large electricity bills, which meant that for the first time two 72 kW GHP units were installed, by M/S GeoSyndicate Power Pvt. Ltd., in a pharmaceutical storage house in Mumbai. The installation used groundwater drawn from a well, as a circulating medium. A shell-and-tube exchanger was used to maintain the space temperature at 27 °C. The unit has run successfully since March 2019. This has increased awareness amongst several commercial establishments, with the result that M/S GeoSyndicate has received several orders from food and grains storage establishments for the purpose of installing space cooling units – a good sign for the prospect of saving on electricity generated from fossil fuel while considerably decreasing CO_2 emissions. Overall use in the country is 0.144 MWt and 3.82 TJ/yr for cooling using heat pumps, and 357.5 MWt and 4004 TJ/yr for bathing, swimming and balneology, for a total of 357.644 MWt and 4007.82 TJ/yr (Chandrasekharam and Chandrasekhar, 2020).

5.2.3. Indonesia

Direct utilization natural hot springs has for hundreds of years been used not only for spas and swimming pools, but also for bathing, washing, cooking, and other purposes. These includes the distillation of vetiver oil, pasteurization of mushrooms, brown sugar processing, fish farming, and coffee-bean and tea-leaf drying. There is no new record of geothermal direct use in Indonesia as reported in the WGC2015. There is currently an aquaculture facility utilizing geothermal fluid in Lampung, a traditional freshwater fishery that mixes natural geothermal hot water (outflow) with freshwater from a river to grow large catfish. The farmer reported that the fish grow better in the geothermal fluid and freshwater mixture. Total brine use was about 50 tonnes/hour for fish farming. Palm sugar processing using brine produced from Lahendong geothermal field, and operated by the Masarang Foundation, was discontinued. Other uses of geothermal for agriculture include: copra drying in Lahendong, Mataloko and Wai Ratai Lampung; mushroom cultivation in Pengalengan (West Java); tea drying and pasteurization in Pengalengan; and geothermal direct used for large catfish growing in Lampung. The estimate for bathing and swimming is 2.30 MWt and 42.6 TJ/yr for a capacity factor of 0.587. No data are available on the other direct-uses. (Darma, et al., 2020).

5.2.4. Iran

In recent years (2015 onwards), governmental authorities have made efforts to publicize the concept of direct use of geothermal energy for agricultural, fish-farming and greenhouse purposes. Iran's major use of its thermal waters has traditionally been as recreational and balneological resources, in the form of swimming and bathing pools. Gradually but slowly, a few attempts have been made to promote the utilization of thermal waters for certain other purposes while still emphasizing recreational activities. Due to economic difficulties, only 6 new geothermal projects for bathing and swimming were completed during 2015-2019, and some existing district heating systems were also developed. Because of the currently subsided energy sources (oil, gas and electricity), the concepts of direct-use of thermal waters have not really caught on. Bathing, swimming and balneology is reported at 7 sites in the country, amounting to 1.52 MWt and 27.10 TJ/yr for a capacity factor of 0.565 (Mousavi and Jalilinasrabady, 2020).

A recent report (Porhail, 2019), however, indicates that there are 196 sites in the country used for bathing and swimming, for a total of 81.741 MWt and 2,576.9 TJ/yr along with 0.482 MWt and 6.36 TJ/yr for geothermal heat pump, giving a total for the country of 82.224 MWt and 2,583.216 TJ/yr. We will use these latter figures.

5.2.5. Israel

No country update report was received from this country and none for WGC2015 either. Thus, the data from WGC2010 will be utilized based on estimates from WGC2005. These included 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 2193 TJ/yr (Lund, et al., 2010).

5.2.6. Japan

No reliable data on conventional direct use exist because no census has been done since 2012. Almost all projects of hot spring water usage are managed by private enterprises in various areas of Japan. The three major usages of hot spring water are "Greenhouse farming" (to cultivate vegetables, mushrooms, fruits, and flowers), "Onshore fish farming" (to breed fish), and "Other usage" (heating of hotels, office buildings, and roads; cooking vegetables, eggs, and meats; and food drying). A typical example of Greenhouse farming is to cultivate mangos in a very cold area in east Hokkaido under the brand name "Sunset of Lake Mashu". The cultivation of tomatoes and cucumbers in the cold area of Mori town in southern Hokkaido is another common example. Other typical examples of onshore farming are to breed tilapia in the cold part of east Hokkaido, shrimp in Fukushima Prefecture, and tiger puffers in Tochigi prefecture. Typical examples of "Other usage" are: hotel building heating in Beppu in Oita prefecture; road heating in front of hot spring hotels in Niigata prefecture; cooking vegetables, eggs, and other foods in a steam box in the Kagoshima prefecture; and drying vegetables in Akita prefecture.

The installation of ground-source heat pumps (GSHP) in Japan has been exponentially increasing, although the total number is still rather small. The total number of facilities using GSHPs is 2,662, including 2,314 closed-loop, 327 open-loop, and 21 using both. It is a large increase over the last WGC2015 report total of 990, for a total installed capacity of 62 MWt. This shows a double or triple increase in 5 years. Many systems have been installed in the northern districts, including Hokkaido, indicating the economic benefit of GSHPs when new GSHPs replace old oil boilers. The largest share is individual houses (44%), followed by offices (12%), and public buildings (7.5%) (Yasukawa and Sasada., 2015).

The summary of geothermal direct-use in Japan is as follows: 91.97 MWt and 2,467.32 TJ/year for individual space heating, 111.37 MWt and 1,669.51 TJ/yr of district heating (which may include hot water supply for swimming pools at the locations), 24.71 MWt and 267.19 TJ/yr for greenhouse heating, 7.61 MWt and 123.10 TJ/yr for fish farming, 6.02 MWt and 76.73 TJ/yr for agricultural drying, 1.06 MWt and 27.02 TJ/yr for industrial process heat, 150.17 MWt and 431.98 TJ/yr for snow melting, 1,999.42 MWt and 24,591.00 TJ/yr for bathing and swimming, 14.69 MWt and 301.11 TJ/yr for other uses (cooking and animal farming), and 163.44 MWt and 764.90 TJ/yr for geothermal heat pumps, for a total of 2,570.46 MWt and 30,723.27 TJ/yr (Yasukawa, et al., 2020).

5.2.7. Jordan

Thermal springs have been used for bathing and irrigation for many years in Jordan. Recently several hotels (spas) reported construction at thermal spring sites. Thermal waters have been used at three locations for treating ailments such osteoarthritis, degenerative disc and post-traumatic stress. Several farms have reported tilapia production. One of them, the Arab Fish Company, has 40 basins producing 20-55 tonnes of tilapia per year. There were future plans were to use geothermal waters for greenhouse heating and refrigeration, but since no data were given in the WGC2015 paper by Saudi and Swarieh (2015) and no report was written for WGC2020, data estimates from 2010 (Lund and Freeston) will be used. It appears that at least six sites have installations for direct-use, mainly for bathing and swimming, for totals of 153.3 MWt and 1,540 TJ/yr.

5.2.8. Malaysia

So far only one high temperature geothermal prospect has been identified in Malaysia, in Sabah Province on the large island of Borneo. The project is known as Tawau or Apas Kiri, after the largest group of hot springs. Other than that, the only use of geothermal energy in Malaysia consists of at least 15 bathing facilities using natural hot water, mainly on the Malaysian Peninsula, with one in Sabah and one in Sarawak. These are probably of tectonic rather than volcanic origin. No technical details are available, but it can be presumed that the total thermal energy usage is small – an estimated 5 MWt and 100 TJ/yr for swimming and bathing (Lawless, et al., 2020).

5.2.9. Mongolia

Mongolia has 43 geothermal areas, many utilized for heating, bathing and medical purposes. Starting in 2008, geothermal (ground-source) heat pumps starting have become the largest use of geothermal energy. The National Sanatoriums utilize thermal waters via shallow wells (typically <100 m) in eight locations. Since about 2010, the two best-developed types of geothermal application are the traditional sanatorium and the newer technology of geothermal heat pumps. Many tourist camps have been established near these hot spring areas, where hot pots and small pools for bathing and swimming are utilized. Geothermal heat pumps have been established in public and private buildings throughout the country, such as at the Corporate Nukht Hotel and the National Renewable Energy Center. Three geothermal heat pump systems have been installed in public buildings, such as a school, dormitory and kindergarten, located in Tuv province center about 45 km southwest of Ulaanbaator, the capital. The country's estimated geothermal energy use is: 3.45 MWt and 54.4 TJ/yr for individual space heating, 15.95 MWt and 261.9 TJ/yr for bathing and swimming at 19 locations, and 3.318 MWt and 82.4 TJ/yr for geothermal heat pumps at 10 locations, for a total of 22.72 MWt and 398.7 TJ/yr (Dorj, et al., 2020).

5.2.10. Nepal

Thirteen new hot springs have been identified in different parts of Nepal in the update period. Of these, 7 lie in Myadgi district alone, 3 in Dhading district, and one each in Dolpa, Humla and Gorkha districts. Those found in Dhading District are Jharlang (Ruby Valley), Hindung Tatopani and Tipling Tatopani. In Gorkha district, one hot spring has been identified at Machha Khola. Geothermal energy remained the lowest priority renewable energy resource in the update period. However, much work has progressed at local and private level for its direct use, mainly for balneotherapy and tourism development. Infrastructure is extending satisfactorily in a number of existing thermal locations where people use it mainly for bathing. Recent developments have made existing spring areas more user-friendly for disabled people and special extended facilities for women as well. Myagdi district is gifted with quite a few soaking areas. West of the district capital of Beni, Singa Tatopani is the most popular hot spring of Nepal, even though most people know the Kodari hot spring equally well since it is closer to Kathmandu, the capital. These are the "must-visit hot springs in Nepal". More than 60,000 people from all over Nepal visit this spring every year mainly to cure rheumatic and gastric diseases. With increased publicity and improved geothermal management, however, other adjoining or distant spring areas are becoming more competitive with Nepal's better-known spas. Geothermal use for swimming and bathing in hot springs is 3.555 MWt and 96.113 TJ/yr (Ranjit, 2020).

5.2.11. Philippines

The Department of Energy (DOE) is currently implementing a local project entitled: "Philippine Geothermal Resource Inventory and Assessment", with the primary objectives of identifying and studying the potential of the country's indigenous geothermal resources for both power and direct-use applications. The effort to fully exploit geothermal resources is still in the infancy stage, compared to other countries. The drying plant in Palinpinon and Manito Lowland were decommissioned in 1997 and 1998, respectively. In line with the country's vast potential in utilizing geothermal energy directly for bathing, swimming and balneology purposes, the DOE has conducted an inventory of hot spring resorts and pools utilizing hot natural water from the foot of Mt. Makiling in Laguna. Part of the DOE roadmap is to study and promote direct use in the country. Direct-use application totals (swimming and bathing) are 1.87 MWt and 12.65 TJ/yr (Fronda, et al., 2020).

5.2.12. Republic of Korea

Geothermal utilization in South Korea is only for direct-uses, especially for geothermal heat pump (GHP) applications, because there are no high temperature resources associated with active volcanoes or tectonic activity. GHP installation in S. Korea has increased rapidly, showing more than 50% annual increase by 2011 and over 100 MWt new installations annually since 2012. Major installations are for large facilities, including mainly public and office buildings, thanks to strong government subsidy programs and the Mandatory Public Renewable Energy Act of 2004. Other direct-uses, including hot springs used for individual space heating, district heating, greenhouse heating and swimming pool heating applications, have remained stagnant for the last five years at 44 MWt. Thus, there is direct use of hot spring water resources at 13 locations with discharge temperatures higher than 42^{o}C, which has remained stagnant since 2008 and no further survey was made. No official statistics are made on GHP sales or capacity of individual heat pumps. In Korea, based on design reports to the Korean Energy Agency (KEA), most of the designed full load hours of heating and cooling of office building are around 570 and 590 hours per year, respectively, while those for residential houses (including apartment buildings) are 1,800 and 540 hours per year, respectively. According to recent official statistics by KEA (2018), the share of installation for residential houses or for capacity smaller than 17.5 kW is around 15.3%. We can see more than an average of 50%

annual increase until 2011 and 100 MWt installations per year since 2012. A powerful subsidy program which was enacted from 2010 is 'Agricultural Energy Efficiency (formerly Greenhouse Deployment) Program' for which the central government subsidizes 50% (used to be 60%) and local government covers 20%, which means rural farmers pay only 30% (used to be 20%) of GHP installation cost for greenhouses and aquacultures. This program drove more than 20 MWt installations per year until 2013 and around 10 MWt new installations per year since 2014.

In summary, the installed capacity and annual energy use for the various geothermal direct-use applications are: 0.66 MWt and 53.43 TJ/year of individual space heating, 2.21 MWt and 31.28 TJ/yr of district heating, 0.17 MWt and 1.33 TJ/yr for greenhouse heating, 32.56 MWt and 507.61 TJ/yr for swimming and bathing, and 1,446.16 MWt and 2889 TJ/yr for geothermal heat pumps, for a total of 1,489.76 MWt and 3,482.65 TJ/yr (Song and Lee, 2020).

5.2.13. Saudi Arabia

The most common low-grade applications are district heating (in winter) and cooling (in summer), various agricultural applications, and medical and touristic applications. A number of swimming pools, medical therapy centers, spas and refreshment places were constructed in the areas of Bani Malik and Al Khouba-Jizan areas, but no data are available. Notably, Saudi Arabia uses energy intensive conventional desalination processes while much of the rest of the world uses reverse osmosis process. The conventional desalination methods consume 12 x 10^9 kWh to generate 1 m^3 of fresh water. Once fresh water is available at affordable cost (at the same cost, but without subsidy) and given its abundant fossil fuel reserves, Saudi Arabia could potentially have strong control over energy and food security while being in a position to help other Gulf and Red Sea countries and countries meet their fresh water demand. Because it appears that the desalination process uses geothermally generated electricity, it cannot be considered a direct-use operation. A figure of 44 MWt is given for the installed capacity for direct geothermal use, with annual energy use of 152.89 TJ/yr and capacity factor of 0.31. In addition, three animal farming locations were listed, estimated (by Lund) at 1.00 MWt and 20.00 TJ/yr. This gives a total for the country of 45.0 MWt and 172.89 TJ/yr (Lashin 2020; Lashin, et al., 2020).

5.2.14. Tajikistan

Based on estimate made for WGC2010 (Lund, et al., 2010), the only use is for bathing and swimming at 2.93 MWt and 55.40 TJ/yr (Lund, et al., 2010). Ilolov et al. (2021) estimates hot spring discharge nationally to be 17.3 MWt and 479 TJ/yr in 2019, a substantial increase since 2010.

5.2.15. Thailand

There are over 1800 hot spring manifestations in the country, exposed in the north and extending towards western and southern Thailand, with surface temperatures ranging from 40 to 100°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 and other products. Results were positive, 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 77°C binary power plant, still in operation. A cold storage plant was also constructed to test the cooling of lemons, onions and lychees. A third drying facility at the Maechan geothermal field was 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. At total of 71 locations are reported, some with as much as 20 MWt of installed capacity and 80 TJ/year of utilization. Presently there are a number of geothermal heat pump facilities installed in the country, but the data are not available and can only be estimated.

The estimated use of geothermal energy for direct-use applications is 0.04 MWt and 0.3 TJ/year for crop drying, 127.470 MWt and 1168.898 TJ/yr for bathing and swimming, and 1.0 MWt and 12.0 TJ/yr estimated for geothermal heat pumps. This gives a total of128.510 MWt and 1181.198 TJ/yr for the country (Raksaskulwong, 2015).

5.2.16. Turkey

Studies in the country have identified more than 460 geothermal fields and over 2000 hot and mineral water resources (springs and wells), which have documented temperatures ranging from 20 to 287°C. At present there are 17 district heating systems in operation, some using water as low as 40-45°C to serve the equivalent of 116,000 residences. Greenhouses cover 4.3 million m^2 of surface area. There are six major greenhouse areas in the country, mostly in the west. Mostly tomatoes are grown in these greenhouses, 10% sold domestically and the rest to the major markets of Russia and Europe. Over twenty million local and about 20,000 foreign visitors enjoy the balneological uses of Turkey's geothermal water, with investments growing in recent years. Heating is provided to spas, hotels and time-share facilities, the equivalent of 46,400 residences, including 450 geothermal spas. The number of geothermal heat pump installations has grown, with large installations in the Metro Meydan M1 Shopping Center in Istanbul, the Terme Maris Facility in Dalaman, the Titanic Hotel in Antalya, in Antalya Terra City, and at the Sabiha Gokcen Airport in Istanbul. Today there are a total of 90 closed loop geothermal heat pump systems in the country.

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, 1,033 MWt and 11,402 TJ/yr for district heating, 0.35 MWt and 10.0 TJ/yr are used for air conditioning, 820 MWt and 15,516 TJ/yr for greenhouse heating, 1.5 MWt and 50 TJ/yr for agricultural drying, 1,205 MWt and 22,800 TJ/yr for bathing and swimming, and 8.5 MWt and 171 TJ/yr for geothermal heat pumps, for a total of 3488.35 MWt and 54,584 TJ/yr (Mertoglu, et al., 2020).

5.2.17. Vietnam

Almost all geothermal sources in Vietnam today are only used for direct utilization such as for spas, bathing, and hot water swimming pools, although recently people in Quynh Phu and Hung Ha districts of Thai Binh province have started using hot water for warming fish breeding ponds and chicken or pig pens farm in the winter. Currently there are only two Ground Source Heat Pump (GSHP) installation pilots in Hanoi, with one pilot project GSHP installed at the Vietnam Institute of Geosciences and Mineral Resources, with 6 sensors attached for monitoring. The COP calculated for cooling is 3.1 and 3.6 for heating. This COP shows that the GSHP installation can bring greater energy efficiency to the Hanoi area. One advantage to installing GSHP in northern Vietnam is that GSHP can be used for both summer cooling and winter heating. In summary, the installed capacity and annual energy use for the various direct-use applications in the country are: 0.53 MWt and 1.66 TJ/yr for fish farming, 17.64 MWt and 185.32 TJ/yr for bathing and swimming, 0.03 MWt and 0.08 TJ/yr for others (animal farming), and 0.01 MWt and 1.46 TJ/yr for geothermal heat pumps, for a total of 18.21 MWt and 188.52 TJ/yr (Thang and Cuong, 2020).

5.2.18. Yemen

Spa baths are located in many areas of Yemen, for an estimated total of 79 hot mineral baths. Thousands of visitors from Yemen, the Gulf and elsewhere visit these baths daily to treat intractable rheumatic and skin diseases, joint and spinal pain, skin and eye sensitivity, poor circulation and other ailments not always treatable through modern medicine. Thus, there is a vast potential for the development of medical tourism using geothermal waters. Currently, the Government of Yemen is seeking to improve the conditions of hot mineral water use in Yemen, so Bath Hammam in Taiz can expect to see a boom in medical tourism. A partial list of maladies thus treatable includes rheumatic infections; chronic arthritis; joint diseases caused by the urea deposits; chronic and non-festering skin diseases; dry allergies; fungal infections; stomach infections associated with high pH; chronic bronchitis; and cases of chronic inflammation in female reproductive systems. In the absence of any numbers from the Yemen Update authors, it is estimated that 5.0 MWt and 100 TJ/yr are used for bathing and swimming as well as medical tourism (Murshed, 2020).

5.3. The Americas

5.3.1. Central America and the Caribbean Islands

5.3.1.1. Costa Rica

The use of geothermal direct-uses resource is limited to low temperature developments at hotel pools dedicated to ecological tourism. Local factors have discouraged the further use of these resources. With the exception of small domestic applications, currently there are no other uses known outside The Institute for Energy (ICE).. It is not known how many pools and spas operate around the country currently, nor what their individual consumption is, so an estimate of the corresponding energy production of energy is necessary. Calculating on the basis of four known geothermic locations, distributed across Chile's central mountain chain, it is estimated that 1.75 MWt and 35 TJ/yr are attributed to bathing and swimming pools in the country (Sánchez-Rivera, 2020).

5.3.1.2. Eastern Caribbean Nations

There is not yet any utilization of geothermal resources for electricity generation on any of the nine islands, nor are there any geothermal heat pump systems in use. Direct-use is limited to "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. At The Baths, a small (~3 x 3 meters x 1 meter deep) concrete sitting structure has been built adjacent to the Charlestown fault which leaks thermal waters at about 40°C. The waters flow through at rates that depend on the time of year and the abundance or lack of rainfall, and there is ~1.5°C temperature change between the entering and leaving waters (0.046 MWt and 0.969 TJ/yr). At Malgretout, water falls from a cliff into a small (3 x 3 x 1 meter deep) concrete sitting pond. The waters overflow into the creek with ~1.5°C inflow-outflow temperature change and at flow rates that depend on the time of year and the climatological conditions (0.067 MWt and 9.13 TJ/yr). At Ravine Claire, the un-named ravine near Wotten Waven, and at the spring just outside of Peggy's Whim, bamboo pipes stuck into thermal water seeps focus water on shower-takers. Flow rates vary by time of year and drought/rainfall conditions. Inflow-outflow temperature changes are not measurable. In summary, the geothermal direct-use for swimming and bathing is 0.103 MWt and 2.775 TJ/yr (Huttrer, 2020).

5.3.1.3. El Salvador

No country update report was available for either WGC2015 or WGC2010. However, based on a visit by one of the authors (Lund, 2008) it was revealed that there were some limited developments of greenhouses, fish farming and fruit drying. During a tour of the Berlin geothermal field, samples of dried pineapples, apples, coconuts, etc. were made available by *Procesco de deshidratado Natural Geotermico*, called "Geo Fruit or FundaGeo." These fruits are processed in Berlin for local consumption. Based on recent evaluations, minimum values of 0.05 MWt and 10 TJ/year are 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 (Lund, et al., 2015).

5.3.1.4. Guatemala

No country update report was available for either WGC2015 or WGC2010, thus data from WGC2005 will be utilized. Geothermal energy in the past has been used for medicinal purposes, agriculture, and domestic use. The areas of Totonicapan, Quetzaltenango, and Amatitian are popular tourist attraction known for their thermal bath houses and spas. 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 1998, the fruit dehydration plant *Agroindustrias Las Laguna* was built to use hot water from a well in the Amatitian geothermal field in the drying process. The company produces dehydrated pineapple, mango, banana, apple and chili peppers. Data from WGC2005 will be used (Lund, et al., 2005). The concrete drying facility is reported at 1.60 MWt and 40.40 TJ/yr, the fruit drying facility is reported at 0.50 MWt and 12.10 TJ/yr, and spas are estimated at 0.21 MWt and 3.96 TJ/yr, (Merida, 1999). The total for the country is then: 2.31 MWt and 56.46 TJ/yr.

5.3.1.5. Honduras

There is a potential market for direct-uses in the country, such as cooling, industrial processes and bathing, especially since Honduras has many activities in the manufacturing area and with tourism companies. Also, due to the warm and humid climate, cooling is needed in varies areas such as supermarkets, industries and residential area. In 2014, Honduras in collaboration with the 4E-GIZ program, developed the project "Feasibility Study for the Development of Low and Medium Temperature Geothermal Resources for Industrial Processes" to promote the use of geothermal resources. Potential sites were identified, specifically in two areas in the northern part of the county at Valle de Sula and Sambo Creek. A number of swimming pools are reported using geothermal energy. These have an estimated installed capacity of 1.933 MWt and energy use of 45 TJ/yr (Henriquez, 2015).

5.3.2. North America

5.3.2. 1. Canada

More than 150 thermal springs of temperatures higher than 10ºC have been identified in the Western Canadian Cordillera. Commercial exploitation of these natural hot springs in the provinces of Alberta, British Columbia and Yukon as well as thermal water pumped from deep aquifers in Saskatchewan is taking place at thirteen 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 the First Nation people had used these for generations prior. Europeans initially visited Banff Hot Springs in 1882 and the first recorded visit at Radium Hot Springs was in 1841, all located on the western flanks of the Rocky Mountains. Construction of bathhouses and hotels at Banff, Mietta and Radium hot springs, respectively began in 1886, 1913 and 1914. Original bathhouses have been modified, restored or reconstructed and the hot spring pools are still operated today. The exploitation of shallow geothermal resources for geothermal heat pumps is concentrated in southern Ontario and Quebec, but installations are present throughout the country. Yukon has employed the direct-use of geothermal energy for several decades in the Takhini Hot Pools, operated near the capital city of Whitehorse. In Nova Scotia geothermal water from the abandoned Springhill mine uses geothermal water for space heating, taking water from one level and injecting in another. A similar project is being proposed for the Penobsquis Mine near the Town of Sussex in New Brunswick which would be used to heat floral greenhouses.

There are substantially more opportunities for low-temperature resources in Canada, particularly direct use applications and the use of geothermal heat pumps. Direct utilization of geothermal heat is currently limited to commercial hot springs and mine water. As mentioned above, 157 hot springs have been identified in British Columbia, Alberta, Yukon Territory, and the Northwest Territories. Sufficient data exist to characterize 48 hot springs, which have an estimated heat output of 250 MWt. However, due to seasonal factors there is variation in the output of these hot springs, making the output difficult to estimate. Currently, 13 natural occurring hot springs in Western Canada have been commercialized and developed into bathing, swimming and balneological facilities with a capacity of 8.780 MWt. In summary, the geothermal direct-use in Canada is: 8.78 MWt and 277 TJ/yr for bathing and swimming, 1,822.5 MWt and 14,235 TJ/yr for geothermal heat pumps, for a total of 1,831.28 MWt and 14,512 TJ/yr (Thompson, et al., 2020).

5.3.2.2. Greenland (Kalaallit Nunaat)

Geothermal springs with homeothermic source water temperature >2ºC can be found all over Greenland, however warm springs >10ºC are rare. They are found primarily on the east coast at a number of locations north and south of Scoresbysund and in several locations on Disko Island, West Greenland. Outside these regions only two occurrences of geothermal springs are known, at Uunartoq Island in South-Greenland and Ikasagtivaq on the southeast coast near Ammassalik. 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. Hot springs are found in a number of locations along the shore both north and south of Scoresbysund. The distance between the northernmost and southernmost sites is 350 km. Among them is the warmest geothermal spring of Greenland, the Unarteq hot spring at Cape Tobin. The maximum temperature is 61.8°C. Geothermal activity is known in several places on the south coast of Disco, for example near Qeqertarsuaq and farther north such as in Diskofjord and in Akugdlit fjord (Mellemfjord). In none of these springs is the temperature above 18°C, and the water discharge is always rather small. The warm springs in Uunartoq and Ikasagtivaq are outside the basaltic regions of Greenland. They occur as individual phenomena, not as a group of geothermal springs such as the thermal springs near Scoresbysund and on Disco Island. On Uunartoq Island there are geothermal springs which flow together into a small stone-dammed pool, 37-38°C. Here people have gone bathing for 1000 years. The first written information on geothermal activity and utilization in Greenland goes back to the medieval Greenland description of Ívar Bárðarson, written after his stay in the Norse settlement sometime around 1300 AD. He mentions warm springs in the small islets of the old Hrafnsfjörður (Ravensfjord), now known as the Island of Uunartoq. He also wrote about their annual temperature fluctuations and therapeutic properties: "In these islets there is a lot of warm water. In winter it is so hot that no one endures it, but in summer it is suitable for bathing. There many people have got holistic treatment and good healing and remedy of illnesses". Archaeological research has revealed ruins of a nunnery built near the hot springs after the Norse settlement in Greenland was converted to Christianity around 1000 A.D. The estimate total geothermal use in Greenland is 0.1 MWt and 3.2 TJ/yr for swimming and bathing (Hjartarson and Ármannsson, 2020).

5.3.2.3. Mexico

Mexico's geothermal energy is almost entirely used to produce electricity. Direct-use has had limited development in the country, restricted mostly to bathing and swimming facilities with recreational and/or therapeutic purposes, despite the great amount of thermal manifestations identified on the surface. More than 1,600 locations have been identified with low to middle temperatures that can be grouped into more than 900 geothermal systems in the country's 26 different states. 50% of these systems have temperatures between 62 and 100ºC, 40% between 100 and 149ºC, and the remaining 10% have temperatures below 62ºC (5%) or higher than 149ºC (5%). Geothermal space heating is provided at the CFE's facility in the Los Azufres geothermal field, which currently provides heat to offices, laboratories and other facilities, as well as the domestic hot water. Agricultural drying is provided by a dehydrator installed in the Domo San Pedro geothermal field, able to produce up to 200 kg of dry fruit per day, using geothermal brine from wells before reinjection. The use of geothermal water for bathing and swimming, including balneology, is the same as reported in 2015. These facilities are located in 18 states in Mexico, the majority of which have been developed and are operated by private investors. A minor part of these facilities is operated by state or municipal government, through tourism offices or associated with local owners. The first geothermal heat pumps (GHPs) were installed around 2014. Today, there are currently 11 GHPs units with a combined capacity of 133 kWt operating as demonstration projects in the states of Puebla, Baja California and Michoacan. These units have been installed in a small school and health clinic, in greenhouses, in laboratories, at the Polytechnic University in Mexicali, and at Michoacan

University in Morelia. All of these units are ground-coupled with both vertical and horizontal arrangements. A total of 11 units have been installed. In summary, in Mexico around 15,721 tonnes/hour of geothermal fluid flows to the surface, of which 13,442 tonnes/hour are utilized for direct use, with an installed capacity of slightly over 156 MWt. The totals are: 0.115 MWt and 3.627 TJ/yr for individual space heating, 0.518 MWt and 13.230 TJ/yr for agricultural drying, 155.347 MWt and 4,166.512 TJ/yr for bathing and swimming and 0.133 MWt and an estimated 0.520 TJ/yr for geothermal heat pumps for a total of 156.114 MWt and 4,183.890 TJ/yr (Gutierrez-Negrin, 2020).

5.3.2.4. United States of America

US geothermal energy is used for both electric power generation and direct-use. The direct-use of geothermal energy includes the heating of pools and spas, greenhouse and aquaculture facilities, space and district heating, agricultural drying, industrial applications, snow melting, and geothermal (ground-source) heat pumps (GHP). The largest application is GHPs accounting for 98% of the installed capacity and 95% of the annual energy use, with the next largest applications being fish farming, bathing and swimming, and individual space heating. Direct-use (without geothermal heat pumps) has remained almost static over the last 10 years, though decreasing over the last five years. However, GHPs are being installed at a 3.71% annual growth rate with 1.68 million units (12 kW size) being installed, down from a growth rate 8% for 2010-2015. Approximately 40% of the GHP installations are for residential use and the remaining 60% are for institutional and commercial use. In the institutional and commercial sector approximately 90% of the GHP units are closed-loop (ground-coupled) and the remaining open loop (water-source). Within the residential sector, of the closed-loop systems approximately 30% are vertical and 70% horizontal -- the latter being cheaper to install. In the institutional and commercial sector, approximately 90% are vertical and 10% horizontal, constrained by limited ground space in urban areas. About 90% of GHP installations are in the eastern, midwestern and southern states with only about 10% installed in western states. The largest installation is at Ball State University in Indiana where 3,600 vertical loops were installed in 2012. The system heats and cools 47 buildings, and replaced four old coal-fired boilers. The system supplies 6°C cold water for cooling and 66°C hot water for heating at an annual savings of US$2 million.

No significant new facilities have been added during the last five years, except for a few residential geothermal wells drilled and brought on-line in Klamath Falls and other communities. When considering direct-use without geothermal heat pumps, the distribution of annual energy use (TJ/year) is 30.5% for fish farming, 29.3% for bathing and swimming, 14.6% for individual space heating, 13.1% for district heating, 9.9% for greenhouse heating, 1.3% for agricultural drying, 0.8% for animal farming, 0.3% for snow melting, and 0.2% for industrial process heating. All 50 states report installations and use of geothermal heat pumps, with most of the units located in the mid-western and eastern states. A total of 21 states record geothermal direct-use projects, all of which report use for swimming and bathing, 14 states report individual space heating, 10 states report fish farming, 9 states report greenhouse heating, 8 states report district heating, and 6 states report industrial applications which include agricultural drying and snow melting. The states with the most use, in terms of both installed capacity (MWt) and annual use (TJ), are Idaho, California and Oregon. The capacity and use values are down from 2005-2015 by approximately 25 to 28%, mainly due to less state and federal government financial support and due to the high initial cost of installing these systems

In summary, direct-use totals in the United States are: 89.43 MWt and 1,073.2 TJ/yr for individual space heating, 89.60 MWt and 958.3 TJ/yr for district heating, 79.78 MWt and 730.2 TJ/yr for greenhouse heating, 122.13 MWt and 2,241.9 TJ/yr for fish farming, 2.34 MWt and 59.0 TJ/yr for animal farming (others), 6.45 MWt and 97.5 TJ/yr for agricultural drying, 0.90 MWt and 17.6 TJ/yr for industrial applications, 2.06 MWt and 18.6 TJ/yr for snow melting, 89.85 MWt and 2,153.2 TJ/yr for bathing and swimming, and 20,230 MWt and 145,460 TJ/yr for geothermal heat pumps, for a total of 20,712 MWt and 152,810 TJ/yr with a capacity factor of 0.23 (Lund, et al., 2020).

5.3.3. South America

5.3.3.1. Argentina

The country continues to develop both high enthalpy and low enthalpy resources, most recently in new thermal areas associated with sedimentary basins (Chiodi et al., 2020). This has allowed the development of therapeutic-recreational complexes that generate new sources of revenue for the region. A number of low enthalpy resources have been developed and put into production for direct-use applications in ten areas, including the provinces of Cordoba, Corrientes, Misiones and Buenos Aires. Other developments are located in the Mesopotamia and Pampa Humeda regions, mainly in the form of therapeutic-recreational complexes. A snow melting project using geothermal steam is used to keep the Copehue ski resort in the Andes open all winter. A total of 66 sites are reported to utilize geothermal water for direct-use, ranging in temperature from 23 to 65°C. Eight sites are used for individual space heating, one for greenhouse heating, two for fish farming, one for snow melting, and 61 for bathing and swimming – many of these sites have combined uses. No use of geothermal heat pumps is reported. In summary, 22.40 MWt and 50.00 TJ/yr are used for individual space heating, 21.48 MWt and 40.10 TJ/yr for greenhouse heating, 7.03 MWt and13.10 TJ/yr for fish farming, 1.36 MWt and 31.60 TJ/yr for snow melting, 137.21 MWt and 1,029.63 TJ/yr for bathing and swimming, and 15.30 MWt and 44.64 TJ/yr for other uses (animal farming), for a total of 204.78 MWt and 1,209.07 TJ/yr (Agostina, et al., 2020).

5.3.3.2. Bolivia

No information was provided by the country update report for Bolivia (Villarroel, 2020), however, photographs of a hot spring in the Altiplano of the Andes have been shown on the Internet. This is at the Termas de Polgues Hot Spring at Uyuni showing a bathhouse and a concrete lined pool. The estimate made by J. Lund is 1.0 MWt and 20 TJ/yr for bathing and swimming.

5.3.3.3. Brazil

Studies have been carried out on very low geothermal energy, also designated as shallow geothermal energy (SGE), for space conditioning purposes including geothermal heat pump and geothermal air conditioning systems. The first very low temperature geothermal system was implemented in 1996 in the state of Rio de Janeiro, to supply the heating and cooling needs of a house. Since then, more than 15 studies have been conducted by universities and companies, showing its technical viability, and two additional plants have been constructed. The largest one is a seawater-geothermal plant constructed in Rio de Janeiro in 2015, supplying the cooling demand of the emblematic "Museum of Tomorrow" and the other a geothermal heat pump system installed in a farm house in the state of Parana. A total of 42 direct-use sites have been identified, the majority of which are for bathing and swimming. Two sites are identified as using geothermal for process heat and one for fish farming, along with some air conditioning and geothermal heat pump use for which and annual energy use has to be estimated. In summary, 2.3 MWt and 40.0 TJ/yr (estimated) is used for air conditioning, 1.0 MWt and 20 TJ/yr are estimated for fish farming, 4.2 MWt and 77 TJ/yr for industrial process heat, 355.9 MWt and 6,545.4 TJ/yr for bathing and swimming, and 0.05 MWt and an estimated 0.30 TJ/yr for geothermal heat pumps, for a total of 363.45 MWt and 6,682.7 TJ/yr (Vieira, et al., 2020).

5.3.3.4. Chile

As in the rest of the Andean countries, Chilean geothermal resources have been traditionally used for recreational and touristic purposes. A number of thermal spring resorts and spas are distributed throughout the country, some of them equipped with sophisticated touristic infrastructure and others still rather rustic. The majority of these thermal springs use geothermal energy only for bathing and swimming. The only two places known for using geothermal energy for heating cabins or for hotel installations are the Centro Termal Armada Liquiñe (Los Rios region) and the Puyuhuapi Lodge (Aysén region). In most cases, the thermal water is collected from natural hot springs and then piped to buildings and pools. Only very few spas have shallow wells drilled to extract the hot water. The use of geothermal heat pumps in Chile began in 1996. A study identified 29 projects using geothermal heat pumps, mostly in the Metropolitan and Bío-Bío regions. Water source (well or lake water) and horizontal closed-loop systems are the predominant installations, but some vertical and closed-loop systems, as well as one pond loop system, were also reported. Two examples are the public hospitals in the cities of Rancagua and Talca. Finally, different industrial uses in aquaculture, greenhouses, and wine industry have included the use of geothermal heat pumps, mainly due to its high efficiency. Two pilot projects in Southern Chile (Aysén) aimed to show the benefits of geothermal direct use. One of these is a geothermal greenhouse in Puerto Aysén, where extreme weather conditions kept crops from growing in winter. With the new system, the greenhouse operators can grow and harvest crops year-round. The other project is a heating system for a public school in Coyhaique, known as one of the most polluted cities in South America due to the wood which residents burn for heat.

In summary, direct-use geothermal energy is used for bathing and swimming at 29 locations at 14.68 MWt and 228.91 TJ/yr which includes two sites with space heating (no figures are available), 61 sites report the use of geothermal heat pumps (GHP) for 7.934 MWt; however, only a few sites list the TJ/yr, thus 50.0 TJ/year are an estimate yielding a capacity factor of 0.20, typical for GHPs. This gives a total for the country of 22.61 MWt and an estimated 278.91 TJ/yr for a capacity factor of 0.39 (Morata, et al., 2020).

5.3.3.5. Columbia

The ancestral use of geothermal resources is based on the hot springs for bathing and swimming, installed in 39 localities. The first heat pump for cooling purposes was installed in an industrial park in Tocancipá 40 km north of Bogotá, the capital. The heat pump works full time and cools a 90 m^3 room down to -10°C. The temperature change in the circulating underground water, at 2500 L/h, is 6°C, rising from 15°C to 21°C. Three vertical wells support the heat pump; two 70 m and one 80 m deep. This was the first geothermal project to get incentives from Law 1715, formalized by a resolution from the Environmental Licenses National Agency (ANLA) in 2018. No data is available on geothermal heat pumps use, thus 1.0 MWt and 20.0 TJ/yr are estimated for the one location. Geothermal direct-use is limited to bathing and swimming, reported for 39 locations at 18.0 MWt and 300.0 TJ/yr, for a total use of 20.0 MWt and 340 TJ/yr (Alfaro and Rodríguez-Rodríguez, 2020).

5.3.3.6. Ecuador

Until 2019, utilization of geothermal resources in Ecuador was restricted to direct uses only, that is, for bathing resorts, balneology and swimming pools. A summary of 22 bathing and swimming site is provided, giving a total installed capacity of 5.157 MWt and an annual energy output of 102.401 TJ/yr., unchanged since the last update. Nevertheless, the National Institute for Geological and Energy Research (IIGE), in charge of development of low temperature geothermal resources, has started construction of the first greenhouse powered by a GSHP with a horizontal ground loop. A ground Thermal Response Test was undertaken on site to determine accurate values of Thermal Conductivity, Soil Diffusivity and Volumetric Heat Capacity. Heat will be extracted from six slinky horizontal ground loops and one horizontal ground loop at a depth of 2 m at an average temperature of 17.5°C. A GSHP will deliver warm air inside the greenhouse with the aid of fan coils when ambient temperatures fall below 12°C. A state-of-the-art control system, which opens and closes lateral windows, will also be installed inside the greenhouse to keep conditions optimal throughout the day. The GSHP is estimated to provide 0.044 MWt and 1.06 TJ/yr, for a total for the country of 5.201 MWt and 103.461 TJ/yr (Beate, et al., 2020).

5.3.3.7. Peru

The first and oldest evidence of the utilization of geothermal heat in Peru is from the pre-Inca and Inca periods. These populations used the thermal water for curative and recreational purposes, in the form of balneology. The oldest and best known is the "Baños del Inca" (Inca baths) in Cajamarca, formerly called "Baños de Pultumarca" (hot place), where 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, later known as Baños del Inca, at that time consisting of buildings which were some of the of the Caxamarca chiefs' principal residences. The chiefs used the hot springs for healing and for rites of worship. After the Incas conquered the Caxamarca culture, the hot springs area then became important residences for the Inca chiefs. Nowadays, geothermal resources are traditionally used for recreational and touristic purposes, where close to popular tourist attractions. However, the use of these resources in Peru is still mainly limited to entertainment and balneology in places such as Baños del Inca in Cajamarca, Callejón de Huaylas in Huaraz, Churín in Lima, Calera in Arequipa and Aguas Calientes in Cusco. The use of geothermal sources in balneology activities (hotels, spas and recreation) in Peru has increased, from the usage of traditional techniques to the construction of hotels located in Cusco (Aguas Calientes) and Arequipa (Colca Canyon). As of 2019, 59 authorizations have been granted for the usage of geothermal sources for touristic purposes, mainly in the regions of Arequipa and Cajamarca. Most of Peru's hot springs are in Cajamarca, Cusco, Ancash, Lima, and Arequipa

Moquegua y Tacna. Cajamarca is the region that has taken greatest advantage of its hot springs, serving guests for health purposes. Peru does not have an official estimate of the direct-use for baths and balneology, thus, based on estimates from WGC2015 the installed capacity is 3.0 MWt and energy use of 61.0 TJ/yr (Cruz and Vargas, 2015).

5.3.3.8. Venezuela
No report on the use of geothermal resources was made available for WGC2020 or WGC2015. Personal communication with Urbani in 2014 indicated that there had been no change since 2005. Thus, the figure of 0.70 MWt and 14.0 TJ/yr are estimated for several small spas in use (Lund, et al., 2005).

5.4. Europe

5.4.1. Western and Northern Europe

5.4.1.1. Austria
Geothermal district heating (GDH) networks represent the most important use type in Austria. Seven such projects currently operate in the Upper Austrian Molasse Basin, with two further projects in the Styrian Basin. Two of these also have additional uses: Geinberg for balneology and greenhouse, and Altheim for power generation. As of 2018, the geothermal district and local heating scheme in the communities Ried im Innkreis and Mehrnbach supplied 2,258 apartments, 169 houses and 97 commercial facilities. The network length was 35.3 km. Plans to establish geothermal grids or to integrate geothermal energy into existing schemes have also been drawn up for the cities of Vienna and Salzburg.

Balneological use of thermal water has a very long tradition in Austria, dating back to Roman times at three sites, using natural warm springs up to 47ºC. Currently, 27 spas are in operation in Austria. However, the number of spa visitors, while relatively high (9.4 million in 2018), has not changed for years. One such example is the facility in Bad Waltersdorf, in the Styrian Basin. Bad Waltersdorf was the first geothermal project in Austria at the end of the 1980s and nowadays makes use of a multi-stage cascade involving heat pumps. The geothermal project in Bad Blumau comprises district heating, an ORC plant, balneology and liquification of CO_2.The geothermal heating of the greenhouses started in 2016. The vegetables cultivated are tomatoes, peppers and cucumbers. They are only sold, thus decreasing the need for imported vegetables, especially during winter.

Water-Water heat pumps play a significant role in the energy supply of larger buildings, especially for the ever more important purpose of cooling. This is a result of climate change as well as the excessive use of glass facades in architecture. Cooling with heat pumps leads to a noticeable warming of shallow groundwater, an effect especially noticeable in areas with a high concentration of GSHP projects. One example is the city of Graz, the second largest city in Austria with nearly 290,000 inhabitants. The total licensed circulation volume of all installations in Graz is on the order of 230 L/s. A general warming of groundwater of about 2 °C has been observed in recent years.

In summary, 61.79 MWt and 1,517.18 TJ/yr are reported for district heating, 21.90 MWt and 501.68 TJ/yr for greenhouse heating, 12.09 MWt and 316.35 TJ/yr for bathing and swimming, and 1,000 MWt and 6,309 TJ/yr for geothermal heat pumps, for a total of 1,095.78 MWt and 8,644.21 TJ/yr (Goldbrunner, 2020).

5.4.1.2. Belgium
In general, geothermal energy has been growing slowly in Belgium over the past 10 years, mainly in the form of geothermal heat pumps (GHP). The Saint-Ghislain and Douvrain wells have produced geothermal water for heating networks since 1985. This heating is provided to public buildings, such as hospitals, schools, swimming pool, etc., and to a few hundred housing units. Ultimately, the residual heat from the Saint-Ghislain network is sent to the Wasmuël water treatment plant to stimulate the fermentation process. After a hesitation in the development of shallow geothermal energy systems in Belgium between 2014 and 2017, a clear revival can now be observed. In Flanders this is mainly due to the tightening of the E-level requirements (energy performance of buildings) and the obligation to produce at least 15 kWh/m^2 renewable energy. This is also encouraged in Brussels where passive construction has been mandatory since 2015 with a required heat demand not to exceed 15 kWh/m^2. As a result, there is a boost in the use of heat pumps. Although air/water systems have the upper hand, more and more geothermal heat pumps are being installed. This is also encouraged in the Brussels area. In summary, there are four district heating systems with an installed capacity of 19.978 MWt and 411.27 TJ/yr, and geothermal heat pumps at 284.622 MWt and 1,027.501 TJ/yr, and 1.12 MWt and 28.73 TJ/yr of other uses, for a total of 305.72 MWt and 1,467,501 TJ/yr (Hoes, et al., 2020).

5.4.1.3. Denmark
At present, three geothermal district heating plants are operating in Denmark with several more in the planning stage. All the geothermal plants use absorption heat pumps and produce heat for district heating. Absorption heat pumps operate at no cost, as long as other heat producers such as biomass boilers can supply at least 160°C, driving heat down to district heating cost levels. Furthermore, all the geothermal plants use the doublet concept: warm formation water is pumped to the surface from a production well using no stimulation of the geothermal reservoir. After heat is extracted and distributed to the district heating system, the cooled water is returned to the reservoir through injection well(s). In Thisted, the production well produces approximately 44°C warm water from the Gassum Formation at a depth of 1250 m where the water has a salinity of 15%. The plant produces up to 7 MW from 200 m^3/h geothermal water and transfer 10 MW heat to the district heating net by heat exchange and through absorption heat pumps driven by heat primarily from a biomass boiler. In Sønderborg, the production well produces 48°C warm water from the Gassum Formation at a depth of 1200 m where the water has a salinity of 15%. The plant is designed to produce up to 12 MW from 350 m^3/h geothermal water with the use of absorption pumps driven by biomass. The Margretheholm plant exploits a geothermal reservoir in the Lower Triassic Bunter Sandstone Formation at 2600 m depth where 19% saline geothermal water is available at approximately 74°C. The plant is designed to extract 14 MW heat from 235 m^3/h geothermal water and transfer 27 MW heat to the district heating net by heat exchange and through three absorption heat pumps driven by 14 MW steam primarily from a wood pellet-based CHP

plant. Closed loop boreholes to around 150 m in depth are also being used for domestic heating, for single houses, for smaller collective networks, and for heating large office buildings. The district heating plants provide 33 MWt and 355 TJ/yr. The number of ground source heat pumps extracting shallow geothermal heat is estimated to be round 40,000 units, with an installed capacity of 751.0 MWt and energy use of 4,023 TJ/yr. In addition, there is an estimated 1.0 MWt and 2.0 TJ/yr for cooling. The total for the country is then 752.0 MWt and 4025 TJ/yr (Røgen et al., 2015; Mathiesen and Røgen. 2020).

5.4.1.4. Faroe Islands

Geothermal energy utilization is quite new in the Faroe Islands, but over the last 10 years more than 300 shallow geothermal wells have been drilled for extraction of ground source heat for private households. These wells have given valuable insights into the variations of the geothermal gradient and the groundwater resources in the Faroese subsoil. Data information from the wells has been very scarce due to poor regulations in the area, but from 2019 on the Faroese Geological Survey has been actively engaged in data-collection and well-logging in all newly drilled wells. It seems that the wells in Kollafjørður and Vestmanna, together with older knowledge about warm springs across the country, has sparked a public and political interest in geothermal and other renewable energy solutions, one which will hopefully continue to expand. At present, only 304 geothermal heat pumps (GHP) are used for space heating on the islands. The total for GHP is 3.66 MWt and 20 TJ/yr for CF = 0.17 (Ellefsen, et al., 2020).

5.4.1.5. Finland

No country update report was submitted from Finland for either WGC2020 or WGC2015, but data from the European Geothermal Congresses in 2013 and 2019 can be used (Kallio, 2013 and 2019). Space heating is provided by the 900,000 heat pumps installed throughout the country, of which 140,000 are geothermal or ground-source (GSHP). The air-source heat pumps have been most popular due to cost; however, half of the new houses utilize GSHP for heating and cooling. An increasing number of large buildings, schools, apartment buildings, shopping centers, markets, hospitals and churches prefer GSHPs for heating and especially for cooling. Apartment buildings in cities are switching from district heating systems to shallow individual geothermal systems. The largest installation in Finland is in the logistics center in the southern part of the country. Here 150+ closed loop borehole heat exchangers (BHE), each 300 m deep (total 90,000 m), are used in two separate buildings. Only closed loop BHE-systems are used in Finland with ethanol-based fluid circulating in the exchangers. These are typically a single or double U-pipe with diameter between 32-40 mm, to depths of 15-300 m, but can go to 400-600 m at around 20 m spacing. Thermal Energy Storage is also used in summer where heat is rejected and stored underground to be used in winter. The governmental target set for 2020 is now 8 TWh, representing about 10% of the energy needed for heating homes. GSHPs produce about 8-9% of the total residential space heating use (70-80 TWh). Thus, the estimate for geothermal use is 2,300 MWt and 23,400 TJ/yr (Kallin, 2019).

5.4.1.6. France

The direct use of geothermal heat is quite well developed in France. The Paris basin has five large aquifers, including the Dogger, which has the largest number of low-energy geothermal operations in the world, with 46 operations providing geothermal energy to about 6-7 % of the total population of 11 million people. The geothermal use is limited to collective heating and cooling applications. A conventional operation in the Paris region allows the heating and the production of sanitary hot water of approximately 4,000 to 6,000 housings. Only four new geothermal doublets have been created from scratch in the last 3 years, 2 tapping the Dogger aquifer. The district heating networks supplied by the Dogger geothermal resource are mainly exploited by private companies, but also by local public-private ventures. The oldest of these installations is located at Melun-l'Almont, commissioned in 1969. Recently Albian and Neocomian aquifers have been used for geothermal district heating and cooling applications but with large heat pumps and for smaller projects in term of housing. There are now six doublets using this resource. Based on EGS technology, another deep geothermal energy project at Rittershoffen in northern Alsace was commissioned in 2016. This heating plant, located less than 10 km from Soultz (in the Rhine Valley), has been designed for the industrial needs of a biorefinery. With an installed capacity of 24 MW thermal, the geothermal plant provides superheated fluid to an agricultural industry for their processes 24/7, covering 25% of their energy needs with low environmental impact. The distribution of different types of heat exchangers in France is: 5% for single housing open loop, 25% for collective open loop based on water, 25% for individual vertical exchanger, and 45% for collective vertical exchangers. For private housing installations, the distribution of vertical heat exchangers is 40% for new, and 60% for refitted housing. For collective installations, it is 55% for new and 45% for refitted.

In summary, there are 72 locations in France using geothermal energy for direct heating, with 174,000 geothermal heat pumps units in individual houses (98%) and large buildings (2%). Uses are for: individual space heating 0.6 MWt and 15.5 TJ/yr; district heating 509.4 MWt and 5,109.4 TJ/yr; greenhouse heating 8.6 MWt and 100.8 TJ/yr; fish farming 9.4 MWt and 204.3 TJ/yr; agricultural drying 24.0 MWt and 691.2 TJ/yr; bathing and swimming 20.5 MWt and 187.2 TJ/yr; other uses 10.0 MWt and 92.3 TJ/yr; and geothermal heat pumps 2,015 MWt and 10,879 TJ/yr, for a total of 2,597.6 MWt and 17,279.6 TJ/yr (Boissavy, 2020).

5.4.1.7. Germany

Due to favorable geological conditions, geothermal district heating and power plants are mainly located in the Molasse Basin in Southern Germany, in the North German Basin, or along the Upper Rhine Graben. In addition to installations using "deep" geothermal energy, numerous small- and medium-sized decentralized geothermal heat pump units are used for heating and cooling of individual houses and office buildings. At the end of 2018, 382,000 geothermal heat pumps were running successfully in Germany and supply renewable heat mostly for residential buildings. Thermal spas are the most widespread form of deep geothermal heat use. However, the number of larger district heating plants is growing continuously. They presently account for about 68% of the deep geothermal heat production, and are increasing. Besides deep geothermal utilizations, numerous geothermal heat pumps for heating and cooling office buildings and private houses make up the major portion of geothermal heat use in Germany. In Germany, common deep geothermal utilizations for direct use are district heating plants or combined heat and power plants (CHP), thermal spas, and space heating. At present, about 190 geothermal installations of these types are in operation in Germany. There are five deep borehole heat exchangers operating in Germany: Arnsberg, with a total depth of 2,835 m heating a spa; Prenzlau (2,786 m, used for district heating); Heubach (773 m, providing heat for industry); Landau (800 m, for space heating); and Marl (700 m, for local heating). Thus, 26 district heating and combined heat and power plants accounted for the largest portion of the geothermal capacity. Also, the use of mine water is becoming ever more important. Between 2008 and 2015 the sales figures of all heat pumps stayed on a relatively constant level (50,000 to 60,000 units per year), before sales increased and reached their highest level of 84,000 units sold in 2018. Within the same time periods, the market share of geothermal heat pumps decreased from more than 50% to less than 30% in 2018, with about 23,500 geothermal heat pumps sold.

In summary, there are 382,000 geothermal heat pumps units installed in the country (11.5 kW average size) accounting for 1.62% of the residential heat demand. These are the largest users of geothermal energy in the country, followed by district heating in 26 cities, and bathing and swimming. The various uses of geothermal energy are: 3.34 MWt and 35.21 TJ/yr for individual space heating; 346.2 MWt and 3,634.87 TJ/yr for district heating; 56.8 MWt and 1,708.56 TJ/yr for bathing and swimming; and 4,400 MWt and 23,760 TJ/yr for geothermal heat pumps, giving a total for Germany of 4,806.3 MWt and 29,138.6 TJ/yr (Weber, et al., 2020).

5.4.1.8. Iceland

Direct uses and especially space heating are predominant in geothermal utilization in Iceland. The pioneer was a farmer in Sudur-Reykir near Reykjavík, who in 1908 started using geothermal water to heat his house by transporting water from a hot spring through a pipeline over a distance of about 500 m. Large-scale utilization of geothermal energy for space heating began in 1930 with the installation of a 3 km-long pipeline transporting hot water from the hot springs of Laugardalur in Reykjavík. Some official buildings and about 70 private houses received this hot water from geothermal wells located close to the old thermal springs in Reykjavík. The formal establishment of Reykjavík District Heating (now Reykjavík Energy) was in 1946. The share of geothermal energy increased from 43% in 1970 to the current level of about 90%. 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 a group of farms as well as summerhouses, greenhouses and other users. Today Reykjavík Energy utilizes low-temperature areas within and in the vicinity of Reykjavík as well as the high-temperature fields at Nesjavellir, about 27 km away since 1990 and at Hellisheidi since 2010. At Nesjavellir and Hellisheidi cold ground water is heated in co-generation power plants. Akureyri is a town of about 19,000 inhabitants located in the north of Iceland, which has been heated by geothermal energy since the end of the 1970s. Hot water is pumped to Akureyri from six different geothermal fields. For centuries natural hot springs were mainly used for bathing in Iceland, but since early in the last century outdoor swimming pools have been gaining popularity and now operate all year round. There are about 165 recreational swimming centers in the country, 140 of which use geothermal heat to keep the water at 28-30°C. Most of the swimming pools are open to the public throughout the year. In the greater Reykjavík area alone, there are fourteen public outdoor pools and a few indoor ones as well. The largest of these is Laugardalslaug, with 1,500 m^2outdoor pools, one 1,250 m^2 indoor pool and five hot tubs where the tub temperature ranges from 35 to 42°C. The number of people visiting Laugardalslaug annually is about 800,000. Among other balneological uses for geothermal energy are the Blue Lagoon (1.3 million visitors in 2017), the bathing facility Mývatn Nature Bath at Bjarnarflag close to Lake Mývatn in northern Iceland, the Laugarvatn Fontana geothermal baths, the Secret Lagoon at Flúdir, and the NLFI Spa and Medical Clinic in Hveragerdis. Geothermal water is used in Iceland to heat sidewalks and pavements to melt snow during the winter. These uses have been gradually increasing and today almost all new buildings in areas with geothermal heating have snow melting systems. Iceland's total area of snow melting systems is around 1,200,000 m^2, mostly in the capital area. Used water from houses, at about 35°C, is used for deicing sidewalks and parking spaces. In downtown Reykjavík, a snow-melting system has been installed under most sidewalks and some streets, covering an area of 70,000 m^2. This system is designed for a maximum heat output of 180 W/m^2 of surface area, and the annual energy consumption is estimated to be 430 kWh/m^2. The largest industrial user of geothermal energy in Iceland is the seaweed drying plant Thorverk, located at Reykhólar in West Iceland. The company harvests seaweed found in the shallow sea waters of Breidafjordur bay using specially designed harvester crafts. Once on land, the seaweed is chopped and dried in a belt dryer that uses large quantities of air heated to 85°C by geothermal water. The plant has operated since 1975 and produces about 4,000 tonnes of rockweed and kelp meal annually. Two salt factories that utilize geothermal energy in their production have been established in Iceland in recent years. The focus is on producing "gourmet" table salt. They use over 100°C hot geothermal water to boil seawater at 51°C under sub-atmospheric conditions and to dry the salt. Heating of greenhouses is one of the oldest and most important uses of geothermal energy in Iceland after space heating. Naturally warm soil had already been used for outdoor growing of potatoes and other vegetables for a long time when geothermal heating of greenhouses started in Iceland in 1924. The majority of the greenhouses are in the south, most enclosed in glass. The heating installations consist of smooth steel pipes hung on the walls and over the plants. Under-table or floor heating is also common. By using electric lighting, the growing season is extended to year-round, maximizing greenhouse use and increasing annual production. CO_2 enrichment in greenhouses is common, primarily by using CO_2 produced in the geothermal plant at Hædarendi. Outdoor growing at several locations is enhanced by soil heating with geothermal water, especially during early spring. The total surface area of greenhouses in Iceland is about 200,000 m^2 including plastic tunnels for bedding and forest plants. Of this area, which has not changed much in the past few years, 50% is used for growing vegetables such as tomatoes, cucumbers and peppers, with the rest used mainly for growing cut flowers and potted plants. The total annual production of vegetables in Iceland is about 18,000 tonnes. Fish farming has been a slowly growing sector in Iceland for a number of years. Salmon and arctic char are raised most often, followed by trout and Senegalese sole. There are about 60 fish farms in Iceland and the total production was about 21,000 tonnes in 2017. Of these fish farms, between 15 and 20 utilize geothermal water. Geothermal water, commonly 20-50°C, is used to heat fresh water, either in heat exchangers or by direct mixing, typically from 5 to 12°C for juvenile production. The main use of geothermal energy in the fish farming sector in Iceland is for producing smolt (juvenile char and salmon). With land-based char production, geothermal energy is also used for post-smolt rearing.

In summary, there are 28 communities and cities that use geothermal energy mainly for district heating, 23 for bathing and swimming, 7 list fish farming, 10 list greenhouse heating, 15 list snow melting, and 16 list industrial processing, using 12,630 kg/s of geothermal water. Geothermal heat pumps report 126 units in operation, including vertical, horizontal and water well installations. The specific direct uses are: 1,650 MWt and 24,604 TJ/yr for district heating, 57 MWt and 668 TJ/yr for greenhouse heating, 110 MWt and 2,264 TJ/yr for fish farming, 80 MWt and 922 TJ/yr for industrial process heat, 260 MWt and 1,889 TJ/yr for snow melting, 210 MWt and 3,232 TJ/yr for bathing and swimming and 5.6 MWt and 19 TJ/yr for geothermal heat pumps, for a total of 2,373 MWt and 33,598 TJ/yr (Ragnarsson, et al., 2020).

5.4.1.9. Ireland

Temperatures of between 13°C and 24.7°C from the warm springs have been recorded as part of extensive research since the early 1980s. Ireland's intraplate geological setting is such that geothermal resources are classified as low enthalpy with lower average geothermal gradients of approximately 10°C/km recorded in the south to higher gradients in the north east and in Northern Ireland where values of up to 35°C/km are observed. Geothermal heating and cooling are estimated to contribute 3.3% to the percentage of renewable energy contributed to gross final energy consumption in 2017 and 1.2% of total energy to renewable energy contribution to thermal energy combined with air source heat pumps. Information on large scale commercial systems operating in Ireland are available through the Geothermal Association of Ireland records; however, many installations (particularly new ones) remain poorly or documented or not at all. Ground source heat pump installation figures from the Heat Pump Association for Ireland in 2018 show a decline in the total number of ground source systems installed, to approximately 150 units, representing approximately an average 1.2% decline from the last report in 2015. This growth rate could be now expected to increase since the introduction of financial support schemes in 2018. The total number of heat pumps installed in Ireland in 2018 is estimated at approximately 181,000 units, of which just under 10% are estimated to be ground source units. The shallow geothermal energy market in Ireland remains dominated by the installations in the residential sector (about 85%) with lower uses in the commercial and industrial processes sector (14% and 4% respectively). Systems of intermediate installed capacity between 10 kW and 24 kW remain the most widespread, but are experiencing a reduction in growth. Large scale, ground source systems are dominated by the installation of open loop collectors with an increased number of large-scale closed loop collectors. The majority of systems being installed range between 60 kW to 250 kW for heating and cooling applications.

In summary, geothermal heat pumps are listed as being installed in 88 locations throughout Ireland, providing an estimate 7.64 MWt and 37.05 TJ/yr of cooling, and 193.23 MWt and 936.95 TJ/yr of heating, for a total of 200.87 MWt and 974.00 TJ/yr (Pasquali, et al., 2020).

5.4.1.10. Italy

There are 37 direct-use geothermal sites in Italy, 5 of which are for district heating, 5 for individual space heating, one an industrial process site, 6 for fish farming, 4 for greenhouse heating, and 16 for swimming and bathing. The main share of geothermal direct-use is held by the space heating sector (42% of the total energy, 52% of the overall installed capacity), followed by thermal balneology (32% for both values) and fish farming (18% and 9% respectively). Agricultural applications, industrial processes and other minor uses together account for around 8% of the total geothermal use. Regarding ground-source heat pumps, they account for 38% of the total installed capacity and some 30% in terms of energy. District heating (DH) systems represent about 8% of the total geothermal heat utilization. The main systems are in Tuscany, within the geothermal electrical power production area. The fluid used to feed the DH networks is produced by the same deep wells feeding the power plants and is delivered as waste or valuable steam. The other main Italian geothermal DH application is in Ferrara, where a 14 MWt-capacity system with two production wells of about 2 km depth produces pressurized hot water at almost 100 °C, all of which is then reinjected into a third well. The other two systems worth mentioning are in Milano, where ground-source heat pumps are used to deliver heat to the network, and Bagno di Romagna. The average CFs of both GSHPs and DHs range around 0.19, while the total geothermal annual CF is equal to 0.24 by reason of the high equivalent working hours of fish farming (CF=0.49), industrial processes (CF=0.28) and agricultural uses (CF=0.28). In summary, the country has: individual space heating 75 MWt and 548 TJ/yr, district heating 150 MWt and 863 TJ/yr, greenhouse heating 67 MWt and 581 TJ/year, fish farming 130 MWt and 2,019 TJ/yr, industrial process heat 15 MWt and 139 TJ/yr, bathing and swimming 456 MWt and 3,501 TJ/yr, and GHPs 532 MWt and 3,265 TJ/yr. Thus, the total for the country is 1,425 MWt and 10,916 TJ/yr (Bargiacchi, et al., 2020).

5.4.1.11. Netherlands,

Geothermal direct-use development in the Netherlands includes deep geothermal energy (DGE), shallow geothermal energy (SGE) (including underground storage (UTES), and ground source heat pumps (GHPS). There are currently 21 DGE projects, with an approximate use and total capacity of 3,600 TJ/yr. and 317 MWt. The amount of SGE systems has also continued to increase. In the beginning of 2019, 2,368 ATES and 60,354 GHPS systems were in operation. 99 % of these projects are low (<25 °C) temperature storage. However, the interest in HT-ATES (> 60 °C) is growing and new pilot projects have started. Shallow geothermal energy consists of ground source heat pumps (GSHP) and underground thermal energy storage (UTES). GSHP systems are focused on only heat or cold supply from the soil and energy supply to buildings, while UTES is designed as a seasonal heat and cold storage and works likes a battery. Prevalent in underground thermal energy storage systems are open systems which use groundwater wells to store heat and cold. This technology is called aquifer thermal energy storage (ATES). The closed version is called Borehole Thermal Energy Storage (BTES) and makes use of borehole loops to exchange heat and cold from the soil. Typical temperature ranges for storing energy are between 7 and 17°C. The lower temperature can be used for direct cooling, the higher abstraction temperature will be used by heat pumps to increase the temperature to 45°C to be used for heating purposes. It is expected that the growth in ATES systems will continue due to contribution of these systems to climate goals, but also because it is an economically attractive alternative to traditional heating and cooling techniques. There is also a growing interest for high temperature storage (HT-ATES). High temperature storage is a technique comparable with ATES, but the storage temperature varies from 30 to 90°C. High temperature storage is suitable in locations with an excess of heat or an expected high demand for heat. It is increasingly seen as a possibility for residential or horticultural areas. HT-ATES with storage temperatures > 30°C has only been implemented in six projects. The first relevant HT-UTES project in the Netherlands was installed in the Beijum district in Groningen (1985, storage of 60°C solar heat using BTES). The first HT-ATES projects were made at Utrecht University (1991, storage of 90°C heat from a CHP installation using ATES) and a health care institution in Zwammerdam in the late nineties (storage of 90°C heat from a CHP installation using ATES). In addition, four medium (< 50°C) temperature storage systems were built over the last 15 years.

In summary, greenhouse heating for the country is 230 MWt and 3,731 TJ/yr, district heating at 3.15 MWt and 63 TJ/yr, and geothermal heat pumps at 1,486 MWt and 4,550 TJ/yr, for a total of 1,719.15 MWt and 8,344 TJ/yr (Bakema, et al., 2020).

5.4.1.12. Norway

The Nordic Countries have been among the leading countries in utilizing ground source heat pumps (GHP) closed loop systems. Single U–pipe collectors in a water-filled-no-grouting-borehole (dia.=115 mm) represents the dominant solution for borehole heat exchangers (BHE). Many of the large GHP installations are borehole thermal energy storage (BTES) installations for both heating and cooling purpose. In general, the GHP systems in Norway are designed with an imbalance between heating and cooling due to heat demands exceeding cooling demands. Still, the cooling peaks may be substantially higher than the heating peaks. In new buildings, such as the ZEB Powerhouse Kjørbo, the dimensioning of the borehole park was determined based on covering the cooling demands via free cooling. Among the reported GHP installations, 1100 are large installations with more than four BHEs or open systems with direct use of groundwater. The trend for large installation is similar to that for all installations, with an increasing number of installations up until 2015 but with a decreasing trend afterwards. The maximum number of large systems installations was reached in 2014 and 2015, with 109 new large installations being reported. It is not known if the decrease in reported installations during the last years is real or if simply due to underreporting. A possible explanation for the sales decrease could be the reduction in subsidies from the Norwegian energy enterprise responsible for the promotion of clean energy (Enova): from 10,000 Euros to 1,000 Euros. Another trend is a decrease in the number of BHEs in the large GHP installations. The average large BHE installations reported in 2018 and 2019 consist of 10 BHEs. The reduction is probably connected to the increased BHE length. The new GHP installations are also more often integrated borehole thermal energy storage (BTES) systems, i.e. with solar collectors, PV, air heat pumps or PCM. This integration limits the need for heat or cold extraction from the BHEs. There are 25 installation of GHP where the total borehole lengths are more than 10,000 meters. The depths of these BHE range from 160 to 300 meters, with the number of boreholes at each location ranging from 38 to 180.

The summary of the energy used in Norway for direct-use is 0.18 MWt and an estimated 1.20 TJ/yr for the heating direct-use at the Oslo International Airport, and 1,150 MWt and 12,600 TJ/yr for geothermal heat pumps, giving a total of 1,150.18 MWt and 12601.2 TJ/yr (Midttømme, et al., 2020).

5.4.1.13. Portugal

Direct use application on the mainland and in the Azores is restricted to small district heating operations and mainly balneological applications. Two main district heating operations are running in thermal baths: one is Chaves, Northern Portugal where a dedicated well, 150 m deep at 76ºC, is used in a small district heating network (swimming-pool and hotel). Another well at 208 m deep and 74ºC, is used to heat tap hot water that feeds the thermal bath as well as the district heating network. A third well, 100 m deep, 68ºC, is maintained as a backup well. The other is at S. Pedro do Sul, central Portugal. This is the main Portuguese spa, and has one inclined well, 500 m deep, 69ºC, with artesian flow, which supplies the thermal bath and also is in use in a small heating operation in two hotels and inside the Spa. Several minor district heating operations operate in Caldas de Monção, Termas da Longroiva and Alcafache in Mainland and at Furnas hotels, in S. Miguel (Azores archipelago). Balneological activities using thermo-mineral waters are quite popular in Portugal for curative and touristic purposes. About 30 thermal baths are operating within a legal framework. Most are open only in summer, but some of them are operating normally all year. All the balneological activity inside the baths is carried out under strict medical control. Since 2004 the INOVA Institute and the Azores Government undertook several initiatives and studies allowing the exploitation and evaluation of the Azorean low temperature geothermal resources for direct use, including touristic activities and balneology. Associated with these activities, new shallow wells were drilled in Ferraria (S. Miguel), Varadouro (Faial) and Carapacho (Graciosa). According to the last data recorded by the European Heat Pump Association (EHPA), there were no new sales of ground-source heat pumps (GSHP) in Portugal in 2014. The aggregated sales until 2014 were about 54 units, with an installed capacity of 0.65 MW. Considering typical values, the averaged installed capacity was 12 kW, with operating hours of 1,340 and a typical seasonal performance factor (SPF) of 3.425. It is difficult to follow the evolution of new projects concerning GSHP, since Portugal still doesn´t have legislation requiring the registration of this kind of project, especially concerning the residential sector. It is possible that a greater number of small installations are installed each year, but are not registered.

There are 21 instances of geothermal energy use on the Portugal mainland and 3 on the Azores, mostly for bathing and swimming, but a few for heating greenhouses and for district heating. 90 GHP units are reported to be installed in the country; however, there are many undocumented installations. Bathing and swimming is estimated at 14.7 MWt and 280.5 TJ/yr, district heating at 3.0 MWt and 95.3 TJ/yr, greenhouse heating at 1.0 MWt and 15.8 TJ/yr, and GHP at 2.36 MWt and 14.9 TJ/yr, for a total of 21.06 MWt and 406.5 TJ/yr (Nunes, et al., 2020).

5.4.1.14. Spain

There are no high enthalpy geothermal facilities in Spain. Shallow geothermal energy is still developing in Spain. Open systems with geothermal heat pumps (GHPs) have been widely used for many years. Closed systems began to be considered in the year 2000, both in buildings and industries. Despite the financial collapse of the construction sector, the installation of GHP systems maintained a growing trend, although slower than desirable given existing capacity and energy needs. The installation of GHP systems has intensified in all types of buildings, both in new and refitted buildings. Furthermore, public administrations are moving more and more towards installing GHP systems in public buildings, due to the need to make new public buildings fit into the concept 'Nearly zero-energy buildings (NZEBs),' as promoted by the European Union. This is also favorable for the implementation of this type of geothermal system in Spain. Geothermal energy for heating and cooling applications in buildings should play an important role in the framework of the future Spanish Climate Change and Energy Transition Law, with the aim of contributing to the fulfilling Spain's energy and climate change commitments. The estimated uses based on data from WGC2015 (Arrizabalaga, et al.) and limited data from the WGC2020 country update (Arrizabalaga, et al.) are: 5.20 MWt and 133.6 TJ/yr for individual space heating, 22.0 MWt and 165.4 TJ/yr for greenhouse heating, 3.80 MWt and 92.0 TJ/yr for bathing and swimming, 513.0 MWt and 3,542.0 TJ/yr for geothermal heat pumps, giving a total for the country of 544.0 MWt and 3,933.0 TJ/yr.

5.4.1.15. Sweden

There is no geothermal power production in Sweden, and the only geothermal plant in Sweden that meets some of the criteria for a deep geothermal plant is the Lund geothermal heat pump plant in south western Sweden. It has been operating since the mid 1980's.

The four production wells initially produced 450 l/s (1,620 m^3/h) at a production temperature of 22°C. The temperatures in the production wells closest to the injection have been influenced by the injection of cold water for more than 30 years, but the wells farthest away are more or less unaffected. The temperature has decreased around 10°C. The geothermal fluid is used as the heat source for two heat pumps. These heat pumps have a combined capacity of 47 MWt. At its peak in 1993, the plant produced 350 GWh of heat, providing 40% of the energy in the Lund district heating network. Between 2015 and 2018 the heat production was between 95 and 131 GWh/year. The decrease in production is mainly due to an increased amount of waste heat and co-generation heat production in other parts of the district heating system, and is not related to the geothermal well capacity. In total the plant has produced 7.7 TWh of heat since its operation started in the 1980's,

The typical Swedish shallow geothermal energy extraction system is a groundwater filled vertical closed loop ground-source heat pump (GSHP) system, drilled in crystalline rock, used for heat extraction only. The heat pump is typically electrically driven and is used for both space heating and domestic hot water (DHW) heating. These systems, mainly used for small to medium size systems for heating of residential buildings, are sometimes recharged with heat from exhaust air or solar. About 20-25% of all shallow geothermal energy systems in Sweden are horizontal ground loops in soft ground material at about 1 m depth. These systems are typically only used for heat extraction, and will freeze the moisture in the ground around the ground loops, thus taking advantage of the phase change energy. Horizontal ground loops work best in finely grained soil with high porosity and moisture content. These are most common in the south of Sweden where the ground temperature is higher and thick layers of soil cover the hard rock. The market for Underground Thermal Energy Systems (UTES), where heat and cold is actively stored, has been continually growing over the last decades. Sales figures from the Swedish Heat Pump Association show that currently some 590,000 ground source heat pumps are installed in Sweden, of which approximately 140,000 are horizontal loop systems, and an estimated number of 10,000 are open groundwater or surface water heat pump systems. Many of the open systems, small and large, were installed in the 1980's. Today between 5-10 new such installations, mainly large systems (>100 kW), are added each year. The total number of ground source heat pump units sold in the capacity range 3 kW-1 MW over the last five-year period is approximately 140,000 units, of which about half are new GSHP systems, and the rest are replacement heat pumps in older GSHP systems. Over the last five years an average of 14,500 new GSHP systems have been installed per year, with a slightly decreasing trend. In 2019 around 12,000 new GSHP systems were installed. It is the market for small units that has shown a decreasing trend these last few years, as the market for single-family buildings is becoming saturated. On the other hand, the market for larger systems is growing. Vertical boreholes in rock and ground water wells are also used for comfort cooling and free-cooling, for instance in the telecom and industrial sectors. There are also some large ground source heat pumps in operation in district heating networks around Sweden. In 2012 these plants provided some 0.65 TWh to the Swedish district heating network. The number of registered Borehole Thermal Energy Storage (BTES) systems with 10,000 m or more total borehole length has almost quadrupled from 21 in 2015, to 76 systems in 2019.The currently registered number of GSHP and BTES systems with 1,000 borehole meters or more is 3,970, and there are 1,701 registered systems with 10 boreholes or more. This is an increase with almost 40% since 2015, when these numbers were 2,883 and 1,238 respectively. An estimate of 720 systems with more than 10 boreholes are for true BTES applications used for both heating and cooling, while the rest are applied for heating only in the residential sector. The largest BTES system in Sweden is currently the system at the Volvo Powertrain plant in Köping. This system comprises a total of 215 boreholes with average borehole depth of 270 m, giving a total borehole length of 58,200 m. The system was constructed in 2015-2016.

Geothermal (ground-source) heat pumps systems are installed in Sweden as follows: 47.0 MWt and 470 TJ/yr in the City of Lund (2 units), where the remaining numbers are for all of Sweden: 440,000 small vertical systems of producing 44,500 TJ/yr, 140,000 small horizontal system producing 11,100 TJ/yr, 10,000 small water source systems producing 1,500 TJ/yr, ATES systems producing 2,400 TJ/yr, and BTES systems producing 2,500 TJ/yr. The total number of units for all systems is 591,000 with a capacity of 6,680 MWt and producing 62,400 TJ/yr. Cooling energy produced by the ATES and BTES units is 3,150 TJ/yr, but is not included here as this puts energy into the ground (Gehlin, et al., 2020).

5.4.1.16. Switzerland

The trends of the individual geothermal direct use applications show a steady increase in deployment, thermal capacity and heat production. By far, borehole heat exchangers with heat pumps are still the predominant application in Switzerland, followed by shallow groundwater utilizations and balneology. Other systems including the use of deep aquifers have been of less relevance up to 2018. The statistical figures for "borehole heat exchangers" also include the rarely deployed geothermal baskets and ground registers. The number of geothermal heat pump applications, now increasingly used for heating and cooling, are growing steadily. The areal density of the installed capacity is still one of the highest worldwide (~3.75 units/km^2 of 12 kW average size). The only large geothermal district heating plant is in Riehen near Basel in northern Switzerland. In operation since 1994, the thermal water is produced from an approximately 1.5 km deep aquifer in the area of a fault zone at the Southern End of the Upper Rhine Graben. The 65 °C warm water was initially produced at a rate of 20 L/s. In 1997, the district heating grid was extended to Stetten (Lörrach), Germany. This system represents one of the first transboundary direct use facilities worldwide. From 2010 to 2014, the Project "Riehen Plus" enlarged the district heating system. Following the installation of a new production pump, the flow rate was increased to 23 L/s in May 2014, and the production temperature rose to 66 °C. After heat exchange to a secondary fluid to maximize efficiency, three heat pumps cool the thermal waters down to temperatures of 30–25 °C resulting in a coefficient of performance (COP) of about 6.5. There has been no deep geothermal heat use in the agriculture and industry sector to date. The first project in Schlattingen in the Canton of Thurgau has been constructed and is currently undergoing extensive testing. One of the two wells drilled has a nearly 800 m long and almost horizontal section within the approx. 1.5 km deep aquifer. In Switzerland, many tunnels exist in the Alpine orogen and the hilly foreland. The Lötschberg base tunnel has a length of 34.6 km. Tunnels drain the water from the surrounding rock zones and, as a result, a considerable amount of warm water flows in the tunnel towards the portals. Strict environmental regulation prohibits the discharge of large amounts of warm water into nearby rivers. Instead of using energy to cool down the water, this energy resource can be used in various applications: in Switzerland tunnel water is used for space heating, greenhouses, balneology, and fish farming. The most straightforward and cheapest form of thermal tunnel water usage is to collect and transport inflowing waters via ducts to the portals. When the temperature level of the tunnel water outflows is too low for direct applications (e.g. for district heating), heat pumps are used. In 2018, geothermal tunnel water applications (with heat pumps) produced 6.5 GWh, of which 4.6 GWh were of geothermal origin. At the Lötschberg base tunnel, an additional 2 GWh of heat was used directly without heat pumps for fish farming

("Tropenhaus Frutigen"). The Lötschberg Tunnel water at the Northern Portal has a flow rate of about 1,380 L/min and has a temperature of about 16-18°C. In two cases, at the Gotthard and the Mappo Morettina road tunnels, the water is also used for cooling purposes during summer time.

Borehole heat exchangers were the largest heat pump use in the country, amounting to 1,843.8 MWt and 10,733.8 TJ/yr or 83.9 of the capacity 80.8 % of the annual use. Shallow groundwater GHPs were 291.5 MWt and 1,533.2 TJ/yr or 13% and 11.5% respectively, thermal baths GHPs 23.3 MWt and 697.7 TJ/yr or about 1.3%, and other system including tunnel water about 1.2% of the GHP use. In summary: 20.5 MWt and 598 TJ/yr are used for individual space heating, 2.7 MWt and 78 TJ/yr for district heating, 1.6 MWt and 48 TJ/yr for bathing and swimming, and 2,172.0 MWt and 12,568.0 TJ/yr for geothermal heat pumps, for a total of 2,196.8 MWt and 13,292 TJ/ar (Link, et al., 2020).

5.4.1.17. United Kingdom

The City of Southampton Energy Scheme remains the only significant exploitation of low enthalpy geothermal energy in the UK. It is owned and operated by Cofely District Energy. The scheme was started in the early 1980s when an aquifer in the Triassic Sandstone containing 76°C fluid was identified at approximately 1800 m in the Wessex Basin. Construction of a district-heating scheme commenced in 1987 and this has since evolved and expanded to become a combined heat and power scheme for 3,000 homes, 10 schools and numerous commercial buildings. While gas fired CHP now supplies the majority of the district energy scheme's low-carbon heat, money from DECC's Deep Geothermal Fund has been provided to allow for the replacement of the original hydraulically driven downhole pump with a modern electro-submersible pump. The hot springs at Bath have long been a tourist attraction along with the Roman architecture of the ancient city. After their extensive refurbishment the hot springs continue to be popular. A recent development is that the cascaded flow from the hot springs, as supplied to the baths, is to be used to provide space heating for a new underfloor installation in the nearby Bath Abbey. In 2018 work commenced on a geothermal borehole to supply the newly refurbished seawater lido pool at Penzance in Cornwall. The first borehole on the esplanade was abandoned at about 100 m depth due to seawater ingress. A second hole was then attempted which reached a depth ~400 m before encountering difficult drilling conditions. However, significant water inflow was encountered at a temperature of ~25°C. The project has been modified to be an open loop water source heat pump system. The contract for this has been leased out, and the system is expected to be operational when the pool complex opens for the 2020 season. The EGC 2016 UK Country Update reported on a significant awakening of interest in the possible use of flooded abandoned coal and metal mines in different regions of the UK, as in Scotland, England, Wales and Cornwall. It is reported that the Coal Authority, who manage abandoned mines in the UK, is developing the heat resource from 16 existing mine water treatment schemes. In South Wales, following feasibility studies and reports, Bridgend Council have started drilling into old coal mines in the Llynfi Valley with the intention of heating 200+ homes. In summary, 1.7 MWt and 72.5 TJ/yr are indicated use for district heating, approximately 1.0 MWt and 34.0 TJ/yr are suggested for bathing and swimming, and 522.0 MWt and 4,134.0 TJ/yr are listed for geothermal heat pump use, for a total of 524.7 MWt and 4,240.5 TJ/yr (Batchelor, et al., 2020).

5.4.2. Central and Eastern Europe

5.4.2.1. Albania

Geothermal energy in the country consists mainly of low enthalpy resources. Natural springs and deep wells produce thermal water up to 65.5°C. The 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 wellness center are Elbasani Llixha Spa located in central Albania, and Peshkopia Spa. The former is one of the oldest spas in the country, where the springs have been used for over 2000 year, whereas the latter is of modern construction and functions as a balneological center. Geothermal heat pumps are installed at seven locations using 138 units for heating and cooling, including for schools, the Cultural Palace, and the Twin Towers in Tirana. Unfortunately, data were limited from the WGC2020 country update report (Kodhelaj, et al., 2020), thus data from WGC2015 will be utilized. This was furnished by Mr. Frasheri, who unfortunately passed away recently. The use for the country is then: 11.728 MWt and 84.33 TJ/yr for bathing and swimming, and geothermal heat pumps for 4.497 MWt and 23.26 TJ/yr, for a total of 16.225 MWt and 107.59 TJ/yr (Frasheri, 2015).

5.4.2.2. Bosnia and Herzegovina

Direct use of geothermal energy is found at 24 locations. Thermal and mineral waters with temperatures from 18 to 75°C are used primarily in balneology and recreation, then to a lesser extent for the space heating and heating of water in swimming pools, industrial processes and as sanitary water. Balneological use is implemented at 11 spas. Recreation centers exist at 16 locations, of which at 5 sites the swimming pools are used only in the summer period (3-4 months per year). Individual space heating is the most common use for spas. Total number of sites with individual space heating is 13 (6 heat exchanger and 7 GSHP). Geothermal waters are used at three locations for industrial processes. Thermal and mineral waters are used at 18 locations for balneological and recreational purposes. The majority of the spas are open the whole year while some recreation centers are active only during the summer period. All spas have installed a system of geothermal heating, except one. The largest user of geothermal energy in the country is the recreation center Termalna rivijera-Ilidža, with total installed capacity 5.77 MWt and total annual utilization 125.30 TJ/y. There, mineral water at 58°C is used for the heating of drinking water for the swimming pools (about 80%) throughout the entire year, and for heating of buildings (20%) in winter time. Water temperatures in spas and recreation centers range from 20.6 to 75°C. Individual space heating is implemented at 13 locations, of which 7 sites have heat exchangers and 5 locations (spas) use heat pumps with water temperature > 20 °C. Average period of heating of buildings is about six month per year, but sanitary waters and water in swimming pools on two locations are heated during the whole year. The largest number of shallow geothermal heat pumps is installed in higher elevation cities in the northern part of Bosnia and Herzegovina (B&H), but over the last 5 years there is a more intensive use at these installations in the central parts of B&H. Also, the application of heat pumps has been recorded in the area of Hercegovina where groundwater is ≤12°C. There is an increase in the number of installed heat pumps, which can be estimated at below 500. We estimate there are 400 small and 30 large units, with the total annual number of hours from 2700 to 2800. Other types of heat and mineral waters use are for water-supply in 12 locations, bottling of mineral water, extraction of free CO_2 from mineral waters at 4 wells, and extracting salt from brine.

In total, geothermal waters are used at 24 locations in B&H, the majority of which (19) are for bathing and swimming, with 13 for individual space heating, industrial process heat used for washing of fruit and vegetables and for milk and dairy processing. The summary for the country is 16.53 MWt and 170.07 TJ/yr for individual space heating, 0.54 MWt and 3.61 TJ/yr for industrial process use, 11.76 MWt and 61.83 TJ/yr of bathing and swimming, and 7.2 MWt and 71.2 TJ/yr for geothermal heat pumps, for a total of 36.03 MWt and 306.71 TJ/yr (Miošić, et al., 2020).

5.4.2.3. Bulgaria

The major factors that contribute to the geothermal development in the country are: long traditions, favorable climate, appropriate hot mineral water consumption, development of new spa centers, and bottling facilities. Because of the relatively low temperatures (<100°C), thermal waters have only direct applications. The 2018 data lists a variety of uses including in terms of MWt installed capacity: balneology, bathing and swimming (60.1%), individual space heating (17.6%), geothermal heat pumps (9.1%), air-conditioning (3.0%), greenhouses (1.5%), and for bottling of potable water and other uses (8.7%). The bottling of water is done in southern Bulgaria where water of low total dissolved solids with a variety of chemical is a fast-developing business. The factories increased from 3 to more than 40 in 30 years where the water is supplied to Black Sea resorts. Heating is only provided to individual buildings using plate heat exchangers, and are in operation along with heating of domestic hot water about 200 days/year. Many old installations in poor condition have been abandoned, and only a few new installations have been constructed. There are 12 localities identified with geothermal direct-uses, all with bathing and swimming, 5 with individual space heating, 5 with greenhouse heating, and 8 with other uses, most likely bottling of potable water. Most of the spa resorts are located in the mountains or along the Black Sea coast. The various geothermal direct-uses are: 19.23 MWt and 150.36 TJ/year for individual space heating, 3.30 MWt and 49.96 TJ/yr for air conditioning, 1.65 MWt and 25.45 TJ/yr for greenhouse heating, 65.69 MWt and 993.98 TJ/yr for bathing and swimming, 9.50 MWt and 59.91 TJ/yr for domestic water production, and 10.00 MWt and 47.30 TJ/yr for geothermal heat pumps, for a total of 109.37 MWt and 1,326.96 TJ/yr (Hristov, et al., 2020).

5.4.2.4. Croatia

Geothermal energy is traditionally used for balneology and space heating nowadays in 15 active spas in the country. Beside spas, there are three places where geothermal energy is used for heating greenhouses, two where individual space heating is used, and one where a small district heating system operates. At one geothermal power generation site, production licenses are also issued for a greenhouse, and there are two spas in the NW part of the country. Shallow geothermal energy shows significant potential for utilization in Croatia. The continental region and the region of the Adriatic coastline have a great perspective for utilization of ground source heat pumps. In the continental region, this is due to favorable geothermal gradients and the geological setting. Ground source heat pump installations are a growing sector in Croatia and the country is also becoming more and more attractive for space heating and cooling for both private houses and the service sector. A total of 19 sites have reported using geothermal energy for direct-use, 14 for bathing and swimming, 9 for individual space heating, and 3 for greenhouses. Geothermal heat pump data are not complete, but estimated at 3.80 MWt and 30 TJ/yr in the heating mode and 2.6 TJ/yr in the cooling mode. The uses of direct-use geothermal energy are: 18.6 MWt and 51.2 TJ/yr for individual space heating, 10.5 MWt and 126.4 TJ/yr for district heating, 2.3 MWt and 87.4 TJ/yr for greenhouse heating, 44.1 MWt and 95.1 TJ/yr for bathing and swimming, and an estimate 3.8 MWt and 30.0 TJ/yr for geothermal heat pumps, giving a total of 79.3 MWt and 390.6 TJ/yr (Kolbah, et al., 2020).

5.4.2.5. Cyprus

The use of geothermal energy in Cyprus for greenhouse heating is restricted to one pilot installation in the Agricultural Research Institute (ARI), in Zygi. The installation has operated for the last 5 years, and provides heating and dehumidification in a 216 m^2 traditional greenhouse. The largest use of geothermal energy in the country is for geothermal heat pumps. The majority of the existing geothermal heat pump installations are reported as vertical closed loop systems, accounting for more than 1,600 boreholes with an estimated total drilled length of more than 150 km. The installations of horizontal closed loop systems remain limited. There are also open loop systems that use sea water as a heat absorption/rejection medium, mainly installed in hotels along the island's southern coastal. An interesting and promising installation that was recently \finalized and should start operation by the end of 2020 is located on the new campus of the University of Cyprus. This installation is the largest in the island and consists of 220 vertical boreholes to a depth of 125 m. It is designed to operate in parallel with the district heating and cooling system of the campus, to provide heating and cooling for the new premises of the Faculty of Engineering. The energy production of this system is estimated at 9.54 TJ, or 14% of the existing energy production from the geothermal heat pumps in Cyprus. By the end of 2018, 163 installations were recorded across the island with a total installed capacity of 9.6 MWt. It is estimated, however, that the actual installations are about 180, with an overall capacity of 10.3 MWt. The estimated geothermal uses on Cyprus are; 0.07 MWt and 0.03 TJ/yr for greenhouses and 10 MWt and 64.97 TJ/yr for geothermal heat pumps, for a total of 10.3 MWt and 65.0 TJ/yr (Michopoulos, 2020).

5.4.2.6. Czech *Republic*

In the Czech Republic there is little direct-use of low-temperature geothermal sources (Jiracova, et al., 2020). The use of these resources is limited to balneology or recreation facilities. Groundwater geothermal heat pumps are used for heating of individual buildings and for a few district heating systems in large urban areas or agglomerations. The largest operating project of district heating is for the town of Děčin with an installed capacity of 6.6 MWt. The system uses a 550 m deep well producing 54 L/s of 30°C water, generating about 72.0 TJ/year. Another large installation is a system of geothermal wells at the campus of the Technical University in Ostrava with a production of more than 3.6 TJ/year. Two new large projects are underway in the country. One is for the new headquarters of the ČSOB bank in Prague. This system supplies both heating and cooling from 179 boreholes, each 150 m deep. The heat pump capacity is 1.30 MWt heating and 1.22 MWt cooling. The second project is a residential housing project 6 km south of Prague, where the entire project will be heated and cooled by a system of heat pumps utilizing approximately 500 geothermal wells. The most famous spas using hot springs are located in western Bohemia in the Eger/Ohře rift area. The warmest spring in Karlovy Vary spa has a temperature of 73°C. At several places in the Czech Republic, hot mineral waters are exploited in wellness resorts. The largest one is close to Pasohlávky in southern Moravia, where pools with a total area of 3000 m^2 are supplied by a 1.5 km deep geothermal borehole. The yield of the well is 74 L /s and the deep-drawn water temperature is 46°C. No data are provided on spa and bathing energy use, but based on data from WGC2010, the estimated capacity for spas is 4.5 MWt and energy use of 90 TJ/yr (Jirakova, et al., 2015). Geothermal heat pumps provide 320 MWt and energy use of 1,700 TJ/yr. The total for the country is 324.5 MWt and 1,790 TJ/yr (Dědeček, et al. 2020).

5.4.2.7. Estonia

No country update report was received from this country. Thus, 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 energy use of 356 TJ/yr with a COP of 3.5 and 2200 full load operating hours annually (Lund, et al., 2010).

5.4.2.8. Greece

Geothermal energy is mainly used in Greece for balneotherapy and greenhouse heating, with its utilization for soil heating, aquaculture and space heating still fairly limited. The exploitation of thermal waters for their therapeutic properties constitutes the oldest and most common geothermal use in Greece. More than 750 thermal and mineral springs have been recorded across the country, half classified as “curative”. Geothermal water is used in nearly 70 spas and bathing centers, as well as in more than 25 outdoor swimming pools. Most of the 18 geothermal greenhouses of Greece are located in the north (Macedonia and Thrace). The total greenhouse surface area has increased since 2015, reaching more than 40 ha in 2019. Most greenhouses are the glass type and produce various types of vegetables (tomatoes, cucumbers, etc.) and flowers, mostly for the domestic market. The largest and most promising geothermal investment ever realized in Greece was built in 2014. It consisted of a multi-span geothermal greenhouse complex for hydroponic cultivation of tomatoes and cucumbers. The unit has been gradually expanded from 4.2 ha in 2015 to 18.5 ha in 2019 and will reach 20 ha in 2020. The same year, the first geothermal greenhouse (3.5 ha) was constructed for breeding and producing rooted cuttings of ornamental plants. The use of low temperature geothermal fluids for outdoor soil heating was started in 1998 with a similar one built in 2005. Both plantations produce early-season white and green asparagus, and, occasionally, other vegetables such as lettuce and watermelon. Spirulina cultivation in geothermally heated water has been practiced in Greece since the late 1990s. Today, three companies are active in this sector, with a total surface area of the raceway ponds of 0.9 ha. The only geothermal dehydration plant in Greece started in 2001. Up to now, it has produced more than 300 tonnes of dried tomatoes and, in recent years, increasing quantities of olives, along with other vegetables (e.g. asparagus, peppers and eggplants) and fruits (e.g. apples, lemons, melons). The unit typically operates each year for tomato drying during the period June-September (and throughout the year when it is needed). The use of geothermal energy for space heating is very limited. During the past years, a small school building, two spa centers, a 2000 m^2 surface of offices and process facilities in a greenhouse unit, and a few houses in northern Greece were heated by low temperature geothermal fluids. The shallow geothermal market of ground-source heat pumps (GSHP), remains the largest segment of the geothermal sector in terms of installed capacity and energy produced. The first documented GSHP system was installed in Greece in the early 1990s. However, considerable growth of the GSHP market has been recorded after the mid-2000s. There is a strong trend towards incorporating GSHP in large buildings (e.g. hotels, hospitals, schools, university buildings, and airport and port facilities). More than 3500 GSHP operating systems are estimated to have been installed in early 2019. Most of the systems have a capacity of less than 100 kW (avg. 30 kW), with about 200 systems exceeding 100 kW (avg. 350 kW). The GSHPs are commonly used in Greece for both space heating and cooling, as well as for domestic water heating. The penetration of GSHP systems in the agricultural sector is poor, but a soil heating system supplied by GSHP was installed 13 years ago in a 19-ha asparagus plantation in northern Greece for early season production. It has been operating effectively ever since, providing energy at low cost. Unfortunately, the asparagus plantation and a demonstration greenhouse in central Greece are the only cases of using GSHPs in agriculture. A 2500 m long network for the heating and cooling of nine public buildings using 1350 kWt GSHP was completed in 2016 in a city near Athens. A geothermal snow melting system was installed in 2014 at the center of the town ‘Karpenisi’, to prevent icing of the 1.2 km long pedestrian walkways. The first winery in Greece that uses geothermal energy is “Ktima Brintziki”, located in NW Peloponnese, near ancient Olympia. The heating, cooling and chilling requirements of the facilities are covered by a closed loop GSHP system. The GSHP heating/cooling system of the CRES bioclimatic building was renovated, and consists of one open loop doublet with titanium plate heat exchanger. The GSHP provides heating and cooling to the building through fan-coils.

In summary, there are 25 locations using geothermal energy directly for heating, the majority for greenhouse heating with some individual space heating. The other major use is for bathing and swimming, consisting of 70 spas and bathing centers and 25 outdoor swimming pools, most of which operate June through October. The specific direct uses include: 1.65 MWt and 17.83 TJ/yr for individual space heating; 38 MWt and 407 TJ/yr for greenhouse heating; 0.24 MWt and 4.75 TJ/yr for agricultural drying; 43 MWt and 260 TJ/yr for bathing and swimming; 1.56 MWt and 17.94 TJ/yr for other uses; and 175 MWt and 1,380 TJ/yr for geothermal heat pumps, for a total of 259.45 MWt and 2087.52 TJ/yr (Papachristou, et al., 2020).

5.4.2.9. Hungary

Geothermal district heating is available in 23 towns in Hungary as of 2019. Some of these are partial geothermal systems, where geothermal energy contributes to existing district heating infrastructure (operated otherwise by gas), where geothermal’s share is anywhere from 30 to 100%. The majority of the systems are so called “thermal water heating cascade systems”, where the gas-based heating of some public buildings (town halls, libraries, schools, hospitals, etc.) is replaced by geothermal. Such systems are not currently connected to existing district heating systems, which only supply heat to a separate part of the settlement through a heat supply center. These local systems are commissioned on the basis of a water license and are often run by local municipalities, or municipality-owned service providers. This contrasts with the district-heating systems where heat is provided by a trading company on a contract basis, regulated by the Hungarian Energy and Public Utility Regulatory Authority. The largest geothermal district heating project is Miskolc in NE of Hungary. It was commissioned in 2013. This site has 2 production and 3 reinjection wells, producing thermal water from karstified-fractured Triassic basement carbonates at a depth of 1500-2300 meters, and with a total installed capacity of 55 MWt. This system supplies the district heating and domestic hot water for the large housing complexes in the Avas district of Miskolc. After the completion of the Miskolc project, the next largest direct use project was near Győr in NW-Hungary, where the system was commissioned in 2015. This system supplies heat to a large industrial user (Audi Motor Hungary) in the town’s suburbs as well as to the town’s district heating system. Its heat capacity is 52 MWt. There are three production wells with 101-102°C outflow temperature at the well-heads. In addition to district and thermal water town heating cascade systems, a significant number of individual space heating projects have been initiated, mostly associated with spas. Agricultural use is an important branch of geothermal energy utilization in Hungary. Greenhouses cover more than 80 ha, with more than 250 ha devoted to plastic tents and soil heated by thermal water. For spas, the outflow temperature typically ranges from 30 to 50 °C. The hottest ones are in SE Hungary at the Romanian border (89°C). There are equally renowned spas in many other places. Thermal water for "public water supply" is mostly considered to mean drinking water. "Drinking thermal water" is a characteristic concept in Hungary, where 90% of the drinking water supply is provided from groundwater. Where the shallow aquifers are contaminated (such as in SE Hungary, where there is a naturally high arsenic content) the preference is to use lukewarm thermal waters with low TDS from slightly deeper confined aquifers. In the case of shallow geothermal systems, the system sizes continue to increase. The size of individual units ranges from 10 kW to 14 kW for residential use. In 2018, a-1,650 kW heating and 720 kW cooling capacity heat pump system was developed and began operation at the NATO base in Pápa. According to the national geothermal potential assessment, the GSHP potential of Hungary is 23 PJ/year. The 2012 estimation of the Hungarian Heat Pump Association forecast 3.6 PJ/year by 2020, a goal which unfortunately will not be met.

There over 24 geothermal locations in the country using geothermal energy along with other sites not identified. Of those listed, 22 sites list swimming and bathing, 16 sites have district heating, 13 sites have individual space heating, 9 list agricultural drying, 8 sites list greenhouse heating, 4 sites list industrial uses, and one site lists fish farming. A total of 6,500 ground-source heat pumps of average 10 kW size are listed. Geothermal use in Hungary consists of 77.20 MWt and 299.00 TJ/yr for individual space heating, 223.40 MWt and 2,288.00 TJ/yr for district heating, 358.10 MWt and 2,891.00 TJ/yr for greenhouse heating, 25.00 MWt and 297.00 TJ/yr for agricultural drying, 19.00 MWt and 220.62 TJ/yr for industrial process heat, 249.00 MWt and 3,684.00 TJ/yr for bathing and swimming, and 72.00 MWt and 1,022 TJ/yr for geothermal heat pumps, for a total of 1,023.70 MWt and 10,701.62 TJ/yr with a capacity factor of 0.34 (Toth, 2020).

5.4.2.10. 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: 0.38 MWt and 8.90 TJ/year for individual space heating, 0.17 MWt and 4.75 TJ/yr for district heating, 0.23 MWt and 6.44 TJ/yr for fish farming, 0.53 MWt and 9.50 TJ/yr for balneology, and 0.32 MWt and 2.22 TJ/yr for geothermal heat pumps (10 units installed), giving a total of 1.630 MWt and 31.81 TJ/yr (Lund, et al., 2010).

5.4.2.11. Lithuania

Klaipeda Geothermal Demonstration Plant (KGDP) started using geothermal resources for district heating in 2000. The absorption heat pumps use a lithium bromide (LiBr) solution. Low-temperature geothermal heat is extracted from geothermal water of the Devonian aquifer. Plant capacity is confirmed by the State Commission at 35 MWt, of which the geothermal part is 13.6 MWt. Managers of KGDP were trying to solve both injection problems and adverse market forces. As a result, the plant only ran during the heating season, from 2013 to 2017. In 2017, the Klaipeda geothermal plant was shut down. We hope that problems faced by this plant will be solved so that this pioneering installation can serve research and education purposes, essential for further geothermal energy development in Lithuania. KGDP's operation from 2001 to 2017 kept 88,000 tonnes of CO_2 emissions from entering the atmosphere. The number of small-scale ground source heat pump systems in Lithuania is growing. At present, there are nearly 7,700 installations thanks to a number of private enterprises. The total installed capacity is estimated at 125.5 MWt and output of 1,044 TJ/yr (Zinevicius, et al., 2020).

5.4.2.12. Macedonia

The utilization of thermal waters consists of 7 geothermal projects and 6 spas. All of them had been completed before and during the 1980s. The present state of the projects is as follows. Istibanja (Vinica) Geothermal Project provides heating of a 6-ha greenhouse complex in combination with a heavy oil boiler for peak loadings. It has been one of the most suboptimal projects before the crisis, but after the privatization in 2000 it was reconstructed and optimized with Austrian and Dutch grants, and now covers the heat requirements for the needs of export roses production. Kocani (Podlog) Geothermal Project ("Geoterma") is at present the largest geothermal project in Macedonia. It heats an 18-ha greenhouse complex and covers the space-heating needs of public buildings in the center of the town. Due to economic circumstances, the paper industry, the vehicle parts industry and a rice drying unit have been lost as heat consumers over the last 12 years. The bankruptcy of ZIK "Strumica" and the slow process of its privatization resulted in the collapse of the organizational structure and proper use of the Bansko Geothermal Project system. Due to an increased number of consumers and failure to cover the peak load requirement, proper operation required the introduction of a centralized managing system and new exploitation boreholes, as well as considerable technical reconstructions and optimizations. Other uses are the heating of the hotel Car Samuil, Spiro Zakov (rest house, rehabilitation facilities for children), other plastic-houses, the rest house Jugotutun, the rest house ZIK Strumica, and experimental and private plastic-houses. Now mostly shut down, Smokvica (Gevgelia) Geothermal System was once the largest geothermal system in Macedonia, covering the heating requirements of 22.5 ha glasshouses and about 10 ha plastic-houses. At present, only 3 wells out of 7 are exploited with total flow of 90 l/s and temperatures between 63.9-68.5°C, to heat 10 ha greenhouses of which 6 ha are glasshouses and 4 ha are plastic-houses. When the outside temperatures are very low, a back-up heavy oil boiler is used. At Negorci (Gevgelija) Spa, reconstruction of the heating installations has been finalized and now all the hotel and therapeutic facilities are heated with geothermal energy. The ground source heat pump (GSHP) systems have gone through their teething period and nowadays are becoming more and more popular, although there are no regulative or control mechanisms. GSHP data are by no means complete, but based on information that could be gathered, GSHP are usually utilized in the residential sector, mostly for individual houses with about 1,000 installed units of 2.5 kW typical size.

Geothermal energy use in the country is: 0.84 MWt and 6.6 TJ/yr for individual space heating, 42.55 MWt and 518.37 TJ/yr for district heating, mainly at Bansko and Kocani, 2.79 MWt and 61.14 TJ/yr for greenhouse heating mainly at Istibanja, and 1.25 MWt and 37.5 TJ/yr for geothermal heat pumps, for a total of 47.43 MWt and 623.61 TJ/yr with a capacity factor of 0.42 (Popovska-Vasilevska and Armenski, 2020).

5.4.2.13. Poland

The applications in Poland involve space heating, bathing and swimming (balneotherapy, recreation), other single uses, as well as shallow geothermal (compressor heat pumps). In 2018 six geothermal space heating plants were operational in the country. In the Podhale region the geothermal district heating system has been operating since 1993 (on a larger scale since 2001). Since 2017 the total maximum artesian water flow rate produced by 3 wells was about 297 L/s of 82–86°C water. In 2018 the installed geothermal capacity was 38.8 MWt, while geothermal heat sales amounted to 451 TJ, i.e. 89.3% of total production. In 2018 about 1600 users were hooked to the system (mostly in Zakopane – the main city of that region and main heat market; with the system meeting about 35% of its heat demand). The Podhale geothermal district heating system is among the largest geothermal district heating systems in continental Europe. The Mszczonów district heating plant has been operating since 2000. Similar to earlier years, the maximum geothermal water flow rate was about 16.6 L/s of 42.5°C. In 2018 the total installed capacity was 8.3 MWt (4.6 MWt gas boilers, 2.7 MWth absorption heat pump, 1 MWt compressor heat pump). In 2018 geothermal heat sales was 15.5 TJ (ca. 38% of total heat sales 43.2 TJ). After the water cools, it is used for drinking. Part of the water flow rate supplies the recreation center (Termy Mszczonów). At Poddębice the geothermal district heating plant has been operating since 2013. It has a 10 MWt geothermal capacity based on 68°C water (average flow rate 32.2 L/s). The plant supplies public buildings, school, hospital (and sends water to its rehabilitation part), and multi-family houses. In 2018 geothermal heat sales were 50 TJ (96.5% of total production). Some part of water stream supplies swimming pools. The Pyrzyce district heating plant has been operating since 1996. In the 2017/2018 season a new production well was included into the heating system (maximum water flow rate about 55 L/s, temperature 65°C) while all four older wells (two production and two injection) started to work as injection wells. The plant's maximum installed capacity is 22 MWt including 6 MWt geothermal. It supplies heat and domestic warm water to over 90% users of the town's population (13,000) and meets about 60% of total heat demand. In 2018 geothermal heat sales were 57 TJ. The Stargard geothermal heating plant has been operating since 2012 (after renovation). It is based on a doublet of production and injection wells. In 2018 maximum water production was about 50 L/s of 87°C water. The geothermal capacity was 12.6 MWt and heat sales 230 TJ (entirely sold to the municipal district heating plant). In 2018 geothermal met about 27% of total heat demand of Stargard (population, 75,000). The district heating plant in Uniejów has been operating since 2001 and as a health resort since 2012. The maximum discharge from one production well is 33.4 L/s of 68°C water. The total installed capacity is 7.7 MWt (3.2 MWt geothermal, 1.8 MWt biomass boiler and reserve 2.4 MWt fuel oil peak boilers). In 2018 about 80% of all buildings in that town were supplied by geothermal. Part of geothermal water flow has been used for spa and recreation center (maximum 27.8 L/s of 42°C water; about 1.5 MWt) which is also heated by geothermal energy. Part of the spent water flow rate (8.3 L/s, 28°C) is used to heat up a football pitch (about 0.3 MWt, 5.5 TJ) and walking paths. To sum up the geothermal district heating in Poland in 2018: the total installed geothermal capacity of six systems was 74.3 MWt and geothermal heat sales were 813.1 TJ. In particular, geothermal district heating share in total heat production/sales ranged from 38 to 100%. In some cases, geothermal heat prices were competitive with prices of heat derived from fossil fuels like gas, and even coal sometimes. In case of individual space heating, geothermal waters (28–80°C) were used to supply school complexes, hotel buildings, and spa facilities, as well as to heat water for swimming pools and spa treatments in several localities. Also, several recreation centers have individual geothermal heating.

In 2015-2019, in twelve health resorts geothermal waters were used for various treatments (two more than reported in 2010-2014). In particular cases the approved water reserves varied from about 0.5 to 56 L/s, while outflow temperatures ranged from about 20 to 90°C. In several cases outflow water temperatures were below 20°C (due to flow rate lower than approved maximum one). Such waters were heated up for spa treatments. At the end of 2018 fourteen geothermal recreation centers were operating. That number included three new centers opened in reported years: two large ones in the Podhale region (already the 6th and 7th centers there!) and one elsewhere in the country. Several centers used geothermal water both for bathing & swimming, and for heating. Moreover, some operated a 0.5–1 MWt compressor heat pump to extract more heat from geothermal water before its surface disposal (total about 3–4 MWt more). In at least one of the centers geothermal heat was used for snow melting.

Since 2015 an Atlantic-salmon fish farm using geothermal water has been operating on the Baltic coast. Geothermal water is applied for heating the facility. In the case of biotechnology, in 2018 an experimental algae cultivation applying geothermal water was initiated in the Poddębice heating plant. Semi-technical wood drying installation in the Podhale region (about 0.3 MWt and 0.6 TJ) was used for heating up a football pitch and walking paths, and for snow melting (in a parking area, for example, in at least one of geothermal recreation centers). In several localities geothermal water has served as the source for extracting iodine-bromine, cosmetic salts and CO_2. Waters are sometimes bottled as medicinal or mineral waters, and this sector of geothermal water use related to cosmetics production is gradually developing. In 2015–2019 progress in geothermal heat pumps (GSHP) installations was continuing. It is estimated that in the third quarter of 2018 the GSHP sales amounted to 5,660 units. Comparing to 2017 the annual growth was about 5% in 2018. It is estimated that at the end of 2018 the number of GSHPs reached about 56,000 units, while their total capacity was at least 650 MWt and annual heat production 3100 TJ. The share of heat pumps in newly built single-family buildings has increased: every seventh building is heated by heat pumps.

The summary of geothermal uses in 2018 includes a total of 44 locations/communities, of which the following are listed using geothermal energy: 27 for bathing and swimming, 8 for individual space heating, 6 for district heating, 1 for industrial uses (wood drying), 1 for fish farming, 1 for snow melting, and 4 for other uses (heating of walking paths, and extraction of iodine-bromine salts). The estimated total number of geothermal heat pump units installed is >56,000 in the 10 to 200 kW size with an average COP of 4.2 and 3,800 full load equivalent operating hours per year. In summary, >10.77 MWt and >99.81 TJ/yr are for individual space heating, 74.3 MWt and 813.1 TJ/yr for district heating, 2.1 MWt and 17.80 TJ/ar for fish farming, 0.3 MWt and 0.6 TJ/yr for industrial heat, 0.5 MWt and 2.0 TJ/yr for snow melting, >17.03 MWt and >137.17 TJ/yr for bathing and swimming, an estimated 1.0 MWt and 5.5 TJ/yr for other uses, and >650 MWt and >3,100 TJ/yr for geothermal heat pumps, for a total of >756.0 MWt and >4,175.98 TJ/yr (Kępińska, 2020).

5.4.2.14. Romania

The following describes the use of deep geothermal resources in the country. Agrippa Ionescu Hospital in Balotesti is one geothermal project financed by the RONDINE program, specifically was for the geothermal space and tap water heating system for the Agrippa Ionescu Hospital in Balotesti, Ilfov County, north of Bucharest. A new geothermal well was drilled near the hospital. After completion and testing, a line shaft pump was installed in the well. It can produce up to 35 L/s geothermal water with a wellhead temperature of about 85ºC. The heating plant near the well supplies the primary thermal heat to the substation near the hospital that supplies space heating and hot tap water to the hospital. The annual geothermal water production is about 270,000 m^3 (depending on the outdoor temperatures in the cold season), and the annual geothermal energy supplied to the hospital about 6,500 MWt. The heat-depleted geothermal water is disposed of in a nearby river flowing into a small lake, as it does not cause any thermal or chemical pollution. The Therme Bucharest Spa Center is to date the largest private investment in a geothermal project in Romania. The company obtained the needed licenses to drill and exploit a new geothermal well. The line shaft pump installed in the well supplies geothermal water of up to almost 90ºC to the plant near the Spa Centre. After treatment to remove all potentially harmful components, the geothermal water is use in one indoor and 9 outdoor pools for health and recreational bathing. The water in the pools is recirculated, filtered and sterilized, and geothermal water is added to keep its temperature at 33ºC. The indoor luxurious vegetation of flowers and palm trees is individually fed by a computer-controlled system. Geothermal energy is also used to heat the treated indoor air to provide a comfortable ambience. The facility is open all year round and can accommodate more than 16,000 visitors at a time.

Extension of the Oradea geothermal district heating system is a project carried out in the City of Oradea (western Romania), which has over 40 years' experience of using geothermal energy. A new reinjection well was drilled about 1 km from the production well in the University of Oradea campus, and a substation was built at the Sports Program High School not far from the campus. The line shaft pump in the geothermal well on the University of Oradea campus was replaced and now supplies geothermal water of about 85ºC not only to the university substation, but also to the new one at the high school. The new substation supplies the district heating system heating of the high school and a few other buildings in the vicinity, the rest being used in the university substation. Total annual geothermal water produced from the production well is about 21,000 m^3, of which about 20% is used by the university substation. Annual geothermal energy use in the new substation is about 4,700 MWt, replacing heat produced by the natural gas fired co-generation power plant in Oradea. After the heat exchangers at the University of Oradea substation were replaced by larger surface ones, the heat-depleted geothermal water temperature is lowered below 40ºC and can now be reinjected.

The most important geothermal heat pump (GSHP) system in Romania is the ELI-NP Extreme Light Infrastructure, which was built in Bucharest-Magurele. ELI-NP is the first pan-European research facility built in Eastern Europe which is oriented to high-level research on ultra-high intensity lasers. The heating and cooling output is in the range of 5.4 MWt, for a total air-conditioned area of 27,000 m^2. The ground source heat exchanger consists of 1,080 boreholes at 125 m depth, with a total borehole length of 135,000 m. The total investment cost of about 356 million € is paid mainly from Romania's allocation of EU structural funds. Unfortunately, there has not been any major progress over the last three years regarding the shallow geothermal energy sector.

There are 40 direct-use geothermal projects that have been reported in Romania, 34 with bathing and swimming, 19 with individual space heating, 14 with greenhouse heating, 12 with district heating, 2 with industrial uses, and 1 with fish farming. Multiple uses were reported at most sites. In summary, individual space heating was 29.63 MWt and 207.28 TJ/yr, district heating was 78.31 MWt and 616.17 TJ/yr, greenhouse heating was 15.69 MWt and 80.49 TJ/yr, fish farming was 4.78 MWt and 9.50 TJ/yr, agricultural drying was 6.32 MWt and 12.70 TJ/yr, industrial process heat was 3.75 MWt and 6.84 TJ/yr, bathing and swimming was 66.65 MWt and 492.34 TJ/yr, and geothermal heat pumps was 40.00 MWt and 480.00 TJ/yr, for a total of 245.13 MWt and 1,905.32 TJ/yr (Gavriliuc, et al., 2020).

5.4.2.15. Serbia

In Serbia, thermal water is currently being used at over 50 locations for balneology, sport, and recreation. Geothermal energy utilization for heating, as well as in agriculture and industrial processes does occur, but at only in a few locations. Geothermal energy utilization for heating is usually connected with systems used for spas and balneology, while district heating systems based on geothermal energy are rather rare. However, there is a growing interest in using geothermal energy from shallow systems using geothermal heat pumps for individual commercial and residential buildings heating. The total heat capacity of all hydro-geothermal drill holes in Serbia is about 200 MWt, with 82.5 MWt in the Pannonian basin. So far, 24 hydro-geothermal systems have been constructed in the Pannonian basin. All were in operation before 1990, the time of peak production, when about 1.6 million m^3 of thermal water was used for heating, balneology, agriculture and industrial processes. In other geothermally active provinces, thermal waters are mainly used for balneology and sport and recreation, and less for heating spas and agricultural installations. In the last decade, interest in geothermal energy has revived due to the increasing cost of fossil and nuclear fuels. The highest interest in Serbia is in geothermal utilization for aqua parks and wellness centers.

There are 66 projects recording the use of direct-use geothermal energy, 49 with bathing and swimming, 21 with district heating, 8 with greenhouse heating, 3 with animal farming, 1 with agricultural drying, and 1 with fish farming, some sites with multiple uses. There are an estimated 1,005 geothermal heat pump units being utilized with sizes varying between 10 and 40 kW, operating 2,860 full load hours per year. Most of these units are water sourced, with a few vertical ground-coupled systems. A summary of geothermal direct-use in the country is: 12.818 MWt and 245.119 TJ/yr for individual space heating, 41.484 MWt and 503.053 TJ/yr for district heating, 5.060 MWt and 89.329 TJ/yr for greenhouse heating, 1.653 MWt and 22.924 TJ/yr for fish farming, 3.947 MWt and 85.854 TJ/yr for animal farming, 0.967 MWt and 26.868 TJ/yr for agricultural drying 33.773 MWt and 628.581 TJ/yr for bathing and swimming, and 15.600 MWt and 124.413 TJ/yr for geothermal heat pumps, for a total of 115.302 MWt and 1,726.141 TJ/yr (Oudech and Djokie, 2020).

5.4.2.16. Slovakia

From 114 wells at 74 sites, geothermal energy is used for heat production. Following a long tradition of using geothermal waters, begun in medieval times, the recreation sector (with or without balneotherapy) remains the predominant use for geothermal waters in Slovakia. Four geothermal **district heating** plants (actually hybrid, as they are combined with natural gas boilers) are now used in Slovakia, all located within major cities. Only 5 wells contribute 11 % of installed capacity (21.9 MWt), yielding a highest thermal output/well of 1.53 MWt. In 2017, the mean thermal output reached 7.65 MWt for all four districts, producing 159 TJ. The newest plant was commissioned in 2017, utilizing geothermal water at 10 L/s free flow and with a wellhead temperature of 92 °C, supporting a two-plate heat-exchangers station with a nameplate capacity of 2x1.55 MWt. The waste heat is then cascaded towards a small health center and thermal spa before being discharged to surface use.

Individual space heating as the primary utilization occurs at 9 sites. However, in some cases heating of buildings supports other purposes, such as greenhouses or spas. A fairly unique use of geothermal waters is to heat mine air along with supplying heat to greenhouses. Installed capacity is 34.6 MWt, representing a 14 % contribution to the total. In 2017 the mean output of wells was 9.56 MWt, producing 273 TJ of heat (14 %), for a cumulative production of geothermal waters 2.2.106 m^3/year. Agriculture use for geothermal waters are mostly for greenhouse heating, using 13 wells at 12 sites, of which 10 operate in the main cities. In some communities the geothermal water is seasonally distributed for space heating and outdoor pools. Under recreation, we assume all utilization of geothermal waters serving to heat pools and not used for curative effects or rehabilitation procedures. There are 47 wells suppling 35 sites where geothermal energy is used to heat pools, whether outdoor or indoor. Recreation is provided from geothermal waters at a total of 18 out of 22 where thermal waters are being produced currently. The current database lists 13 sites where 39 wells supply thermal water for curative purposes (balneology). Thermal spas in Slovakia deal with a wide range of health problems supporting both healing and regeneration processes. Besides bathing and pool activities geothermal waters of low mineralization and temperature is used for drinking and massages. Cumulatively, wells in spa resorts delivered 5 million m^3 of geothermal waters. Use of wells that declared curative effects are strictly regulated, and the operators are obliged to provide precise and regular monitoring of groundwater quality and quantity, resulting in usually smaller withdrawals compared to proven flow rates. Compared to other purposes, wells in curative spa resorts produce 365 days a year. Two sites operate fish farming in the country, providing geothermal water for fish culture. Seasonal use of geothermal water supply is for culturing pools; however, the geothermal waters at these sites are primarily operated for recreation and individual space heating. The use of shallow geothermal energy in domestic and large-scale installations has a somewhat limited market because of the large existing natural gas-based supply grid. The main estimate of shallow geothermal energy use can be derived from heat pumps' share of the market. In large installations, we'd rather refer to statistics presented at EGC2016, so as not to make assumptions about domestic installations. A total of 10 locations reported using geothermal heat pumps.

A total of 68 sites report use of geothermal energy for heating, of which: 39 sites for bathing and swimming, 11 for agricultural drying, 6 sites for industrial applications, 4 sites for district heating, and one site for fish farming. In summary, 34.6 MWt and 273.2 TJ/yr are used for individual space heating, 21.9 MWt and 159.5 TJ/yr for district heating, 45.02 MWt and 229.3 TJ/yr for greenhouse heating, 0.18 MWt and 0.4 TJ/yr for fish farming, 127.0 MWt and 1,325.0 TJ/yr for bathing and swimming, and 1.6 MWt and 13.5 TJ/yr for geothermal heat pumps, for a total of 230.3 MWt and 2000.9 TJ/yr (Fričovský, et al., 2020).

5.4.2.17. Slovenia

Individual space heating with domestic hot water heating is implemented at 20 locations predominantly thermal spas and resorts, mostly through heat exchangers. The GHP units usually of bigger capacity, are installed now at 20 locations to increase the thermal water temperature. Bathing and swimming (including balneology) is the leading category of direct heat use for thermal water in the country, implemented at 25 localities. There are 15 thermal spas and health resorts, and an additional 10 recreation centers (7 of them part of the hotel accommodations) where swimming pools with a surface area of 51,600 m^2 and volume of 67,160 m^3 are heated by geothermal water directly or indirectly through heat exchangers or geothermal heat pumps (GHPs). Wellhead water temperatures in thermal spas range from 21.5 to 76°. Only one geothermal district heating (DH) system is operational in Slovenia at present, in Lendava, where a many public buildings (school, kindergarten, Petrol Geo HQs, etc.) and blocks of flats (total 65,000 m^2) are heated. In eastern Slovenia the heating of greenhouses using geothermal water began in 1962. It is used on 4.5 ha for cultivation of flowers, mostly for the domestic market. Other locations use the already thermally spent water flowing from a district heating system with 40°C to heat 1 ha of greenhouse for tomato production. At another location 4 ha of greenhouses were constructed for orchid cultivation, both for domestic and foreign markets. New greenhouses of 9 ha were built for tomato and also exotic fruit cultivation. Air conditioning (cooling) of the hotels and other touristic buildings using geothermal energy is not well documented for the six localities that are known. Snow melting is a relatively new direct use application in the country, implemented in three localities, using waste geothermal heat to heat sidewalks, two football pitches at a hotel, and three other pitches elsewhere. Geothermal heat pumps are used at seven recreation centers and at twelve health or spa resorts, plus at two other locations. The GHP units, typically of larger capacity (13.2 MWt altogether), are used in an open loop system for raising the thermal water temperature for further use in swimming pools and space heating, or just to maintain the water temperature in swimming pools, and for DHW heating. There are about 12,100 operational small GSHP units (typically 12 kW) of which 46% are open-loop systems, 41% are horizontal closed-loop and 13% are vertical closed-loop systems. There are also larger capacity GSHP units (>20 kW) installed within about 670 systems in public and other buildings. Of these, 530 units are open-loop water-water type (79%), 107 units vertical closed-loop (16%), and 33 (5%) horizontal closed-loop systems. Full load operating hours are usually less than 2000 hours/year.

There are 31 locations in Slovenia using geothermal energy for direct-use application, 25 for bathing and swimming, 20 for individual space heating, 5 for air conditioning, 3 for greenhouse heating, 3 for snow melting and 16 for other uses (mainly for heating domestic hot water). For geothermal heat pumps, 12,100 units are small (3-20 kW) and 670 units are large (>20 kW) providing 500 to 6,600 equivalent full load heating hours/year. Both open loop (ground water) and closed loop systems are used. In summary, 17.46 MWt and 161.42 TJ/yr are for individual space heating, 2.21 MWt and 18.10 TJ/yr for district heating, 3.22 MWt and 32.87 TJ/yr for air conditioning (cooling), 10.79 MWt and 111.57 TJ/yr for greenhouse heating, 1.03 MWt and 14.64 TJ/yr for snow melting, 23.36 MWt and 197.33 TJ/yr for bathing and swimming, 4.37 MWt and 42.79 TJ/yr (domestic hot water heating), and 203.11 MWt and 1,031.77 TJ/yr for geothermal heat pumps, for a total of 265.55 MWt and 1,610.49 TJ/yr for a total capacity factor of 0.19 (Rajver, et al., 2020).

5.5. Commonwealth of Independent States

5.5.1. Armenia

No country update report was received nor was one received for WGC2015, WGC2010, or WGC2005. The data reported here is based on 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 plant 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 numbers from Lund, et al., (2005), it is estimated that the capacity is 0.5 MWt and use of 7.5 TJ/year for individual space heating, and 1.0 MWt and use of 15 TJ/yr for bathing and swimming, for a country total of 1.50 MWt and 22.50 TJ/yr.

5.5.2. Belarus

Existing regulations in the country do not require registering geothermal installations with the Ministry of Mineral Resources and Environmental Protection. Therefore, their exact number is not known and could only be estimated. The first small heat pump systems were installed for heating waterworks and sewage plant buildings, mostly in the Minsk District in 1997. The situation gradually increased during following years. At present, the total number of geothermal installations in the country is estimated to be around 300. The largest installation exists in the southwestern part of the country at the greenhouse complex “Berestye” in Brest. It uses fresh warm ground water, pumped from a 1000 m deep borehole. Water temperature at the well mouth reaches 24°C, and the well flow rate is about 42 m^3/hour. Two heat pumps operate there, with a heat output of 505 kW each. Other heat pump installations use an open circulation loop pumping fresh water, or use closed loop systems with horizontal or vertical heat exchangers. The main consumers of the underground heat are the “Novaya Rudnya” border crossing at the Ukrainian border, as well as nearby dwellings and a church. We assume their power output is underestimated. A few hundred small heat-pump systems were installed in private cottages within and around the main towns and cities. Most installations extract heat from cool groundwater taken from shallow boreholes with ambient temperature of 8–10°C as a primary energy source, or have closed horizontal circulations loops. One installation uses river water. A total of 28 locations are listed using about 300 geothermal heat pumps (mostly water-source) in the country, for a total capacity of 10.0 MWt and use of 137.0 TJ/yr (Zui, 2020).

5.5.3. Georgia

There are 42 locations in Georgia using geothermal energy for direct-use applications: 22 for greenhouse heating, 19 for bathing and swimming, and one for fish farming. Space heating and domestic hot water heating occur in the Tbilisi area. Five geothermal heat pump units are reported at Kutaisi airport. In summary, there is 8.11 MWt and 261.04 TJ/yr for space heating, 5.46 MWt and 172.20 TJ/yr for district heating, 18.12 MWt and 571.0 TJ/yr for greenhouse heating, 0.03 MWt and 1.1 TJ/yr for fish farming, 37.45 MWt and 1,180.72 TJ/yr for bathing and swimming, and 0.03 MWt and 0.16 TJ/yr for geothermal heat pumps, for a total of 69.2 MWt and 2,186.22 TJ/yr (Melikadze, et al., 2020).

5.5.4. Russia

Direct use of geothermal resources is most developed in Kuril-Kamchatka region, Dagestan and Krasnodar Krai, for heat supply and greenhouses heating in eastern (Kamchatka peninsula) and in southern Russia (Caucasus Mountains). 10 locations in Russia use geothermal energy for direct-use applications, 7 for district heating, 7 for individual space heating, 6 for greenhouse heating, 5 for bathing and swimming, 2 for agriculture drying, 1 for fish farming, and 1 for industrial uses -- with some locations having multiple uses. 1000 geothermal heat pumps units are in operation at 6 locations in western and central Russia; however, no data were given, so an estimate is made. In summary, 110 MWt and 2,185 TJ/yr are used for individual space heating, 110 MWt and 2,185 TJ/yr for district heating, 160 MWt and 3,279 TJ/yr for greenhouse heating, 4 MWt and 63 TJ/yr for fish farming, 4 MWt and 63 TJ/yr for animal farming, 4 MWt and 69 TJ/yr for agricultural drying, 25 MWt and 473 TJ/yr for industrial process heating, 4 MWt and 63 TJ/yr for bathing and swimming, and an estimated 12 MWt and 95 TJ/yr for geothermal heat pumps, for a total of 433 MWt and 8,475 TJ/yr (Svalova and Povarov, 2020).

5.5.5. Ukraine

There are 10 areas in the country which use geothermal energy for direct-use applications. Three other areas are identified as having “small” facilities. The 10 areas that are identified have a total of 30 locations (cities and counties). All are listed as having both individual space heating and bathing. An estimated total of 110,000 geothermal heat pumps are listed with sizes between 5 and 20 kW for a total 1,600 MWt and 4,990 TJ/yr. The only other uses that are identified are bathing and swimming (balneology) for 6.96 MWt and 95.95 TJ/yr, thus, the total for the country is 1,606.96 MWt and 5,085.95 TJ/yr (Morozov, et al., 2020).

5.6. Oceania

5.6.1. Australia

There are 24 locations which list geothermal direct-use, in 5 states: New South Wales, Queensland, South Australia, Victoria and Western Australia. The uses include 21 for bathing and swimming, 2 for fish farming, one for industrial use, and one for air conditioning. The most popular and one of the larger uses of geothermal energy is at Peninsula Hot Springs on the Mornington Peninsular south of Melbourne, where 540,000 visitors use the bathing facilities at the spa which uses geothermal well water at 47°C. There are an estimated 3,348 geothermal heat pump units installed in the country in 7 states and one territory, mostly vertical closed loop systems, but some horizontal closed loop and water source systems. In summary, there are 2.5 MWt and 25 TJ/yr for air conditioning, 2.9 MWt and 47 TJ/yr for fish farming, 1.3 MWt and 21 TJ/yr for industrial process heat, 26.7 MWt and 381 TJ/yr for bathing and swimming, and 61.0 MWt and 379 TJ/yr for geothermal heat pumps, for a total of 94.4 MWt and 853 TJ/yr (Beardsmore, et al., 2020).

5.6.2. New Zealand

There are 10 locations in the country which report geothermal direct-use, on both North and South Islands. 9 use geothermal for bathing and swimming, 3 for individual space heating, 2 for district heating, 2 for fish farming, one for industrial process heat, and three for other uses (irrigation, frost protection and in a tourist park). There are at least 126 geothermal heat pump units in use with 2,628 equivalent full load operation hours per year. Most of the systems are water source units, but a few are either vertical or horizontal closed loop systems. The two largest units are at the Christchurch airport and town hall. In summary, there is an estimated

31 MWt and 300 TJ/yr used for individual space heating, and 31 MWt and 278 TJ/yr used for district heating, 24 MWt and 366 TJ/yr for greenhouse heating, 17 MWt and 196 TJ/yr for fish farming, 0.1 MWt and 2 TJ/yr for animal farming, 304 MWt and 6,220 TJ/yr for industrial process heat (mainly for extracting and drying silica from geothermal waters), 58 MWt and 1,375 TJ/yr for bathing and swimming, 33 MWt and 992 TJ/yr for other uses, and >20 MWt and 391 TJ/yr for geothermal heat pumps, for a total 519.1 MWt and 10,120 TJ/yr (Daysh, et al., 2020).

5.6.3. Papua New Guinea

Geothermal resources on the island of Lihir are exploited to generate electricity for the gold mine operation. On New Britain Island, low-enthalpy heat is used to boil megapod eggs, and the megapods (a local fowl) use the hot ground to incubate their eggs, 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 fuels, and for all countries it means the elimination of pollutants such as carbon particles 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 produce heat, such as in a furnace.

Using 1,020,887 TJ/yr of energy consumed in direct geothermal applications by 2020 (see Table 1) and estimating that a barrel of fuel oil contains 6.15×10^9 J, and that the fuel is used to produce electricity, the savings would be 474 million barrels of oil or 64.4 million tonnes of oil annually (300 lbs/barrel = 136 kg/barrel = 42 gallons/barrel = 159 L/barrel @ density = 0.855 kg/L). If the oil were used directly to produce energy by burning it for heating, then these savings would be 237 barrels or 32.2 tonnes. The actual savings are most likely somewhere in between these two values. Note that 474 million barrels is about 1.6 days of worldwide oil consumption.

Using figures developed by Lawrence Livermore Laboratory for the U.S. Department of Energy (Kasameyer, 1997) and by private consultants Goddard and Goddard (1990), the following savings would be realized for carbon, CO_2, SO_x, NO_x (also, see Table 11). Compared to using electricity, the carbon savings would be 20.32 tonnes/TJ from natural gas, 86.81 tonnes/TJ from oil or 100.82 tonnes/TJ from coal for a total carbon production savings of 14.81, 63.38 or 73,62 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 emission when producing electricity from natural gas, oil and coal, respectively, the savings in CO_2 emissions would be 54.27, 229.88, 268.07 million tonnes. The savings in SO_x and NO_x producing electricity from natural gas, oil and coal would be 0.33, 1.39 and 1.51 million tonnes of SO_x and 14.06, 42.22 and 45.76 thousand tonnes of NO_x. If the heat were produced by burning these fuels, the carbon, CO_2, SO_x and NO_x emissions would be half 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.

If emission reductions in the cooling mode of geothermal heat pumps are considered, which is not geothermal, then this is equivalent to an additional annual reduction of approximately 122 million barrels (18.1 million tonnes) of fuel oils, and 15.5 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 11.

Table 11: Direct-use Worldwide Saving in Energy, Carbon and Greenhouse Gases Using Geothermal Energy Including Geothermal Heat Pumps in the Cooling mode (in Millions) in terms of fuel oil (bbl = 42-gallon barrels).

	Fuel oil bbl	Fuel oil TOE	Carbon TOE	CO_2 TOE	SO_x TOE	NO_x TOE
As Electricity	596	81.0	78.1	252.6	1.75	0.054
As Fuel Oil	298	40.5	39.0	126.3	0.89	0.027

7. WELLS DRILLED FOR BOTH GEOTHERMAL ELECTRIC POWER AND DIRECT-USE DURING 2015-2019

Approximately 2,647 wells were reported drilled by 42 countries during the period 2015-2019 for both electric power and direct-use. Shallow heat pump wells are not included in these figures, but probably amount to approximately 20,000 holes up to 100 m deep. This is a 3.6% annual increase over the 2010-2014 period (also for 42 countries). The average was 63 wells per country. The countries which drilled more than 100 wells are China, Turkey, Kenya, Indonesia and Costa Rica (in descending order). In terms of the types of wells, 43.2% were drilled for electric power generation, 40.5% for direct-use, 8.7% as combined heat and power wells, and 7.6% as research or gradient wells. The total depth drilled by the 42 countries was 4,464 km for an average of 1.69 km compared to 4.30 km per well for 2010-2014; however, average direct-use well depths would be less. The countries drilling together more than 100 km during this period were: China, Kenya, Turkey and Indonesia (in descending order); China drilling 1,624 km. The following are the regional allocations:

- 15.0% in Africa by 4 countries (396 wells)
- 10.5% in the Americas by 9 countries (278 wells)
- 58.0% in Asia by 9 countries (1,537 wells)

- 12.2% in Europe by 18 countries (322 wells)
- 4.3% in Oceania by 2 countries (114 wells)

8. PERSON-YEARS OF PROFESSIONAL PERSONNEL WORKING IN GEOTHERMAL FOR BOTH ELECTRIC POWER AND DIRECT-USE DURING 2015-2019

Approximately 34,500 person-years of professional effort was reported in 59 countries, work allocated to geothermal development, restricted to personnel with university degrees, during the period 2015-2019 for both electric power and direct-use (no distinction made between the two). The average was 585 person-years per country over the five-year period (117 person-years/year/country). This is almost the same total compared to 2010-2015, but a 12% decrease/country (52 countries). The countries with more than 100 person-years/year are: France, USA, Russia, Iceland, Belgium, Ukraine, Norway, Georgia, and Italy, in descending order; however, the data are approximate, as several years during the five-year period were missing or estimated. The allocation of effort by category was: 13.5 % for government, 23.5% for public utilities, 10.9% for universities, 1.8% for paid foreign consultants, 0.7% for foreign aid programs, and 49.6% by private industry. Again, the person-years for direct-use project would be less. The following are the regional allocations for 59 countries:

- 5.1% in Africa by 9 countries (350 person-years/year)
- 11.4% in the Americas by 11 countries (787 person-years/year)
- 44.0% in Asia by 10 countries (3,037 person-years/year)
- 33.1% in Europe by 27 countries (2,288 person-years/year)
- 6.4% in Oceania by 2 countries (445 person-years/year)

9. TOTAL INVESTMENT IN GEOTHERMAL FOR BOTH ELECTRIC POWER AND DIRECT-USE DURING 2015-2019

Approximately US$ 22.262 billion were reported as invested in geothermal energy by 53 countries during the period 2015-2019 for both electric power (64%) and direct-use (36%), about 11.1% more than the 2010-2014 amount for 49 countries. The average was US$ 420 million per country, with countries investing over US$ 500 million being Indonesia, Turkey, China, Taiwan, Kenya, Republic of Korea, Mexico, Chile and Italy (in descending order). In terms of categories of investment: 27.9% was for electric power utilization in 16 countries, 15.4% was for direct-use in 30 countries, 32.4% was for field development including production drilling and surface equipment in 33 countries, and 24.3% for R&D including surface exploration and exploratory drilling in 47 countries for a total of $22.262 billion. Table 12 lists some direct-use significant contributions to a country’s economy. Again, the investment for direct-use projects would be less. The following are the regional investments by continent:

- 6.3% in Africa by 7 countries ($1.412 billion)
- 10.2% in the Americas by 11 countries ($2.275 billion)
- 74.2% in Asia by 11 countries ($16.506 billion)
- 8.7% in Europe by 22 countries ($1.926 billion)
- 0.6% in Oceania by 2 countries ($0.143 billion)

10. CONCLUDING REMARKS

As in previous WGC reports, several countries stand out as major producers and consumers of geothermal fluids for direct use (China, USA, Sweden, Turkey, Japan, Germany, Iceland, Finland, France, and Canada); however, in most countries, development has been slow. This is not surprising as fossil fuels are a major competitor. Another obstacle is the initial high investment costs of geothermal projects. However, many countries have been doing the necessary groundwork, conducting inventories and quantifying their resources in preparation for renewed development once the economic situation improves, and once governments and private investors can see the benefits of developing a domestic renewable energy source. This is true for many of the east African countries, such as Djibouti, Eritrea, Malawi, Mozambique, Rwanda, Tanzania, Uganda, Zambia and Zimbabwe, which 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 12. The distribution of geothermal use by continent is shown in Table 13, indicating that Asia and Europe are the leaders, with 57 of the 88 countries reporting, for 77.0% of the world’s installed capacity (MWt) and 80.6% of the direct-uses (TJ/year).

With the increased interest in geothermal (ground-source) heat pumps, it is now evident that geothermal energy can be developed anywhere for both heating and cooling. They now make up 72.0% of the installed capacity (MWt) and 58.8% of the annual energy use (TJ/yr), as illustrated in Figures 3 and 4. This use has increased since 2015. Low-to-moderate temperature geothermal resources are also being used in combined heat and power plants (CHP), where hot water, often with temperatures below 100^{o}C, is first run through a binary (organic Rankine cycle) power plant, then cascaded for space heating, swimming pools, greenhouses, industrial applications, and/or aquaculture pond heating, before being injected back into the aquifer. CHP projects certainly maximize resource use while improving ROI. This has been shown in Iceland, Austria, and Germany, as well as on the Oregon Institute of Technology campus in Klamath Falls, Oregon, USA.

Table 12: Significant Contribution of Direct-use Geothermal Energy to a Country's Economy

Iceland	90% of buildings space heated
Japan	2,000 onsens, 5,000 public baths, 1,500 hotels serving 15 million guest/year
Sweden	40% of buildings heated using geothermal heat pumps
Switzerland	110,000 geothermal heat pumps installed (~3.7 units/sq. km)
Tunisia	244 ha of heated greenhouses
Turkey	116,000 apartments/residences heated in 17 cities - approaching 40% of units
USA	Approximately 1.685 million geothermal heat pumps (4.0% growth/year)

Table 13: Distribution of Direct-use Geothermal Energy Utilization by Continent

Continent	Countries	%MWt	%TJ/year
Africa	11	0.2	0.4
Americas	17	21.7	17.7
Asia	19	45.6	53.4
Europe*	38	31.9	27.4
Oceania	3	0.6	1.1

* Includes CIS Countries (Georgia, Russia and Ukraine)

Key data and explanations were often missing from WGC2020 country update reports used in this worldwide summary. Some data also appeared to be wrong or misreported, such as showing capacity factors > 1.0. We have attempted to correct these errors by contacting the author(s) and/or making estimates for the missing data based on our limited knowledge of developments in the country.

Despite these discrepancies and the effort required to correct them, work on this review has proven useful, as it has allowed us to demonstrate that using low-to-moderate temperature geothermal resources in 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. Even though the initial cost of developing a geothermal resource is high (exploring, drilling wells, constructing pipelines and plants), the long-term cost is low. Compared to 2015, geothermal direct-use has increased in its contribution to the world's annual energy mix from about 0.5 to 1.0 day per year.

At the time of writing this report (December, 2019), the cost of crude oil was US$ 63.00 per barrel, but has varied over the last five years between US$ 40 and US$80 per barrel. However, when geothermal energy becomes more competitive with fossil fuels, especially if carbon penalties are applied to the price, and the environmental benefits are better understood and accepted, development of the natural "heat from the earth" should begin to accelerate. This growth is well illustrated in Tables 8 and 9 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.

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Table: 1A (Appendix)

Country	MWt	TJ/yr	GWh/yr	Load Factor
Albania	16.225	107.590	29.886	0.210
Algeria	77.700	2,375.100	659.750	0.969
Argentina	204.780	1,209.070	335.853	0.187
Armenia	1.500	22.500	6.250	0.476
Australia	94.400	853.000	236.944	0.287
Austria	1,095.780	8,644.210	2,401.169	0.250
Belarus	10.000	137.000	38.056	0.434
Belgium	305.720	1,467.500	407.639	0.152
Bolivia	1.000	20.000	5.556	0.634
Bosnia & Herzegovina	36.030	306.710	85.197	0.270
Brazil	363.450	6,682.700	1,856.306	0.583
Bulgaria	109.370	1,326.960	368.600	0.385
Burundi	0.350	7.000	1.944	0.634
Canada	1,831.280	14,512.000	4,031.111	0.251
Chile	22.610	278.910	77.475	0.391
China	40,610.000	443,492.000	123,192.222	0.346
Columbia	20.000	340.000	94.444	0.539
Costa Rica	1.750	35.000	9.722	0.634
Croatia	79.300	390.600	108.500	0.156
Czech Republic	324.500	1,790.000	497.222	0.175
Cyprus	10.300	65.000	18.056	0.200
Denmark	743.600	4,002.000	1,111.667	0.171
Eastern Caribbean	0.103	2.775	0.771	0.854
Ecuador	5.201	103.461	28.739	0.631
Egypt	44.000	152.890	42.469	0.110
El Salvador	3.360	56.000	15.556	0.528
Estonia	63.000	356.000	98.889	0.179
Ethiopia	2.200	41.600	11.556	0.600
Faroe Islands	3.660	20.000	5.556	0.173
Finland	2,300.000	23,400.000	6,500.000	0.323
France	2,597.600	17,279.600	4,799.889	0.211
Georgia	69.200	2,186.220	607.283	1.002
Germany	4,806.340	29,138.640	8,094.067	0.192
Greece	259.450	2,087.520	579.867	0.255
Greenland	0.100	3.200	0.889	1.015
Guatemala	2.310	56.460	15.683	0.775
Honduras	1.933	45.000	12.500	0.738
Hungary	1,023.700	10,701.620	2,972.672	0.331
Iceland	2,373.000	33,598.00	9,332.778	0.449
India	357.644	4,007.820	1,113.283	0.355
Indonesia	2.300	42.600	11.833	0.587
Iran	82.224	2,583.261	717.573	0.996
Ireland	200.870	974.000	270.556	0.154
Israel	82.400	2,193.000	609.167	0.844
Italy	1,425.000	10,916.000	3,032.222	0.243
Japan	2,570.460	30,723.270	8,534.242	0.379

Country	MWt	TJ/yr	GWh/yr	Load Factor
Jordan	153.300	1,540.000	427.778	0.319
Kenya	18.500	602.400	167.333	1.033
Latvia	1.630	31.810	8.836	0.619
Lithuania	125.500	1,044.000	290.000	0.264
Madagascar	2.814	75.585	20.996	0.852
Macedonia	47.430	623.610	173.225	0.417
Malawi	0.550	11.000	3.056	0.634
Malaysia	5.000	100.000	27.778	0.634
Mexico	156.113	4,185.369	1,162.603	0.850
Mongolia	22.720	398.700	110.750	0.556
Morocco	5.000	50.000	13.889	0.317
Nepal	3.555	96.113	26.698	0.857
Netherlands	1,719.150	8,344.000	2,317.778	0.154
New Zealand	518.000	10,120.000	2,811.111	0.620
Nigeria	0.700	14.000	3.889	0.634
Norway	1,150.180	12,601.200	3,500.333	0.347
Papua New Guinea	0.100	1.000	0.278	0.317
Peru	3.000	61.000	16.944	0.645
Philippines	1.670	12.650	3.514	0.240
Poland	756.000	4,175.980	1,159.994	0.175
Portugal	21.060	406.500	112.917	0.612
Romania	245.130	1,905.320	529.256	0.246
Russia	433.000	8,475.000	2,354.167	0.621
Saudi Arabia	45.000	172.890	48.025	0.122
Serbia	115.302	1,726.141	479.484	0.475
Slovakia	230.300	2,000.900	555.806	0.276
Slovenia	265.550	1,610.490	447.358	0.192
South Africa	2.300	37.000	10.278	0.510
South Korea	1,489.760	3,482.650	967.403	0.074
Spain	544.000	3,933.000	1,092.500	0.229
Sweden	6,680.000	62,400.000	17,333.333	0.296
Switzerland	2,196.800	13,292.000	3,692.222	0.192
Tajikistan	17.300	479.600	15.389	0.840
Thailand	128.510	1,181.200	328.111	0.291
Tunisia	43.800	364.000	101.111	0.264
Turkey	3,488.350	54,584.000	15,162.222	0.496
Ukraine	1,606.960	5,085.950	1,412.764	0.100
United Kingdom	524.700	4,240.500	1,177.917	0.256
United States of America	20,712.590	152,809.500	42,447.083	0.234
Venezuela	0.700	14.000	3.889	0.634
Viet Nam	18.210	188.520	52.367	0.328
Yemen	5.000	100.000	27.778	0.634
TOTAL	**107,726.564**	**1,020,887.165**	**283,579.768**	**0.300**