Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

Geothermal Development in the Republic of Korea: Country Update 2015-2019

Yoonho Song and Tae Jong Lee

Korea Institute of Geoscience and Mineral Resources, 124 Gwahak-ro, Yuseong-gu, Daejeon 34132, Korea

song@kigam.re.kr

Keywords: geothermal, country update, direct-use, heat pump, EGS, Republic of Korea

ABSTRACT

Geothermal utilization in Korea is for direct-uses, especially with geothermal heat pump (GHP) application, because there are no high temperature resources associated with active volcanoes or tectonic activity. GHP installation in Korea has increased rapidly, showing more than 50% annual increase by 2011 and over 100 MWt new installation annually since 2012. Total installed capacity is estimated to become over 1,400 MWt in 2019, more than double of the number reported at WGC 2015. Major installations are for large facilities including public and office buildings mainly thanks to strong government subsidy programs and the mandatory act. Other direct-uses including hot springs, individual heating and space heating application remain stagnant for the last five years at 44 MWt.

There is no geothermal power generation in Korea yet due to lack of high temperature hydrothermal resources. However, there have been continuous R&D efforts for utilizing deep geothermal resources including theoretical and technical potential assessments, exploration of potential hydrothermal resources, pre-feasibility study and a pilot project of enhanced geothermal system (EGS). Unfortunately, the pilot plant EGS project and exploration programs of potential hydrothermal resources have been stopped or suspended due to public concerns on possibly causing damaging earthquake.

1. INTRODUCTION

Direct use geothermal utilization in Korea has been continuously active for the last five years, especially geothermal heat pump (GHP) installation. The rapid increase of GHP installation is mainly due to active government subsidizing programs for renewable energy deployment. There are several areas producing hot spring water of discharge temperature higher than 60 °C, which circulates through deeply extended fractures in crystalline rocks. This hot water has been utilized for floor heating in a hot spring area for more than 20 years. In another place, a small-scale district heating and greenhouse heating with hot spring water started in 2008.

There are neither high temperature hydrothermal resources for power generation nor the regional anomalous zones such as deep sedimentary basin for large-scale district heating in Korea. For the limited Tertiary sediment region, Pohang in southeastern part of the Korean Peninsula, there have been extensive exploration and drilling works to find a way of exploiting low-temperature geothermal water resources since 2003. Although the expected flow rate was not achieved, we could realize high geothermal potential and the activities have led to launching of the government funded EGS pilot project at the end of 2010. The Pohang EGS pilot project targeted a MW class power generation plant through a pair of injection and production wells. However, because of the damaging earthquake which occurred at a close vicinity of the well site two months after the stimulation tests any further development activities have been stopped.

Renewable energy of the national energy policy is getting more important, but geothermal is not separately specified yet. The Third National Energy Master Plan which was fixed and declared on June 2019 by the Korean Government has a vision of 'Sustainable growth and improving the quality of people's life through energy transition'. It specifies the five major tasks: 1) Converting energy policy paradigm to focusing on consumer innovation, 2) Switching to the clean and safe energy mix, 3) Enlarging distributed and participatory energy systems, 4) Strengthening global competitiveness of energy industry, and 5) Expansion of foundation for energy transition. For the task 2, it states a target of renewable share of power generation being 30-35% by 2040. There are ongoing subsidy programs and mandatory act for supporting renewable energy deployment, which are described in Chapter 3 with GHP statistics.

2. GEOLOGIC SETTING AND GEOTHERMAL POTENTIAL

Figure 1 shows digital geologic map of South Korea (KIGAM, 1995) and its superimposed on a topographic relief map of Korean Peninsula by Korea Institute of Geoscience and Mineral Resources (KIGAM). The geology of Korea is composed of relatively old rocks and also various formations that age from Precambrian to Quaternary. The Precambrian metamorphic rocks (PR and AR groups in Figure 1) crop out extensively in the Korean Peninsula from the north to south covering almost a half of the territory. Especially in South Korea, Archean (AR) groups mainly consist of gneiss and schist complexes and exposed in the Gyeonggi Massif, central Korea and in the mountainous area over southern part of the Peninsula.

The Paleozoic sediments (PT, O, and og group) are distributed mainly in central-eastern part of South Korea forming high mountains. It is hard to find hot spring or geothermal manifestation in those areas composed of Precambrian and Paleozoic (PAL group) rocks. The major outcrop of the Jurassic granite (J group) occurs as batholith stretching along NE direction in the middle part of the Peninsula across the country from the east to the west. Cretaceous granite is mainly limited in the southeastern part. Following the granite intrusion and tectonic movement in the southeastern part during the Cretaceous (K group) and the early Tertiary (P group), several linear structures has formed with direction of NNE, parallel to the southeastern coast line. Major hot springs are mostly found in these granite areas. Quaternary volcanic rocks (Q group) are exposed in some islands in the South and East Sea, and in some areas in the main land of Korea. There is no surface geothermal manifestation such as hot springs in those volcanic areas.

Red circles on the right map of Figure 1 indicate potential geothermal areas where various exploration activities have been performed for the last fifteen years. Among them, the area in the southeast is where Pohang EGS pilot project was performed, which has been stopped due to M_w 5.5 earthquake occurred on November 15th, 2017. A small, remote Ulleung Island in the East Sea is the area where recent exploration activities including drilling of the four gradient boreholes of maximum 1 km deep and 3-D magnetotelluric (MT) survey have been done to conclude potential existence of hydrothermal resources (Lee et al., 2019). However, further activities including exploration well drilling down to 2 km depth is suspended due to growing concerns on potential induced earthquake related with geothermal development. For the Seokmo Island, various geophysical surveys and well loggings have been performed around existing artesian wells (Lee and Song, 2010) and heat supply to a small-scale greenhouse and 21 house-holds started operating in 2008 as can be found as Locality of GangHwa in TABLE 3. Jeju Island is a volcanic island where intensive MT surveys were done during the years from 2004 until 2007 to locate potential geothermal area (Choi et al., 2013). But because most of the central area is designated as a national park where a deep conductive anomaly has been interpreted, no further exploration activity has been made yet.

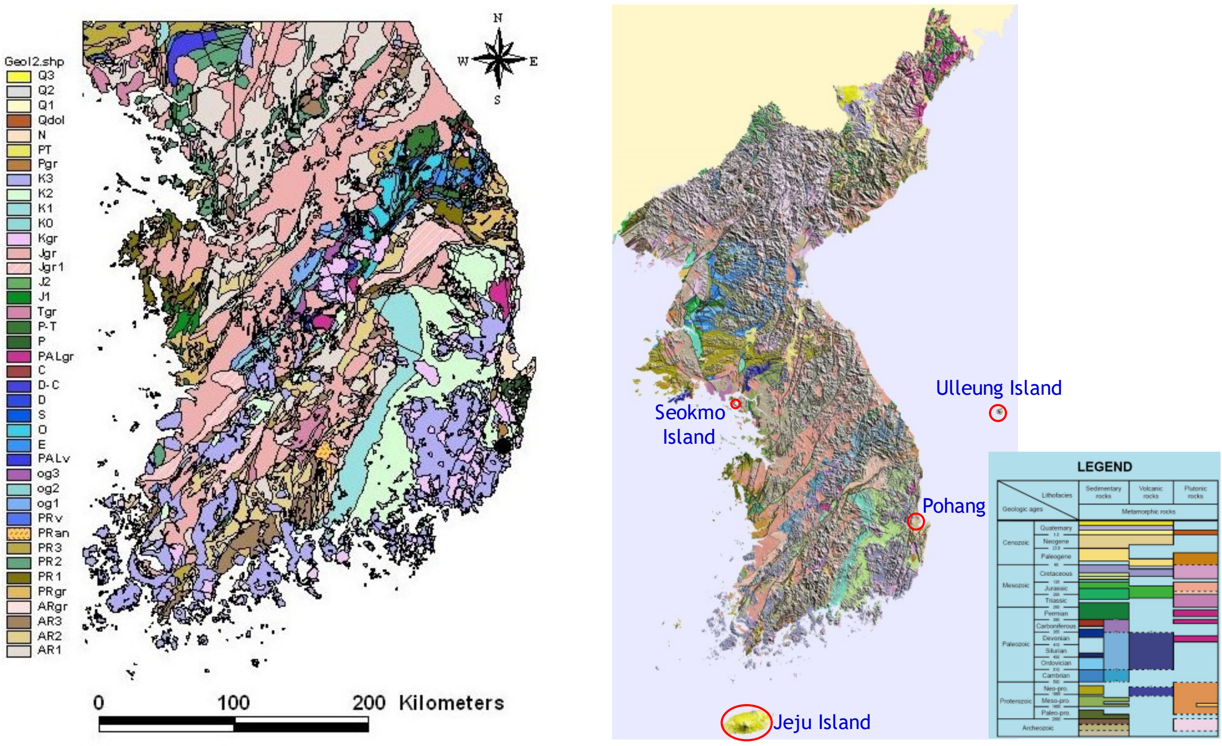

Figure 1: Digital geology map of Korea (KIGAM, 1995) and its superimposed on a topographic relief map of Korea Peninsula by KIGAM. Red circles in the right map indicate potential geothermal areas where exploration activities have been made.

In 2011, Song et al. (2011) performed the estimation of geothermal power generation potential of Korea with EGS technology. The methodology and some of the resultant figures are summarized in the 2015 report (Song and Lee, 2015). Major features of the estimation were that theoretical potential down to 10 km reaches up to 6,975 GWe which amount to almost 60 times total electricity generation capacity of Korea in 2019. Technical potential down to 6.5 km appears 19.6 GWe.

3. GEOTHERMAL UTILIZATION - STATISTICS AND DISCUSSION

There is no geothermal power generation in Korea yet as can be found in TABLE 1. Electricity generation by other renewables is still less than 5% of gross national power generation.

TABLE 3 summarizes direct uses of hot spring water resources at 13 locations with discharge temperatures higher than 42 °C, which has remained stagnant since 2008 and no further survey was made.

TABLE 4 shows summary of GHP in Korea. No official statistics are made on GHP sales or capacity of individual heat pumps. Instead, total capacities of the seven capacity ranges are considered in recent statistics. Therefore, total number of GHP units can only be assumed from total number of installed sites. Official statistics on renewable energy deployments are made by Korea Energy Agency (KEA, formerly KEMCO), the national energy authority, as annual basis. So far, GHP is only considered for geothermal in national official statistics and thus statistics on other direct uses such as hot spring usage are not accounted for.

In 2015 country update (Song and Lee, 2015), we adopted a new method to estimate heating and cooling energy production from installed capacity accounting for different full load hours between office building and other types. However, because the full load hours of the other types of applications appeared much smaller than individual residential houses (Paek et al., 2015), we accounted for residential houses (small size of GHP than 17.5 kW) only as higher full load hours for heating in this report. In Korea, based on design reports to 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 (Korea Energy Agency, 2018), share of installation for residential houses or for capacity smaller than 17.5 kW is around 15.3%. Then, considering accredited rate of COP for heating and cooling as 3.73 and

4.75, respectively, we can come up with the following formulae for estimating geothermal contribution of heating and cooling energy production:

Heating: $Q_{rated,H} \times [0.847\times570 + 0.153\times1{,}800] \times(3.73-1)\div3.73=554.92\times Q_{rated,H}$

Cooling: $Q_{rated,C} \times [0.847\times590 + 0.153\times540] \times(4.75-1)\div4.75=459.75\times Q_{rated,C}$

Note that even for the same GHP the rated values of capacity for heating and cooling are different from each other and also it holds true for COP. Above formulae for estimating geothermal contribution to the energy production are nothing more than assumption because those are based on design parameters and there is no validation of performance based on actual monitoring. However, we argue that this is the best estimation at the moment because no systematic monitoring data is available.

Figure 2 shows increasing trend of GHP installation in Korea since 2006. We can see more than average 50% of annual increase until 2011 and 100 MWt installations per year since 2012. Main drivers of the rapid increase in GHP installation are active government subsidy programs and a special Act for new and renewable energy ('Mandatory Act'). There are several subsidy programs; 'Building (formerly Deployment Subsidy Program)', 'Local (formerly Rural Deployment Program)', and 'Residential (formerly 1 Million Green home by 2020 Program)', and 'Hybrid' programs through which government subsidizes up to 50% of total installation cost based on competition with pre-determined budget each year. Another 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.

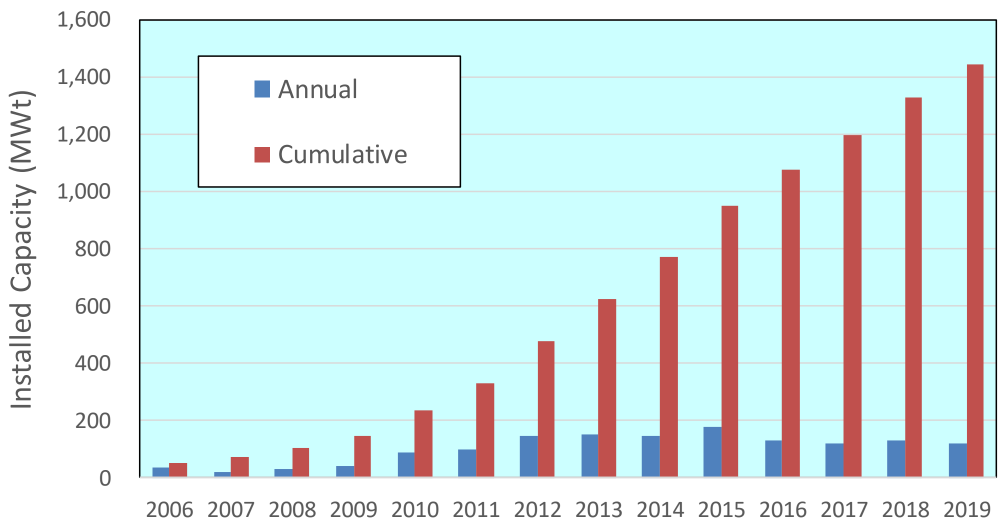

Figure 2. Increasing trend of GHP installations in Korea. Data are based on 'New and Renewable Energy Deployment Statistics' by KEA and modified to account for unreported installations. Data for 2018 and 2019 are estimated accounting for plans according to 'Mandatory Act' and subsidizing programs.

In 2012, the 'Mandatory Public Renewable Energy Use Act' (Mandatory Act) was amended to state that "In all public buildings bigger than 1,000 m^2 in area, minimum 10% of annual energy uses should be from new and renewable energy sources". The minimum percentage is to increase annually; 11% in 2013, 12% in 2014, 18% in 2016, 24% in 2018, and targeting 30% in 2020. According to the Act, annual GHP installation plans of 90 to 110 MWt since 2015 are reported, which would become realized two or three years after planning considering the construction period.

Direct uses summary in TABLE 5 shows the total installed capacity is estimated to reach 1,490 MWt, of which GHP's share is 97% (1,446.2 MWt). In terms of annual energy use, heating by GHP reduces to 83% of total because of smaller overall capacity factor which resulted from the fact that major installations are for office buildings.

TABLE 6 shows number of wells drilled for exploration and research purposes and total depths amounting to 10.7 km. Two of them are the ~4.35 km deep wells for the Pohang EGS pilot project and the other two for 1 km deep gradient boreholes at Ulleung Island remote in the East Sea. Note that from 2015 report we do not include wells drilled for hot spring development which no longer provides reliable data and most of production temperature is lower than 30 °C.

From TABLE 7, we can see number of professional person in geothermal sector remains stagnant although installation of GHP is increasing more than 100 MWt per year. This is due to many installations are made rather in routine design and construction phases. Most of private industries work for GHP business while professionals in universities and public research organizations research for general geothermal topics including deep exploration, EGS related issues and hydrogeological processes.

TABLE 8 shows investment trend for the last 25 years. Investments for R&D and surface exploration was increasing until 2014, which got back to the former level because the government investments for the EGS pilot project ended in 2015. Around 75% of the

R&D and exploration are from government funding. Note that from WGC2010 report we do not account for development and utilization for hot spring business because we cannot be provided with reliable data any longer. Therefore, more than USD 700 million for direct utilization is solely for GHP installations.

4. MAJOR R&D ACTIVITIES

R&D for geothermal energy is mainly funded by government through a funding agency, Korea Institute of Energy Technology Evaluation and Planning (KETEP). Annual R&D investment through KETEP has been around USD 4 to 5 million for the last five years and private matching funds were 20-40% of government investments. Biggest single funding which were given to the Pohang EGS pilot project has been ended in 2015. Others are mainly for R&D on shallow geothermal utilizations such as various types of GHP design and installations.

Until the end of 2015, the major R&D fund has been invested to the Pohang EGS pilot project (Song et al., 2015). By the end of 2015, the deepest well PX-2 has been completed down to 4,348 m vertically. After pre-stimulation test at the PX-2 early 2016, PX-1 sidetracking toward WNW direction according to the microseismic monitoring result was made down to 4,362 m in measured depth in 2016. Total of five small-scale stimulation tests were performed by middle of September, 2017. However, almost two months after injection finished, Mw 5.5 earthquake occurred at the vicinity of the well site and all other further activity has been stopped.

There was another exploration project funded by KETEP, a potential geothermal resources exploration at a remote island in the East Sea. Figure 3 shows a site map of MT survey at the remote Ulleung Island in East Sea and the depth-sliced images of conductivity distribution as a result of 3-D inversion of MT data incorporating the effect of the surrounding deep sea (Lee et al., 2019). Because area of the island is of ~73 km^2 (~11 km long) and the depth of the sea is ~2 km, measured MT data were seriously affected by the conductive sea water. Therefore, incorporating sea in the model is the only way to correctly reconstruct the conductivity structure. As we can see from the conductivity images, there is an East-West conductivity anomaly at the depth range from 800 m down to 1.5 km, which is interpreted as a convection zone through fractures. This interpretation coincided with the borehole temperature profiles at the four boreholes (pink dots in the site map of Figure 3) which show higher gradients along the two holes at East and West sides while those at the other holes at North and South sides appear lower. Exploration well drilling down to 2 km depth at the western part of the conductivity anomaly was planned, but the project has been suspended after the earthquake occurred at the vicinity of Pohang EGS pilot project site.

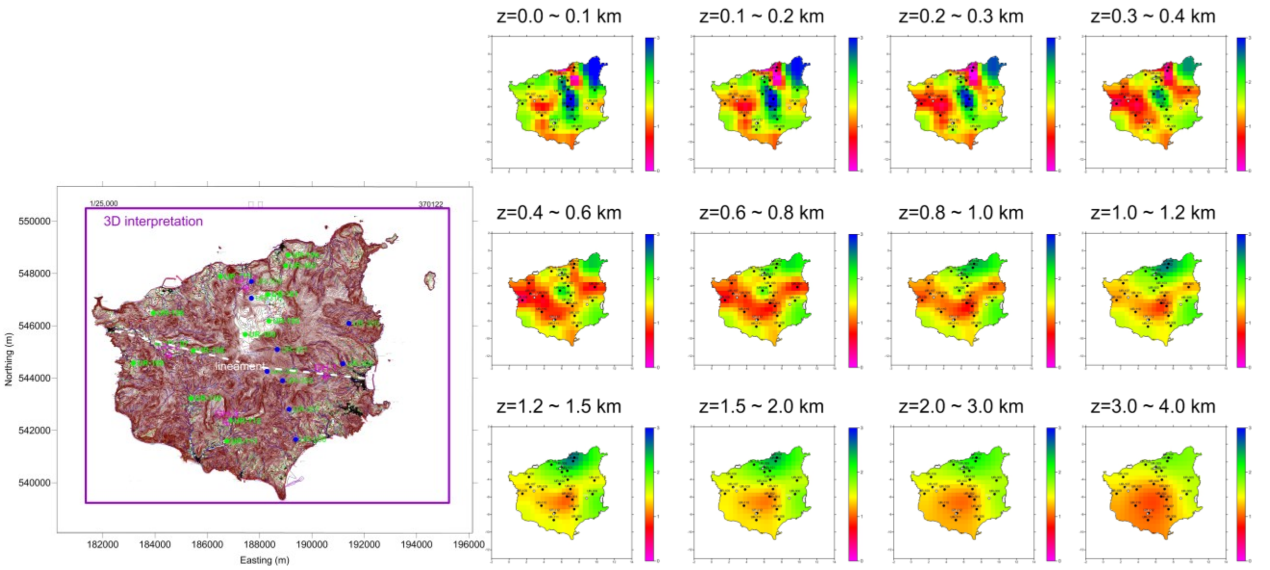

Figure 3. Site map of MT survey over Ulleung Island (left) and depth-sliced images of electrical conductivity as a result of 3-D inversion incorporating sea effect (right) (Lee et al., 2019).

5. SUMMARY AND FUTURE OUTLOOK

Geothermal utilization in terms of GHP installation will continue to increase for the next few years: more than 100 MW_t annually is expected. This is due to the active subsidy programs and the special 'Mandatory Act'. There are concerns about the low performance or malfunctioning of GHP systems because the rapid increase in market deployment is accompanied with some installations being of lower quality, without proper design or performance validation. Long-term performance modeling and validation are important tasks to keep GHP installation uptake growing, especially for large systems bigger than 1 MW_t capacity.

Geothermal utilization statistics are another issue. In Korea, official statistics on geothermal energy deal with GHP only and thus other direct uses including space heating, spas, and greenhouse heating are not included in the national statistics. We have been reporting other direct use statistics to IEA Geothermal TCP with the help of hot spring survey data. For GHP statistics, there is no official distinction between heating and cooling, but just a lump sum of all energy production throughout a year, which does not consider what the 'pure geothermal contribution' is yet. Efforts are needed to establish a revised method of collecting official statistics on geothermal uses that is compatible with international standards such as IEA statistics. In 2018, IEA Geothermal TCP started collecting GHP statistics with the new scheme proposed as a result of Working Group activities (Song et al. 2020) and this new scheme could guide the updating Korean GHP statistics once it is accepted by international community.

The outlook for geothermal power generation in Korea is not positive due to growing concerns of possibly causing damaging earthquakes. After the Mw 5.5 earthquake occurred close to the Pohang EGS site in November 2017, all deep geothermal exploration activity was stopped and all projects are currently in hiatus. The Korean Government is very keen to foster renewable energy deployment, but even so the outlook for geothermal investment is not promising for the time being.

REFERENCES

Choi, J., Lee, T.J., Yang, J., Lee, S.K., Park, I.H., and Song, Y.: Three-dimensional Interpretation Considering the Static and the Sea-effects of Magnetotelluric Data Obtained in Jeju, Korea, *J. Appl. Geophys*., **98**, 54-61 (2013).

Korea Energy Agency: *New and Renewable Energy Supply Statistics 2017 (2008 Ed.)*, Ministry of Trade, Industry and Energy (2018). (in Korean)

Korea Institute of Geoscience and Mineral Resources (KIGAM): *Geology Map of Korea (1:1,000,000)* (1995).

Lee, T.J., and Song, Y.: Geothermal Exploration for Combined Heat and Power Generation in Seokmo Island, Korea: *Proceedings World Geothermal Congress 2010,* Bali, Indonesia, 25-29 April (2010).

Lee, T.J., Kim, M.S., Park, I.H., Song, Y., Nam, M.J., Song, S.Y., and Yun, K.-H.: Geoelectrical Structure of Ulleung Island, Korea: Interpretation of Three-dimensional Magnetotelluric Data, *Expl. Geophys*., **50** (in printing) (2019)

Paek, K.N., Song, Y., Lee, T.J., and Song, Y.S.: Comparison of Geothermal Energy Consumption Applied to Load Factor of GSHP by Building Types, *J. Korean Soc. Miner. Energy Resour. Eng*., **52**, (2015), 380-393. (in Korean with English abstract and illustrations)

Song, Y., Baek, S.-G., Kim, H.C., and Lee, T.J.: Estimation of Theoretical and Technical Potentials of Geothermal Power Generation Using Enhanced Geothermal System, *Econ. Environ. Geol*., **44**, (2011), 513-523. (in Korean with English abstract and illustrations)

Song, Y., and Lee, T.J.: Geothermal Development in the Republic of Korea: Country Update 2010-2014, *Proceedings World Geothermal Congress 2015*, Melbourne, Australia, 19-25 April (2015).

Song, Y., Lee, T.J., Jeon, J., and Yoon, W.S.: Background and Progress of the Korean EGS Pilot Project, *Proceedings World Geothermal Congress 2015*, Melbourne, Australia, 19-25 April (2015).

Song, Y., Link, K., Yasukawa, K., and Weber, J.: Proposal of New Data Collecting Spreadsheet for Geothermal Heat Pumps Statistics: An Outcome of IEA Geothermal Working Group Activities, *Proceedings World Geothermal Congress 2020*, Reykjavik, Iceland, April 26-May 2 (2020).

TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (PV, Wind, Bio)		Total	
	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2019*			79,128	401,801	6,490	7,270	21,850	133,505	11,623	28,070	119,091	570,646
Under construction in December 2019**			7,357				7,000					
Funds committed, but not yet under construction in December 2019												
Estimated total projected use by 2020***			83,322		6,490		26,050		15,971		131,833	

* Monthly Energy Statistics (Vo. 35-05, April 2019) Korea Energy Economics Institute

** The monthly Report on Major Electric Power Statistics(No. 485, March 2019), Korea Electric Power Corporation

*** The eighth Basic Plan for Long-term Electricity Supply and Demand (December 2017) Ministry of Trade, Industry and Energy

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019 (other than heat pumps)

1) I = Industrial process heat; H = Individual space heating (other than heat pumps)
C = Air conditioning (cooling); D = District heating (other than heat pumps)
A = Agricultural drying (grain, fruit, vegetables); B = Bathing and swimming (including balneology)
F = Fish farming; G = Greenhouse and soil heating
K = Animal farming; O = Other (please specify by footnote)
S = Snow melting

2) Enthalpy information is given only if there is steam or two-phase flow

3) Capacity (MWt) = Max. flow rate (kg/s)[inlet temp. (°C) - outlet temp. (°C)] x 0.004184 (MW = 10^6 W)
or = Max. flow rate (kg/s)[inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

4) Energy use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.1319 (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.03154

5) Capacity factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171
Note: the capacity factor must be less than or equal to 1.00 and is usually less, since projects do not operate at 100% of capacity all year.

Note: please report all numbers to three significant figures.

Locality	Type[1]	Maximum Utilization Flow Rate (kg/s)	Temperature (°C) Inlet	Temperature (°C) Outlet	Enthalpy[2] (kJ/kg) Inlet	Enthalpy[2] (kJ/kg) Outlet	Capacity[3] (MWt)	Annual Utilization Ave. Flow (kg/s)	Energy[4] (TJ/yr)	Capacity Factor[5]
1. DongRae	B	46.88	42	27			2.94	21.89	43.31	0.467
	H	46.88	64	44			3.92	10.62	28.02	0.226
2. HaeWunDae	B	36.2	42	27			2.27	17.85	35.32	0.493
3. GangHwa	B	44	42	27			2.76	15.4	30.47	0.350
	D	44	68	56			2.21	19.76	31.28	0.449
	G	3.34	68	56			0.17	0.84	1.33	0.251
4. YuSeong	B	81.79	42	27			5.13	32.87	65.03	0.402
5. SokCho	B	59.05	42	27			3.71	32.76	64.82	0.555
6. SuAhnBo	B	44.91	42	27			2.82	14.42	28.53	0.321
7. OnYang	B	44.03	42	27			2.76	24.29	48.06	0.551
8. DeokSan	B	12.91	42	27			0.81	8.61	17.03	0.667
9. BaekAm	B	74.27	42	27			4.66	40.43	79.99	0.544
10. PoHang	B	14.58	42	27			0.92	8.49	16.80	0.582
11. CheongDo	B	8.1	42	27			0.51	2.17	4.29	0.268
12. MaGeumSan	B	16.67	42	27			1.05	12.79	25.31	0.767
13. BuGok	B	35.41	42	27			2.22	24.6	48.67	0.694
	H	35.41	76	44			4.74	6.02	25.41	0.170
TOTAL							43.60		593.65	

TABLE 4. GEOTHERMAL (GROUND-SOURCE) HEAT PUMPS AS OF 31 DECEMBER 2019

This table should report thermal energy used (i.e. energy removed from the ground or water) and report separately heat rejected to the ground or water in the rejected to the ground in the cooling mode as this reduces the effect of global warming.

1) Report the average ground temperature for ground-coupled units or average well water or lake water temperature for water-source heat pumps

2) Report type of installation as follows: V = vertical ground coupled (TJ = 10^{12} J)
H = horizontal ground coupled
W = water source (well or lake water)
O = others (please describe)

3) Report the COP = (output thermal energy/input energy of compressor) for your climate - typically 3 to 4

4) Report the equivalent full load operating hours per year, or = capacity factor x 8760

5) Thermal energy (TJ/yr) = flow rate in loop (kg/s) x [(inlet temp. (°C) - outlet temp. (°C)] x 0.1319
or = rated output energy (kJ/hr) x [(COP - 1)/COP] x equivalent full load hours/yr

6) Cooling energy = rated output energy (kJ/hr) x [(EER - 1)/EER] x equivalent full load hours/yr

Note: please report all numbers to three significant figures
Due to room limitation, locality can be by regions within the country.

Locality	Ground or Water Temp. (°C)[1]	Typical Heat Pump Rating or Capacity (kW)	Number of Units	Type[2]	COP[3]	Heating Equivalent Full Load Hr/Year[4]	Thermal Energy Used[5] (TJ/yr)	Cooling Energy[6] (TJ/yr)
All over the country	10~18	10~150	>10,000	V(75%) W(20%) H(5%)				
TOTAL					3.73	758.2	2,889.00	2,393.50

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2019

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.004184
or = Max. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg)] x 0.001

2) Annual Energy Use (TJ/yr) = Ave. flow rate (kg/s) x [inlet temp. (°C) - outlet temp. (°C)] x 0.131! (TJ = 10^{12} J)
or = Ave. flow rate (kg/s) x [inlet enthalpy (kJ/kg) - outlet enthalpy (kJ/kg) x 0.03154

3) Capacity Factor = [Annual Energy Use (TJ/yr)/Capacity (MWt)] x 0.03171 (MW = 10^6 W
since projects do not operate at 100% capacity all year

4) Other than heat pumps
5) Includes drying or dehydration of grains, fruits and vegetables
6) Excludes agricultural drying and dehydration
7) Includes balneology

Use	Installed Capacity[1] (MWt)	Annual Energy Use[2] (TJ/yr = 10^{12} J/yr)	Capacity Factor[3]
Individual Space Heating[4]	8.66	53.43	0.196
District Heating [4]	2.21	31.28	0.449
Air Conditioning (Cooling)			
Greenhouse Heating	0.17	1.33	0.248
Fish Farming			
Animal Farming			
Agricultural Drying[5]			
Industrial Process Heat[6]			
Snow Melting			
Bathing and Swimming[7]	32.56	507.61	0.494
Other Uses (specify)			
Subtotal	43.6	593.65	
Geothermal Heat Pumps	1,446.16	2,889	
TOTAL	1,490	3,483	

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2015 TO DECEMBER 31, 2019 (excluding heat pump wells)

1) Include thermal gradient wells, but not ones less than 100 m deep

Purpose	Wellhead Temperature	Number of Wells Drilled: Electric Power	Direct Use	Combined	gradient and research	Total Depth (km)
Exploration[1]	(all)	2			2	10.7
Production	>150° C					
	150-100° C					
	<100° C					
Injection	(all)					
Total		2			2	10.7

* Exclude hot spring wells

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

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

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	1	25	20			85
2016	1	25	25			90
2017	1	25	30			90
2018	1	25	30			90
2019	1	25	30			90
Total	5	125	135			445

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2019) US$

Period	Research & Development Incl.	Field Development Including Production	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	0.15	92	184		99.9	0.1
2000-2004	6.3	14.53			89.8	30.2
2005-2009	41.8	0	236.8		45	55
2010-2014	73.8	0	702.8		30	70
2015-2019	42.7	0	738.2		40	60

From 2005, data do not include hot spring developments, and direct utilization is only on GHP