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Country Update Report for Kenya 2015-2019

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ABSTRACT

Kenya is the leading country in Africa in terms of geothermal power generation and 9th in Global ranking of geothermal producing countries. Main high temperature geothermal sites under development in Kenya are located within the Kenya rift with only one project located within the Nyanza rift. Kenya is currently one of the fastest growing geothermal power producers in the world having increased its production by 218 MWe-in the last 5 years to a total installed capacity of 865 MWe contributing to about 29% of total installed electricity capacity in Kenya and about 47% of electricity consumed in 2019. The installed geothermal capacity comprises 706.8 MWe by Kenya Electricity Generating Company (KenGen), 155 MWe by OrPower4, Inc and 3.6 MWe by Oserian Development Company Ltd. Between 2015 and 2018, 45 MWe was added to the grid by Orpower4, Inc. Olkaria geothermal field is so far the largest producing site with current installed capacity of 689.7 MWe while Eburru field has installed capacity of 2.52 MWe. Direct utilization of geothermal resources installed capacity stood at 18.5 MW_{th} (est). Geothermal power development is projected to increase by 328 MWe between 2020 and 2022 with the commissioning of the following power plants: Olkaria PPP, 140 MWe; Olkaria 1 unit 6, 83.3 MWe and 3x35 (105) MWe under development at Menengai geothermal field. The Menengai project will involve Geothermal Development Company (GDC) as steam supplier while three IPPs will each install 35 MWe. KenGen has continued to appraise and develop several sectors of Olkaria field. GDC has further mobilized a drilling rig for exploration drilling in Paka prospect and results of the first three wells are due by end of 2019. GDC also plans to drill exploratory wells in Silali, Korosi and the Greater Menengai field within the next few years. Having recognized the potential part that could be played by private investors, the Government has so far licensed thirteen IPPs to undertake greenfield projects at Barrier, Longonot, Akiira, Elementaita, Homa Hills, Menengai North, Lake Magadi, Arus, Baringo, Emuruangogolak, Namarunu, and Emuruapoli prospects. According to licensing conditions, the IPPs are required to drill exploration wells within three years of licence issuance. The Government of Kenya is continuing with its ambitious plan to increase the geothermal installed capacity to 5,000 MWe by year 2030.

1. INTRODUCTION

1.1 Historical Perspective

Earliest recorded geothermal use in Kenya was for pyrethrum drying in an area north west of Nairobi at Eburru geothermal field where a pyrethrum drier using geothermal heat was built in 1939 and which is still operational to date (USAID, 2013). There is also a water recovery system using rudimentary techniques but which provided all of the water used by the community between 1939 and 1991. Geothermal exploration for power generation in Kenya began in earnest in 1952 championed by the then East African Power & Lighting Company Ltd (EAPL) and supported by UNDP and other international agencies (KPLC, 1992). The study resulted in the drilling of two wells, OW-X1 and OW-X2, in 1956 and temperatures of up to 235°C were recorded but the wells failed to discharge until 1971 when X2 discharged after stimulation. Subsequent studies commissioned to evaluate the resources in various sectors of the rift selected Olkaria geothermal area for detailed evaluation buoyed by steam production from OW-X2. Studies then resulted in drilling of six deeper exploration and appraisal wells in Olkaria which were successfully completed and proved existence of a viable geothermal system. This resulted in the staged development of the 45 MWe Olkaria I power plant between 1981 and1985. Kenya currently has total geothermal installed capacity of 865 MWe. Currently, Kenya is opening development of all its geothermal potential sites along the rifts using both state corporations (KenGen and GDC) and private investment.

1.2 Policy, Regulatory and Institutional Framework

Before 1998, electricity generation, transmission and distribution was tasked to Kenya Power and Lighting Company (KPLC). KPC was a state owned, vertically integrated corporation under the Ministry of Energy. To improve efficiency and to open the sector to private participation, the government unbundled the generation, transmission and distribution functions through sessional papers of 1996 and 2004. A policy paper on economic reforms set out the governments intentions to separate the regulatory and commercialize functions of the sector, facilitate restructuring and promote private-sector investment. Consequently, the Electricity Power Act of 1997 reduced the government's mandate, through the Ministry of Energy, to policy formulation while devolving its regulatory mandate to Energy and Petroleum Regulatory Authority (EPRA). This rationalization and unbundling redefined the scope of Kenya Power and Lighting Company (KPLC) such that it was limited to transmission and distribution of electricity while Kenya Electricity Generating Company was incorporated in 1997 with a mandate to undertake grid electricity generation functions. The act also opened up for Independent Power Producers (IPPs) to enter electricity generation industry.

Sessional Paper No. 4 of 2004 and the Energy Act No.12 of 2006 further proposed additional restructuring of the sector by unbundling transmission and distribution functions and incorporation of a wholly state owned company to undertake upstream stages of geothermal development through government funding. Kenya Electricity Transmission Company was incorporated in

2008 to take up the transmission function from KPLC while Geothermal Development Company (GDC) was incorporated to undertake the riskier upstream stages of geothermal exploration and development. Part of GDC roles are therefore to undertake surface exploration of geothermal fields, undertake exploratory, appraisal and production drilling, develop and manage proven steam fields and enter into steam sales or joint development agreements with investors in the geothermal sector. There is currently one active IPP in Kenya generating electricity from geothermal resources for the national grid.

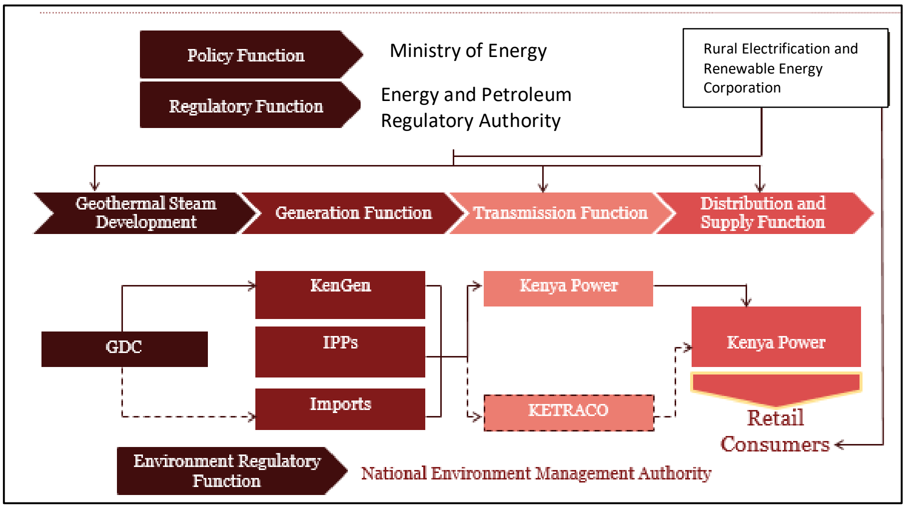

Figure 1: Kenya Energy sector Institutional setup

1.3 Energy Situation in Kenya

The energy sector in Kenya is largely dominated by petroleum and electricity, with wood fuel providing the basic energy needs of the rural communities, urban poor, and the informal sector. Biomass accounts for 68% of the total energy consumption, petroleum accounts for 27%, while electricity accounts for 9% (LCPDP, 2018). The interconnected installed capacity in 2018 was 2,997 MWe out which geothermal contributed about 865 MWe, hydropower 837 MWe, thermals at 807 MWe, solar at 92.5 MWe and wind had 336 MWe. Additionally, Kenya has an off-grid installed capacity amounting to 31.1 MWe comprising thermals at 26.3 MWe, wind at 0.55 MWe, solar at 0.64 MWe and geothermal at 3.6 MWe (Mangi, 2018). However, the off-grid installed solar capacity might be more since not all the installed solar home systems are documented. Electricity consumption per capita stood at about 121 kWh. Kenya considers development of geothermal resources as offering the lowest cost of power. This has seen rapid growth of the geothermal plants by KenGen and private sector. According to the LCPD (2018), Kenya plans to have additional electricity installed capacity expected to come from coal, hydropower, solar, wind, nuclear and geothermal. It is planned that geothermal sources will contribute 5,000 MWe by 2030.

2. GEOLOGICAL BACKGROUND

2.1 Geological Setting

The geothermal occurrences in Kenya are closely associated with the Kenya rift which is part of the East African Rift System (EARS) which extends from the Afro Arabian rift in the Red Sea in the north to Mozambique in the southern Africa. Within the latitude of Kenya, the rift bifurcates into eastern branch where Kenya rift belongs and the western branch that extends from Uganda though Rwanda, Tanzania, Malawi, Zambia and Mozambique (Figure 2).

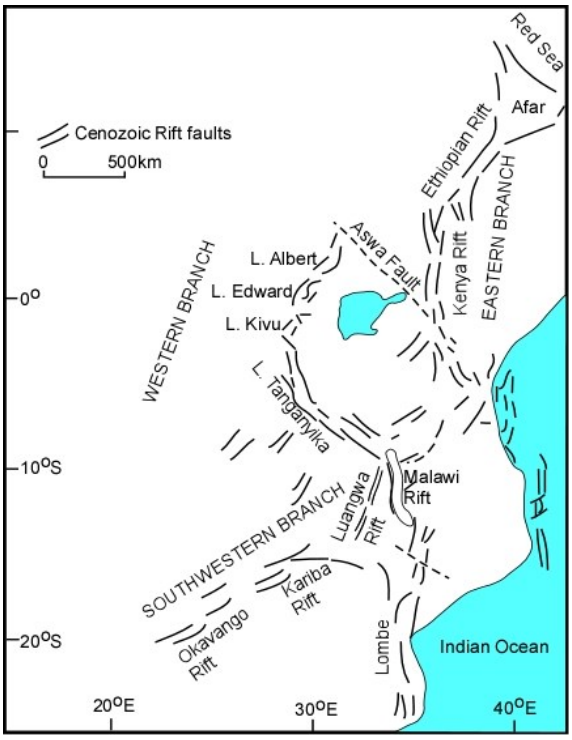

Figure 2: Structural map of the East African Rift System

The development of the Kenya Rift began during the Pliocene (about 30 million years ago) with uplift and volcanism which became more intense about 14 million years ago. Subsequent to rifting was the development of the graben structure in Kenya from about 5 million years ago and was followed by fissure and central eruptions in the axis of the rift during 2 to 1 million years ago. Increased extension during the Quaternary period saw the development of large central volcanoes, most of which are geothermal prospects (Dunkley et al. 1993). These Quaternary volcanoes include Suswa, Longonot, Olkaria, Eburru, Menengai, Korosi, Paka, Silali, Emuruangogolak, Homa Hills, and Barrier (Figure 3).

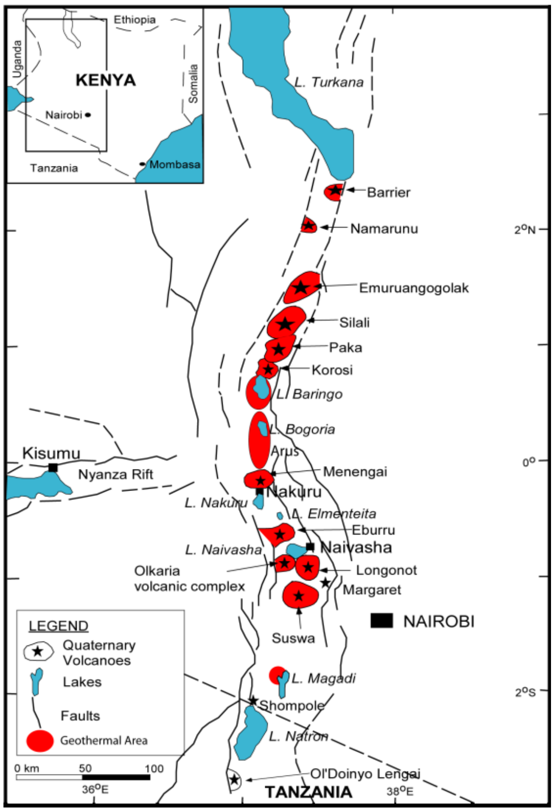

Figure 3: Simplified Geological Map of Kenya showing geothermal areas (Omenda and Simiyu, 2015)

2.1 Geothermal Occurrence in Kenya

Most of the geothermal systems in Kenya are volcano hosted and closely associated with Quaternary central volcanoes of the rift axis. Detailed exploration have been undertaken in many of the prospects including Olkaria, Suswa, Longonot, Eburru, Menengai, Paka, Silali, and Barrier (Figure 3). Out of these, drilling has only been undertaken in Olkaria, Eburru, Menengai and Paka. The resources at Olkaria has been utilized since 1981 and Eburru since 2010 while production drilling is ongoing at Menengai with power plant development having commenced in 2019. GDC recently commenced exploration drilling at Paka prospect and results of flow test is awaited for the first well. However, high temperatures are reported from downhole surveys (GDC press release). The geothermal model that fits the systems at the volcanic centers is volcano hosted system where main heat sources are hot rock bodies or magma chambers under the volcanoes. However, there are prospects located away from central volcanoes but having large hot spring discharges which are defined by the fault controlled deep circulation model. The prospects include Arus, Lake Magadi, Lake Baringo, and Mwananyamala located at the coast of Kenya. It is presumed that several geothermal occurrences could exist within the inter volcano regions with or without any association with the neighboring volcanoes. The fault controlled geothermal systems have not been drilled to date.

<u>2.2.1 Olkaria Geothermal field</u>

The Olkaria volcanic complex is the main geothermal area in Kenya. The rock outcrops is dominated by rhyolite flows and pyroclastics of which the youngest is the Ololbutot rhyolite obsidian flow that erupted at 180±50 yr BP (Clarke et al., 1990). The landscape is also dotted with volcanoes. The structural systems at Olkaria are dominated by reactivated old rift structures that trend NW-SE and younger near N-S faults. The NW-SE structures are more common in the west where they merge into the Pliocene Mau escarpment and end within the Olkaria area (Figure 4). These reactivated oblique structures form the most important reservoirs for the Olkaria geothermal system. The younger N-S faults formed loci for recent volcanic eruptions, e.g. Ololbutot lava flow. Since these faults are more open, they provide channels for shallow ground water recharge into the geothermal systems (Omenda, 1994, 1998). The heat source for the Olkaria system is due to shallow discrete magma bodies associated with the surface rhyolites while the reservoir is hosted within 'flood' Trachyte. Most of the geothermal area has been heavily drilled and produces the current 862.5 MWe with a further 223.3 MWe under development. Plans are underway to explore the areas outside the exploited area.

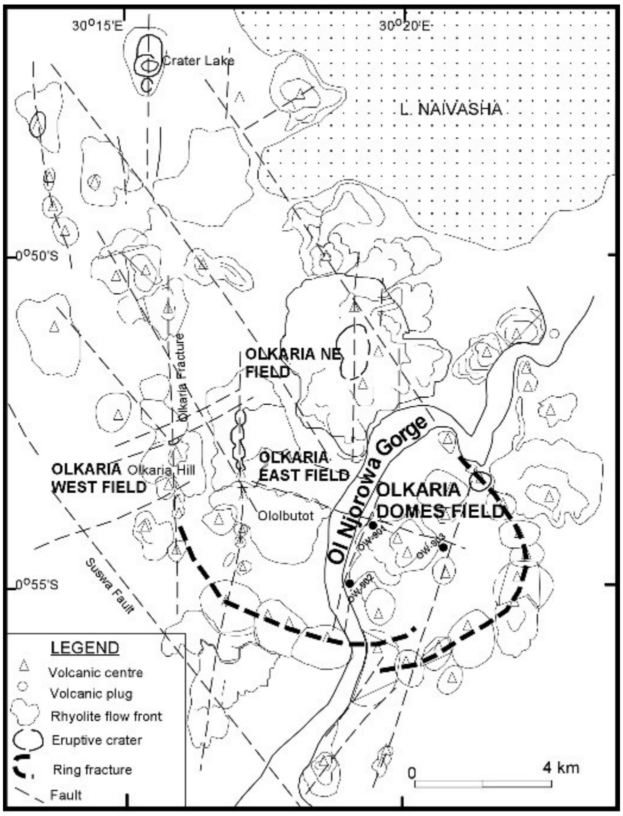

Figure 4. Structural map of Olkaria Geothermal field

<u>2.2.2 Eburru Geothermal Field</u>

Eburru geothermal field is located to the north of Olkaria in an area of high physiography marked by the Eburru hills. Detailed surface studies were undertaken in the 1980's which culminated in drilling of three exploration wells in 1990-1991 which confirmed existence of a geothermal system under the mountain. Subsequently three appraisal wells were drilled which indicated that the resource is small and is restricted to an area defined by a ring of explosive craters measuring 4-km in diameter (Figure 5). Out of the wells drilled, well OW-01 encountered over 250° C is able to sustain discharge of more than 2.52 MWe while the others either flow low enthalpy fluids are non-productive (Omenda and Karingithi, 1993). However, MT/TEM surveys undertaken after drilling of the wells refined the old model. An additional 25 MWe is planned for development.

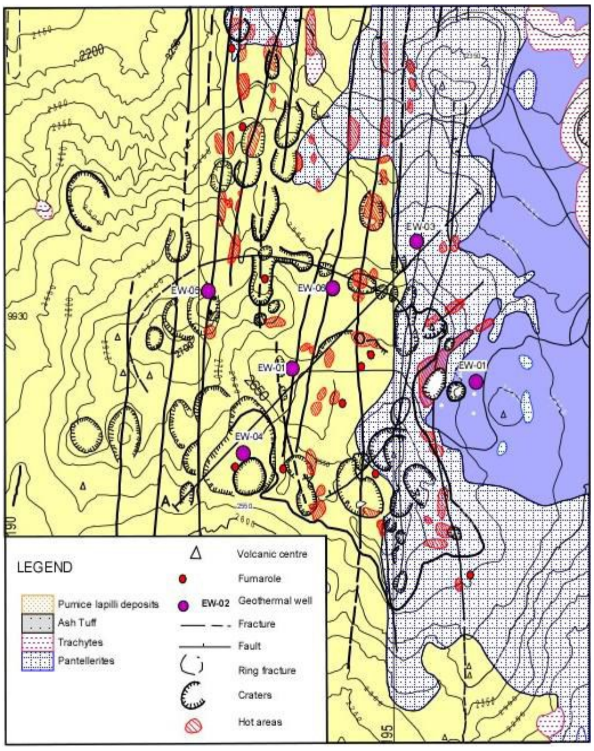

Figure 5: Map of Eburru geothermal field (Omenda and Simiyu, 2015)

2.2.3 Menengai Geothermal field

Menengai is a caldera volcano within the axis of the rift near Nakuru town, about 160 km from Nairobi. Initial exploration was undertaken by KenGen in 2004 and detailed surface studies were concluded by GDC in 2011 and resulted in siting of exploration wells (Figure 6). Exploration drilling commenced in Menengai in 2011 and currently more than 40 deep wells of depths varying from 2,100 m to 3,200 m have been drilled. A number of wells have encountered temperatures close to 400˚C at 2,000 m in several wells making it the "hottest" geothermal system in Kenya. At least six wells may have been drilled into magma and had to be terminated due to blockage of the drill string. The extremely high temperatures at Menengai are due to the occurrence of magma bodies at shallow depth (~2,100m depth). However, the orientation of the magma bodies have not been resolved. This makes Menengai one of the few geothermal fields in the world where magma have been drilled into. The others were in Krafla in Iceland in 1977 and 2009 (450^{o}C), and Hawaii in 2005. GDC is planning development of the project in stages up to estimated 465 MWe.

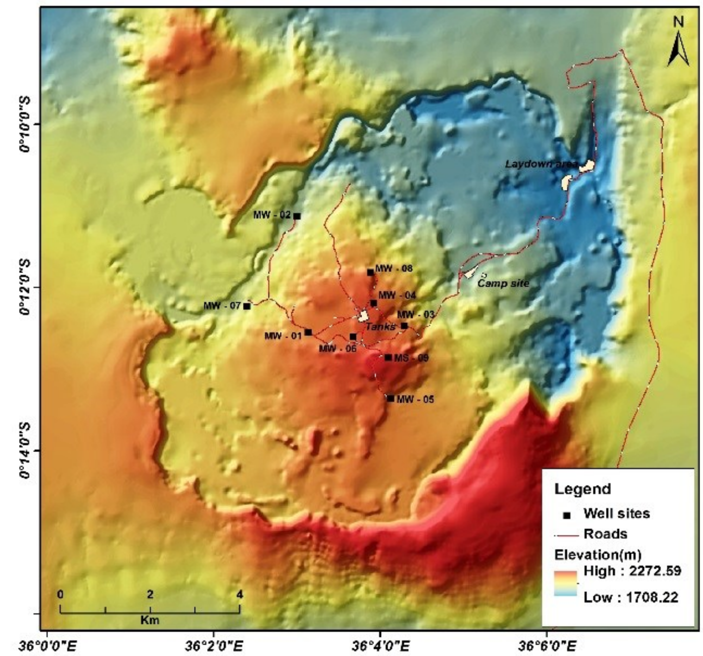

Figure 6: DEM image of Menengai geothermal field

2.2.4 Paka volcano

Paka is a Quaternary volcano located in north rift of Kenya. Volcanic activity commenced about 390 Ka and continued to 10 ka. The structure of Paka is dominated by a broad zone of normal faulting 7.5 km wide graben bound by the eastern and the western fault boundaries, respectively. It is a relatively small (compared to the other volcanoes in the rift) shield volcano constructed largely by trachyte. Paka is one of the areas with the most active geothermal manifestations in the summit of the volcano that include fumaroles and sulphur encrustations. Detailed surface studies revealed the existence of a geothermal system at the prospect which has been confirmed by drilling undertaken by GDC in 2019. Exploration wells being drilled were sited within the "mini caldera" at the summit and the surrounding region of the volcanic edifice (Figure 7).

2.2.5 Other Prospects

The other geothermal prospects under active investigations are Korosi, Barrier, Longonot, Suswa, Silali, Homa Hills and Arus (Figure 3). Barrier was licensed to a Kenyan company known as Olsuswa Energy Ltd and the company in 2019 undertook detailed surface studies which revealed possible existence of a high temperature geothermal system within and surrounding the nested calderas of Kakorinya. Exploration drilling is planned for 2020. Longonot prospect was licensed to AGIL Ltd in 2006 and the concessionaire has undertaken detailed surface studies. Exploration drilling was meant to have been undertaken in 2010 but some delays occasioned its postponement and not it is planned for 2019/2020. Suswa prospect was hitherto licensed to a private developer but the license reverted to the government who then assigned GDC to develop the prospect. Detailed studies have been undertaken and partial funding obtained for exploration drilling and infrastructure development. Korosi and Silali prospect were evaluated in detail by GDC in 2016 which showed potential existence of a high temperature geothermal systems. The studies were supported by technical assistance from JICA and UNEP respectively. GDC plans to drill exploration wells in the prospects as part of the ongoing drilling works in the so called Baringo-Silali geothermal block. Homa Hills and Arus prospects have been licensed to Capital Power Ltd and Arus Energy Ltd., respectively. The concessionaires have received grants from GRMF-AUC to undertake detailed surface studies which should lead to drilling of exploration wells. The other prospects that include Lake Baringo, Elementaita, Namarunu, Emuruangogolak, and Lake Magadi which are licensed to GDC and private developers are still in the planning stages.

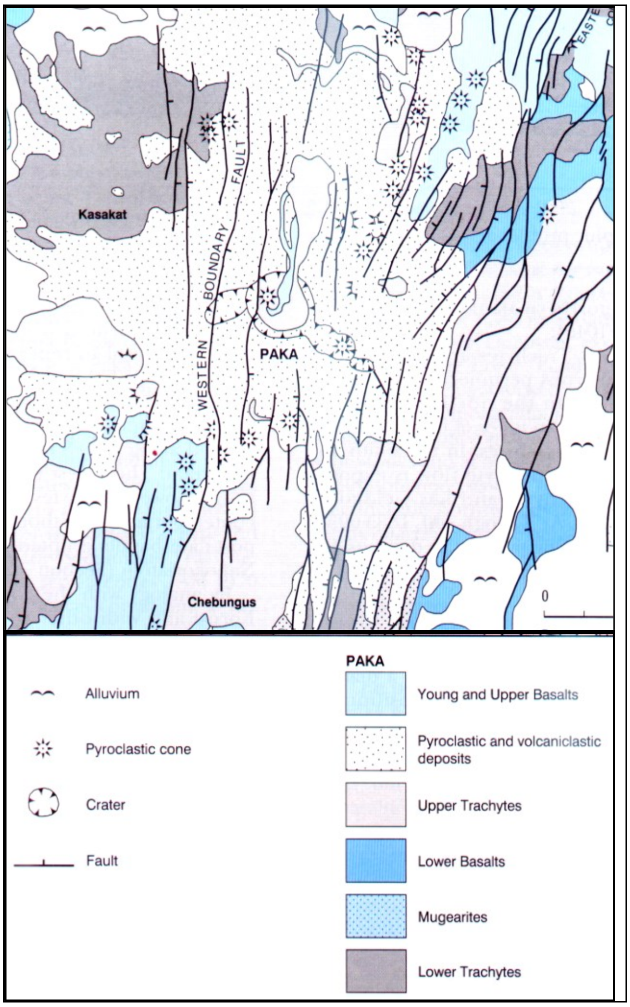

Figure 7: Geology of Paka volcano (Dunkley et al. 1993)

3. GEOTHERMAL UTILIZATION

3.1 Electricity

Generation of electricity from geothermal resources in Kenya began in June 1981. The power plant was located in the Olkaria geothermal field with an installed capacity of 15 MWe. Currently, electricity generation from geothermal resources takes place in both the Olkaria and Eburru geothermal fields. Five power plants have so far been constructed in the Olkaria geothermal field. They include; Olkaria I, II, III and IV. The field is divided into seven segments for the purpose of easy management. The divisions include Olkaria East, Olkaria West, Olkaria Northeast, Olkaria Domes, Olkaria South East, Olkaria Central and Olkaria Southwest (see figure 8). Currently, the total geothermal power installed capacity is 865 MWe (see Table 1). The Eburru field has 2.52 MWe while the rest is generated from the Olkaria geothermal field. Additionally, plans are underway to construct a 105 MWe in the Menengai geothermal expected to be commissioned in 2020 (see Table 1).

3.1.1 Olkaria I

Olkaria I power plant is the oldest geothermal plant in Kenya and generates 45 MWe. It has three units with each generating 15 MWe which tap steam from the Olkaria East field. The first unit was installed in June 1981, second unit in November 1982 and the third unit in March 1985 (Table 1). The three units utilize steam from 22 wells. One well is used for re-injection while 10 wells are used as standby wells. To fully utilize steam realized after further exploration and drilling of the Olkaria East and Northeast fields, a 150 MWe Olkaria IAU (Units 4 and 5) plant were developed and commissioned in 2014. Furthermore, the construction of an 83.3 MWe Olkaria IAU (Unit 6) power plant to tap in the excess steam in the two fields is underway.

3.1.2 Olkaria II

Olkaria II power plants taps its steam from the Olkaria Northeast field and generates a total capacity of 105 MWe. The plant has three units with each of the units generating 35 MWe (Table 2). The first two units were commissioned in 2003 while the third unit was commissioned in 2010. The plant utilizes steam from 22 wells. The plant is owned and operated by KenGen.

Figure 9: A view of Olkaria 1 Power plant located in the Olkaria East production field

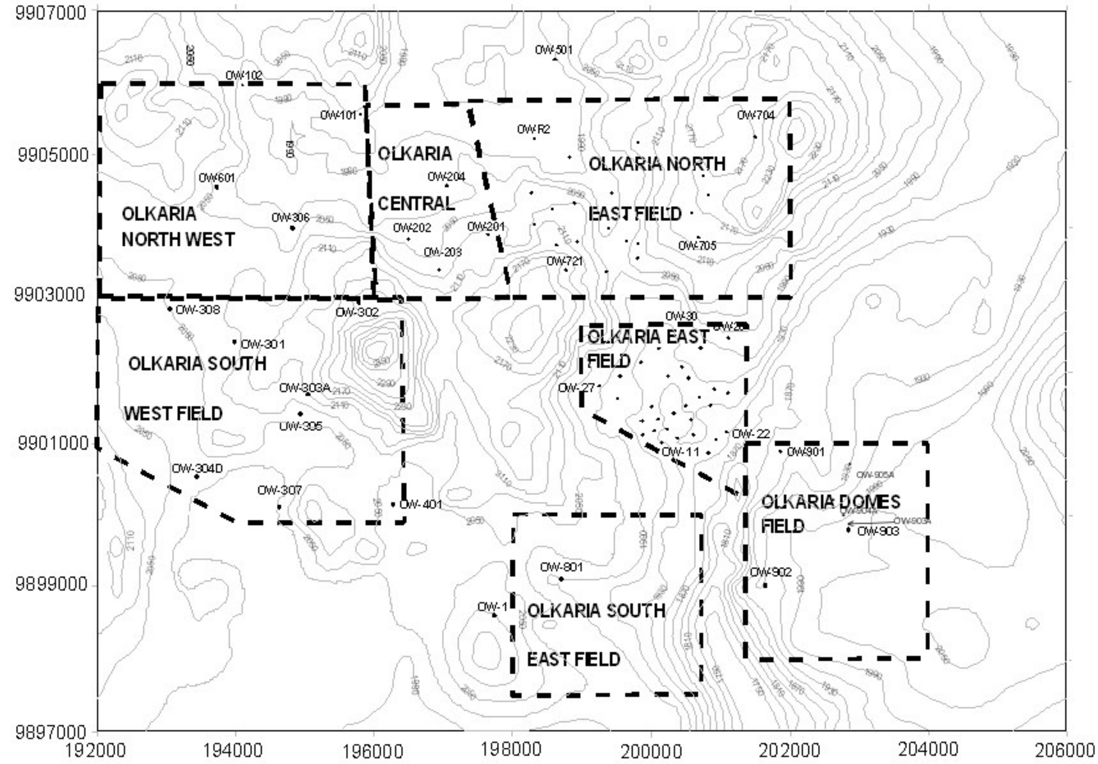

Figure 8: The seven segments of Olkaria geothermal field

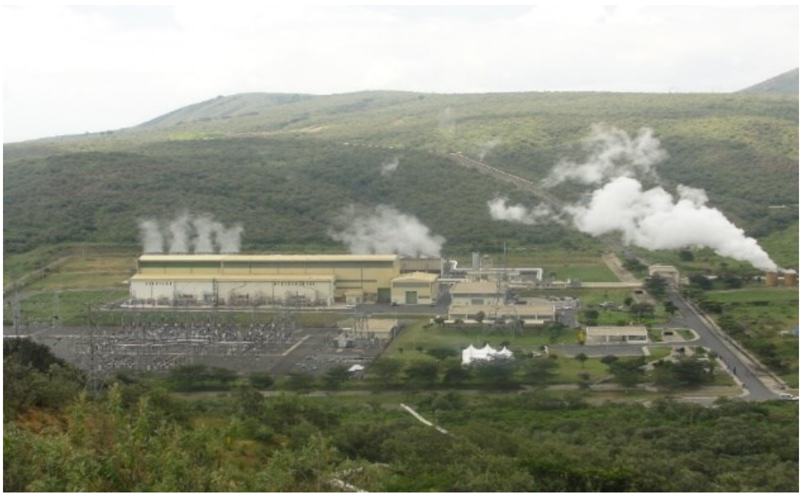

Figure 10: A view of Olkaria II power station

3.1.3 Olkaria III

After the power sector reforms of 2006, ORMAT international was licensed by the Kenya Government to explore and generate power from the Olkaria Northwest field in 1997. In 2000, ORMAT through its local subsidiary OrPower 4, Inc. commissioned an 8 MWe combined cycle pilot plant called Olkaria III. This was later increased in 12 MWe. In 2009, OrPower 4 further commissioned a 35 MWe generating unit, followed by a 36 MWe in 2013, 26 MWe generating unit in 2014, 29.6 MWe unit in 2016 and 15 MWe in 2018 bringing the total to 155 MWe. OrPower 4 uses the combined cycle plant technology to generate the 155 MWe.

3.1.4 Olkaria IV

Detailed surface exploration resulted in the drilling of seven production wells in Domes area in 2007. With the improved drilling technology, deeper and directional wells tapped in more steam resource with a capacity to sustain a more than 150 MWe electricity generating power plant. This resulted in the start of the construction and subsequent commissioning of the 150 MWe Olkaria IV power plant in March 2012 and October 2014 respectively. The plant has two power generating units with each the units generating 75 MWe. The plant is owned and operated by KenGen. GDC supplies part of the steam requirements for the Olkaria IV and Olkaria IAU power plants.

Figure 11: A view of Olkaria IV power plant located in Domes area.

3.1.5 Wellhead Generation

The wellhead technology is a power technology developed to tap fast-track utilization of steam from production wells before they are connected to conventional power plants. Unlike the main generating power plants, it takes relatively short time (6 months compared to the 24-36 months taken by main power plants) to put up and commission a wellhead generator, hence ensures quick return on investment from geothermal resources. KenGen has 15 wellheads installed with a generation capacity of 81.1 MWe. The first wellhead generator at Olkaria owned by KenGen was commissioned in June, 2012 in the Olkaria East field with a generation capacity of 5 MWe. KenGen accelerated the installation of wellhead generators between 2014 and 2018 with installation of 15 wellhead generators with an aggregate capacity of 81.1 MWe.

3.1.6 Oserian Power Plant

Oserian Development Company Ltd owns and operates geothermal power plants for own use in the greenhouses and farm installations. The Company installed a 1.8 MWe binary plant in 2004 using steam from well OW-306 that was drilled as an exploration well by KenGen but was not used due to long distance to KenGen power plants. In 2006, the Company installed a second 1.8 MWe backpressure power plant for own use. The plant uses steam leased from KenGen.

3.1.7 Eburru

The Eburru geothermal field is managed by KenGen. Detailed surface studies carried out between 1987 and 1990 by KenGen resulted in the drilling of six exploration wells between 1989 and 1991. One of the wells recorded temperatures of over 250° C with an output of 2.5 MWe. Further studies involving the combination of MT data and data from drilled wells indicated that Eburru field has a geothermal potential of more than 50 MWe. In 2011, KenGen commissioned a 2.52 MWe wellhead generating unit. In 2016 and 2017, KenGen carried out more detailed exploration studies in the larger Eburru area. Currently, plans are underway to drill appraisal and production wells.

3.1.8 Menengai

Three IPPs have entered into a steam sales agreement with GDC for power generation. These are Quantum East Africa Power Ltd., OrPower 22 Ltd., (a consortium of Ormat, Civicon and Symbion) and Sosian Menengai Geothermal Power Ltd., (SMGPL). Each of the IPPs will install a 35 MWe power plant and GDC is the Steam-field developer. So far, 49 wells have been drilled with 25 tested providing an estimated potential of about 170 MWe. The development of Menengai geothermal power plant is planned under the signed Project Implementation and Steam Supply Agreement (PISSA). The PISSA agreement mandates GDC to provide steam and manage the reservoir during generation while the IPPs to finance, design, construct, install, operate and maintain the plants on a Build-Own-Operate basis. KPLC, which is the off-taker, has signed a PPA agreement with the IPPs.

3.2 Direct Use

3.2.1 Eburru Geothermal field

The first recorded direct use application in Kenya was the pyrethrum dryer built in 1939 in Eburru for use in drying pyrethrum flowers and grains. The drier is supplied with geothermal water from a well at 95°C adjacent to the drying chamber at about 43°C (Tables 3 and 5). The community pays per weight of materials to be dried as co share for maintenance of the facility. Eburru area is water scarce and potable water mainly comes from condensed steam from fumaroles and a well drilled for that purpose using old techniques of water recovery. It is reported that up to 6,000L/day is recovered per day from the condensers.

Figure 12: Photo of Eburru geothermal pyrethrum dryer

3.2.2 Oserian Greenhouse Heating

Oserian Development Company in Naivasha owns and operates the world's largest geothermally heated greenhouse growing rose flowers. Whereas Kenya is located within the tropics where temperatures are generally high throughout the year, night time temperatures often fall below 10^{o}C which result in high night-time humidity which encourages fungal diseases. Heating the greenhouse from geothermal water is therefore used to raise the temperatures thus reducing humidity levels in the greenhouses thereby alleviating fungal diseases. The geothermally heated greenhouse project at Oserian covers 50 hectares where about 185 TJ/yr of energy is used (Table 3 and 5). The project uses hot water from a well OW-101 leased from KenGen (Knight, Hole, & Mills, 2006). The system uses a plate heat exchanger so that fresh water is heated and piped to heat the green houses.

3.2.3 Menengai Direct use pilot projects

GDC developed pilot direct use facility at Menengai geothermal field that includes greenhouse heating, geothermal operated laundry, aquaculture pond heating and geothermal milk pasteurization. In the project, geothermally heated water from well MW-03 at 90oC is cascaded through laundry, milk pasteurizer, aquaculture and finally greenhouse after which the water is recirculated. The greenhouse has tomatoes and capsicum. GDC has also installed a grain dryer to demonstrate use of geothermal heat in drying agricultural produce.

3.2.4 Olkaria Spa and bath

A large scale commercial bathing and spa has been developed by KenGen at Olkaria II geothermal field. The spa utilizes separated brine meant for reinjection in the field. Three hot water pools/lagoons receive hot brine sequentially from the source depending on the desired pool temperature. The brine flows into the first lagoon at about 95°C then to the second lagoon at about 85°C and into the third lagoon at about 69°C. The main and largest lagoon is maintained at temperature of 35^{o}C. KenGen has also setup a sauna and steam bath running on brine. The other use of geothermal resources for hot bath is at the Lake Bogoria hotel where shallow hot wells are used to provide hot water for the swimming pool.

3 FINANCING OF GEOTHERMAL PROJECTS

Financing of geothermal projects in in Kenya has relied on private, public and grant financing. Public finance was used for undertaking most of the early stages of geothermal exploration in Kenya through KenGen and GDC. Only Akiira and Barrier geothermal prospects are the only ones so far funded by private investors for exploration drilling and detailed surface studies, respectively. All the successful projects so far in Kenya are those that benefitted from public financing at some stage of their development. Public finance was used in all the successful projects starting with the development of Olkaria's 45 MWe, Olkaria II, Olkaria IV and Olkaria V projects developed by KenGen through concessionary finance. Geothermal Development Company was established to use funding from exchequer and concessionary finance guaranteed by the government to undertake early stage geothermal development to de-risk geothermal projects to attract private investment.

Whereas Olkaria III project is being undertaken by private investor, the initial stages from surface exploration to appraisal drilling was undertaken by KenGen through public finance before the field was licensed to Orpower4, Inc by the Government of Kenya through PPP arrangement. Subsequent projects that include production drilling, steam field and power plant development were financed by the IPP through equity and loans. GDC in developing Menengai geothermal field has undertaken exploration, appraisal and production drilling, steam field development and has then entered into a steam sales agreement with three IPPs for the development of 105 MWe. GDC will be steam supplier while the IPPs will use private finance to setup the power plants and enter into PPAs with off-taker. Due to scarcity of public finance, the Government of Kenya has licensed IPPs to explore and develop geothermal resources for power generation using own financial resources.

4 HUMAN CAPACITY IN GEOTHERMAL DEVELOPMENT

Kenya has seen rapid geothermal developments, partly, due to the large number of well-trained human resource in all required expertise for geothermal development including geology, geochemistry, geophysics, reservoir engineering, drilling engineering, power plant engineering, and environmental and social sciences. It is estimated that about 242 graduate experts were active in the country in 2019 and these included foreign experts who were engaged in various projects (Table 7). Kenya has planned to have a total generation of about 5,000 MWe from geothermal resources by the year 2030. To achieve this target, more than 1,000 trained personnel will be required. Skills development for the staff will be undertaken through training in international institutions and to a larger extent training at the newly established Africa Geothermal Centre of Excellence that is based in Kenya but with ownership of African countries.

5 PLANNED AND FUTURE GEOTHERMAL DEVELOPMENTS

Kenya Government has laid a blueprint for rapid development of geothermal resources with a target for an installed generation of 5,000 MW by the year 2030. The additional capacity of about 4,000 MWe will come from expansion of Olkaria and Eburru geothermal fields by KenGen and IPPs and additional installations at Menengai by GDC. GDC is currently undertaking exploration drilling in the Baringo-Silali geothermal prospect with a plan of generating some hundreds of MWe. First exploration well drilled in Paka was successful, however, flow test result is awaited to confirm well capacity. Additional generation is planned to come from IPPs that have been licensed various geothermal prospects. These include; Akiira Geothermal Ltd for area south of Olkaria Domes field; AGIL for Longonot prospect; Mumbi Geothermal Ltd for Elementaita prospect; Arus Energy Limited for Arus prospect, Olsuswa Energy Ltd for the Barrier prospect, and Capital Power Ltd for Homa Hills prospect. Other prospects that have been licensed to private developers include Lake Magadi, Namarunu, Emuruangogolak, and Emuruapoli.

6. DISCUSSION

Since WGC2015, Kenya added 218 MWe with 173.2 MWe at Olkaria V and 45MWe at Olkaria III. However, this was much slower than the period 2000-2014 when 472 MWe was added to the grid (Table 2). The developments in the geothermal sector saw investment of more than US$919.5 from both public and private sectors (Table 8). However, public financed projects accounted for nearly 90% of the projects undertaken during the period (2015-2019). By December 2019, nearly 47% of power consumed in Kenya is contributed by geothermal resources (Table 1). Renewable energy sources currently accounts for more than 76% of electricity consumed in Kenya and the Kenya Government has planned to increase renewable energy contribution to 100% by 2025. Out of the new additions, geothermal resources is expected to contribute additional 5,000 MWe by year 2030. Kenya’s per capita electricity consumption currently stands at about 172kWhr/year. It is expected that the cost will come down as more geothermal power is put on the grid as it is currently the least cost source of power with cost of generation at about US cents 7/kWhr and high availability of more than 95%.

Direct use of geothermal resources in Kenya saw sight growth during the period 2015-2019 with development of pilot projects at Menengai (Table 3 and 5) but there was no change at the direct use facilities at Olkaria. The large scale use was in greenhouse farming at Oserian flower farm and geothermal spa at KenGen which is owned and operated by KenGen. Slow growth of geothermal projects in Kenya is largely attributed to lack of clear policy and regulatory framework that would guide its development and use. This has resulted in lack of concessionary financing for direct use which therefore makes potential direct use projects unviable.

Rapid growth of geothermal power in Kenya is contributed by progressive government policy that supports private investment. So far, more than 380 wells have been drilled in Kenya (Table 6). The new Energy Act (2019) has brought clarity to the electricity market in terms of environmental safeguards, community and county profit share on geothermal generation, dispatch preference, and enhanced fiscal incentives available to developers. Fiscal incentives include duty waiver on geothermal project equipment, corporate tax holidays, and letter of support which act as a political guarantee. Private investors are also allowed to repatriate all or part of profits from the venture. However, policy that supports direct utilization of geothermal resources as it is mentioned just in passing in the Energy Act (2019).

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TABLE 1. PRESENT AND PLANNED PRODUCTION OF ELECTRICITY

	Geothermal		Fossil Fuels		Hydro		Nuclear		Other Renewables (Wind)		Other Renewables (Solar, Bioenergy,biogas)		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	Capacity MWe	Gross Prod. GWh/yr
In operation in December 2019	865	7,199	776	4,080	837	4,397	0	0	335	1,027	184	628	2,997	17,331
Under construction in December 2019	188	1,567											188	1,567
Funds committed, but not yet under construction in	140	1,165											140	1,165
Estimated total projected use by 2020	1,193	9,930,643	776	4,080	837	4,397	0	0	335	1,027	184	628	3,325	20,063

TABLE 2: UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2019

Locality	Power Plant Name	Year Com-missioned	No. of Units	Status[1)]	Type of Unit[2)]	Total Installed Capacity MWe[3)]	Total Running Capacity MWe[4)]	Annual Energy Produced 2019 GWh/yr	Total under Constr. or Planned MWe
Olkaria	Olkaria I Unit 1	1981	1	Operating	1F	15	15	124,830	
Olkaria	Olkaria I Unit 2	1982	1	Operating	1F	15	15	124,830	
Olkaria	Olkaria I Unit 3	1985	1	Operating	1F	15	15	124,830	
Olkaria	Olkaria II (Unit 1&2)	2003	2	Operating	1F	70	70	582,540	
Olkaria	Olkaria II Unit 3	2010	1	Operating	1F	35	35	291,270	
Eburru	Eburru	2010	1	Operating	B	2.52	2.52	20,971	
Oserian	Oserian	2004 and 2006	2	Operating	B, 1F	3.6	1.8	14,980	
Olkaria	Olkaria Wellhead	2013	1	Operating	1F	5	5	41,610	
Olkaria	Olkaria Wellheads	2014	4	Operating	1F	12.8	12.8	106,522	
Olkaria	OrPower 4 -Unit I	2000	4	Operating	B	52.8	52.8	439,402	
Olkaria	OrPower 4 -Unit II	2008	4	Operating	B	39.6	39.6	329,551	
Olkaria	OrPower 4 -Unit III	2014	1	Operating	B	17.6	17.6	146,467	
Olkaria	Olkaria IV Unit 1	2014	1	Operating	1F	75	75	624,150	
Olkaria	Olkaria IV Unit 2	2014	1	Operating	1F	75	75	624,150	
Olkaria	Olkaria I Unit 4	2014	1	Operating	1F	75	75	624,150	
Olkaria	Olkaria Wellheads	2014	6	Operating	1F	32.8	32.8	272,962	
Olkaria	Olkaria Wellheads	2014	5	Operating	1F	30.5	30.5	253,821	
Olkaria	Olkaria I Unit 5	2014	1	Operating	1F	75	75	624,150	
Olkaria	Orpower4	2015-2018		Operating	B	45	45	374,490	
Olkaria	Olkaria V	2019	2	Operating	1F	173.2	173.2	592,344	
Olkaria	Olkaria I Unit 6	2020	2	Construction	1F				83.3
Olkaria	Olkaria PPP	2022	2	Planned	1F				140
Menengai	Menengai	2021	3	Construction	1F				105
Total						865	864	6,338,019	328

1F = Single Flash	B = Binary (Rankine Cycle)
2F = Double Flash	H = Hybrid (explain)
3F = Triple Flash	O = Other (please specify)
D = Dry Steam	

N = Not operating (temporary), R = Retired. Otherwise leave blank if presently operating.

TABLE 3: UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2019

Locality	Type[1]	Maximum Utilization					Capacity[3]	Annual Utilization		
		Flow Rate	Temperature (°C)		Enthalpy[2] (kJ/kg)			Ave. Flow	Energy[4]	Capacity
		(kg/s)	Inlet	Outlet	Inlet	Outlet	(MWt)	(kg/s)	(TJ/yr)	Factor[5]
Oserian	G	28	95	45			5.3		185	1
Olkaria	B	34	95	35			8.5		269	1
Eburru dryer	A	3	65	40			0.3		9.9	1
Lake Bogoria	B	5	37	27			0.2		6.5	1
Menengai	F,G,O	20	95	45			4.2		132	1
TOTAL							18.5		602.4	

O - Laundromat, milk processing at pilot scale

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.

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

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)
TOTAL								

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

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

Use	Installed Capacity 1) (MWt)	Annual Energy Use 2) (TJ/yr = 10^{12} J/yr)	Capacity Factor 3)
Individual Space Heating 4)			
District Heating 4)			
Air Conditioning (Cooling)			
Greenhouse Heating	5.3	185	
Fish Farming	0.2	6.5	
Animal Farming			
Agricultural Drying 5)	0.3	9.9	
Industrial Process Heat 6)			
Snow Melting			
Bathing and Swimming 7)	8.7	275.5	
Other Uses (Laundromat and Milk processing)	4	125.5	
Subtotal	18.5	602.4	
Geothermal Heat Pumps	0	0	
TOTAL	18.5	602.4	

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. ((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)

less, 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

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)

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration 1)	(all)	27	0	0		67.5
Production	>150° C	282	0	1		707.5
	150-100° C		2		18	50
	<100° C				5	12.5
Injection	(all)	51				127.5
Total		360	2	1	23	965

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

TABLE 7: ALLOCATION OF PROFESSIONAL PERSONNEL TO GEOTHERMAL ACTIVITIES

(Restricted to personnel with University degrees)

Year	Professional Person-Years of Effort					
	(1)	(2)	(3)	(4)	(5)	(6)
2015	4	180	2	4	5	8
2016	4	185	2	2	5	10
2017	5	190	2	6	5	10
2018	5	203	2	10	7	10
2019	10	203	2	10	10	7
Total	28	961	10	32	0	45

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

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

Period	Research & Development Incl. Surface Explor. & Exploration Drilling	Field Development Including Production Drilling & Surface Equipment	Utilization		Funding Type	
			Direct	Electrical	Private	Public
	Million US$	Million US$	Million US$	Million US$	%	%
1995-1999	8.8	5	0	13.8	0	100
2000-2004	0.125	20	8	194	13	87
2005-2009	1	186	0	195	24	76
2010-2014	16.5	1,004	1.2	1,138	21.2	78.9
2015-2019	49.4	294	0.1	576	16	84