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Country Update Report for Kenya 2020 - 2022

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ABSTRACT

Kenya is the leading country in Africa in terms of geothermal power generation and is ranked 7th global in terms of installed geothermal capacity. High temperature geothermal sites under development in Kenya are located within the Kenya Rift with only one project located outside the main rift. Kenya is currently one of the fastest growing geothermal power markets in the world with a total gross installed capacity of 952MWe as of December 2022. Geothermal electricity currently contributes about 30.44% of total installed electricity capacity in Kenya and about 47% of electricity consumed. The installed geothermal capacity comprises 799MWe by Kenya Electricity Generating Company (KenGen), 150MWe by OrPower4, Inc and 3.6MWe by Oserian Development Company Ltd. Sosian Energy is constructing a 35MW power plant in the 105MW Menengai project by Geothermal Development Company. Direct utilization of geothermal resources installed capacity stood at estimated 18.5MW_{th}. Direct use of geothermal resources has remained low with the largest utilization at the Oserian flower farm and KenGen's Olkaria spa pool. GDC has developed direct use pilot plants for greenhouses, milk pasteurizer, aquaculture and laundry. GDC hopes to expand on these initiatives in the near future. Installed capacity is projected to increase by 35MWe in 2023 after commissioning of Sosian power plant. Other projects in the pipeline include 83 MW Olkaria VI PPP project. KenGen and GDC have continued to explore and appraise several geothermal sites in Kenya including Eburru, Paka, Korosi and Silali geothermal prospects. Having recognized the potential part that could be played by private investors, the Government has so far licensed thirteen IPPs to undertake greenfield geothermal projects at Barrier, Longonot, Akiira, Elementaita, Homa Hills, Makongeni/Menengai, Lake Magadi, Arus, Baringo, Emuruangogolak, Namarunu, and Emuruapoli prospects.

1 INTRODUCTION

Commercial energy in Kenya is dominated by petroleum and electricity while wood fuel provides household energy needs for the traditional sector including rural and urban communities. At the national level, wood fuel and other biomass account for about 68% of the total primary energy consumption, followed by petroleum at 22%, electricity at 9% (242 KWh per capita) while others including coal accounts for less than 1%. Solar energy is also extensively used for drying and, to some extent, for heating and lighting. Current interconnected installed electric capacity in Kenya is constituted by hydro (837MWe), fossil fuel (646.3MW), geothermal (952MWe) wind (436MWe) solar (210MWe) and imports (200MWe) (Table 1). Additionally, Kenya has an off-grid installed capacity comprising thermals (36MWe), wind (0.6MWe), solar (2.3MWe) and geothermal (3.6MWe). However, the off-grid installed solar capacity might be more since not all the installed solar home systems are documented. In terms of interconnected energy consumed in the country in year 2021, the largest supply came from geothermal followed by hydro, wind, thermal, imports and solar and bioenergy as shown in the Table 2. Electricity consumption per capita therefore for year ended June 2021 was 242kWh. The big share from geothermal is due to the use of geothermal as baseload.

2 INSTITUTIONAL FRAMEWORK FOR THE ELECTRICITY SECTOR

The energy sector in Kenya comprises of various government and private actors that relate as depicted in Figure 1. This structure is the result of a series of restructuring since 1997 following government policies touching on the sector. The Ministry of Energy is responsible for overseeing the electricity sector in Kenya. It provides policy guidance, vision and strategy towards the creation of an enabling environment for efficient operation and growth of Kenya's energy sector.

Kenya Electricity Generation Company (KenGen) as a corporate identity was adopted on 2nd October, 1998 and is charged with all publicly owned power generating plants. The Government of Kenya holds 70% of shares while 30% is owned by the public. KenGen is charged with electricity generation in the country from geothermal, hydro, solar, wind and hydrocarbons. KenGen produces about 80% of electricity consumed in Kenya. Kenya Power and Lighting Company (KPLC) is a State Corporation in which the Government of Kenya has a shareholding of 50.1%. The private shareholding amounts to 49.9%. Kenya Power purchases electrical energy in bulk from KenGen and other Independent Power Producers and sells to consumers. It owns some high voltage transmission lines and distribution lines.

Kenya Electricity Transmission Company (KETRACO) is a State Corporation charged with high voltage transmission from the generating stations to the load centers. The transmission of electricity was previously part of the mandate of the KPLC until the incorporation of KETRACO in the year 2008. The mandate of KETRACO is to plan, design, and construct, own, operate and maintain new high voltage electricity transmission infrastructure. The Geothermal Development Company (GDC) was incorporated in the year 2008 to speed up the development of geothermal resources in Kenya. It is fully owned by the Government of Kenya. GDC's mandate is de-risking of geothermal fields and direct use application.

Energy and Petroleum Regulatory Authority (EPRA) was established as an energy sector regulator under Section 4 of the Energy Act, 2019. It is charged with the responsibility of economic and technical regulation of electric power, renewable energy, and downstream petroleum sub-sectors. Its functions also include tariff setting, review, licensing, enforcement, dispute settlement and approval of power purchase and network service contracts

The Rural Electrification and Renewable Energy Corporation (REREC) was established under Section 66 of the Energy Act No 12 of 2006. With mandate to manage the Rural Electrification Programme Fund; develop and update rural electrification master plan as well as implement and source additional funds for the rural electrification programme, among other functions. With mandate conferred by the Energy Act, 2019, RECEC has an expanded mandate of spearheading Kenya's green energy drive, in addition to implementing rural electrification projects. Nuclear Power and Energy Agency (NuPEA) is responsible for the promotion of nuclear electricity generation development, including research, capacity-building and programme implementation. Energy & Petroleum Tribunal: independent legal entity mandated to determine disputes and appeals in accordance with the Constitution of Kenya, Energy Act 2019, and other relevant laws.

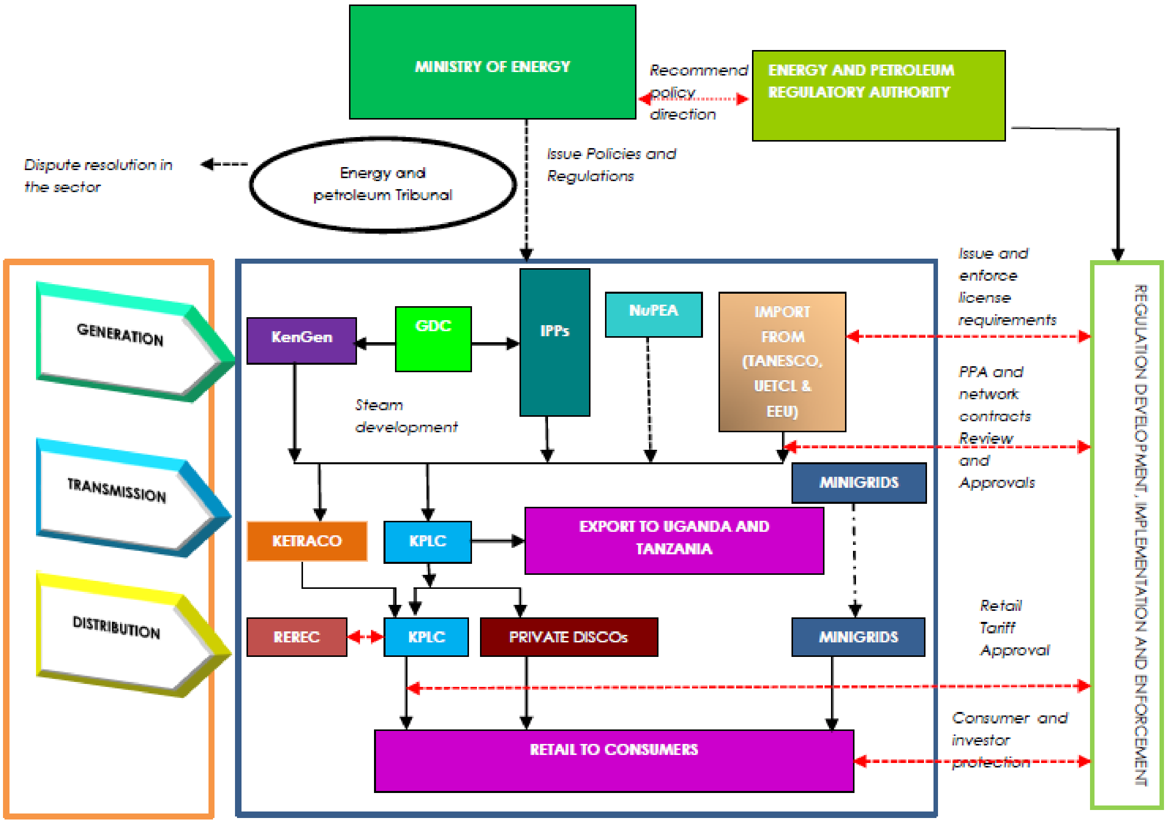

Figure 1: Institutional setup of the Energy sector (LCPDP 2021-2040).

3 GEOLOGICAL BACKGROUND

The East African Rift System is part of the Afro Arabian rift system that extends from the Red Sea in the north to Mozambique in the south. As the rift extends from the Ethiopian segment southwards it bifurcates at about 5°N into the eastern and western branches, skirting around the Tanzania craton of the Late Proterozoic, Mosley (1993); Smith and Mosley (1993). The eastern branch that comprises the main Ethiopian Rift and Kenya Rift is older and relatively more active volcanically than the western branch that comprises Western Rift and Malawi Rift (Figure 2). All the high temperature geothermal occurrences in Kenya are mainly associated with Quaternary volcanoes in the axis of the main rift valley, Mwangi (2005; Omenda et al., (2000). The heat sources for most of the systems are shallow magma bodies under the volcanoes. There are 14 large Quaternary volcanoes in Kenya and together with other prospective sites provides an estimated possible resource of 10,000 MWe.

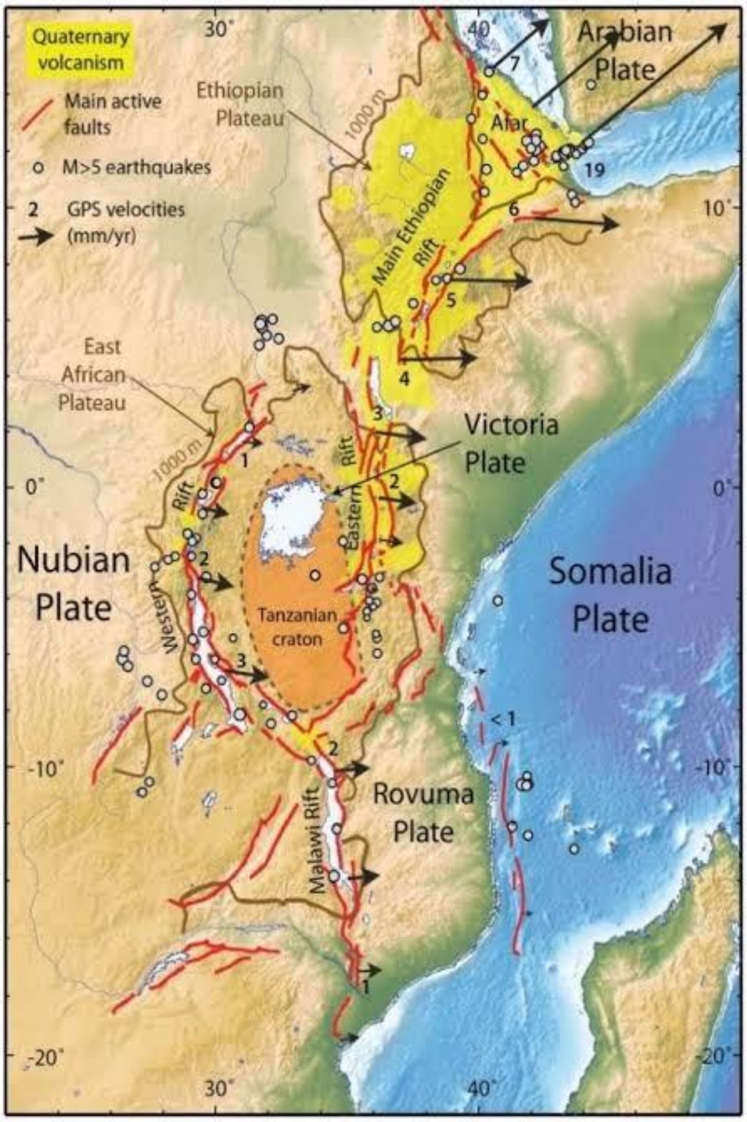

Figure 2: Map showing the East African Rift System, Calais (2016)

The development of the Kenya Rift followed the standard model for active rift formation that involved lithospheric extension accompanied by upwelling of the underlying asthenosphere and collapse. Decompression of the asthenosphere resulted in large volumes of magma generation and development of volcanoes on the crest of uplift. Some of the volcanoes developed shallow magma chambers of intermediate to silicic composition which are the most important geothermal resources. Further brittle extension of the crust resulted in down-faulting and formation of the graben. In the case of the EARS, extensions are more active in the north being more than 3-4 cm/year in the Red Sea-Gulf of Aden, 2-3 mm/year in the Main Ethiopian Rift, and less than 2 mm/year in the Kenya Rift and southwards. In response to the increased extension in the EARS, the Moho Continuity is at between 0-5 km at Afar to 35 km along the axis of the rift in Kenya.

In the axis of the Eastern Rift occur numerous central volcanoes of Quaternary age overlying older volcanic products of Miocene and Pliocene age. The shield volcanoes are built largely of intermediate lavas and the associated pyroclastics, thus indicating the presence of shallow hot bodies (magma chambers). In the Western Branch, there is paucity of volcanism along the entire length of the rift with the main volcanic areas being Virunga and Rungwe. The geothermal manifestation in the East African Rift occurs in the form of hot springs, fumaroles, hot and altered grounds, and is closely associated with Quaternary volcanoes in the axis of the rifts. The association is related to the shallow hot magma bodies under the massifs, which are the heat sources. In the Afar, Ethiopian and Kenya rifts where the crust has been thinned due to extension tectonics, high heat flux is contributed by shallow mantle. In the less magmatic western branch of the rift, heat sources are a combination of buried intrusions and high heat flux associated with relatively thinned crust.

The rifting activity in Kenya Rift began about 30 million years ago with uplift in the Lake Turkana area and then migrated southward being more intense about 14 million years ago. Formation of the graben structure in Kenya started about 5 million years ago and was followed by fissure eruptions in the axis of the rift to form flood lavas by about 2 to 1 million years ago. During the last 2 million years, volcanic activities became more intense within the axis of the rift due to extension Dunkley et al. (1993). During this time, large shield volcanoes, most of which are geothermal prospects, developed in the axis of the rift. The volcanoes include Suswa, Longonot, Olkaria, Eburru, Menengai, Korosi, Paka, Silali, Emuruangogolak and Barrier. Homa hills is a geothermal prospect in the

Nyanza Tertiary rift in western Kenya while Mwananyamala is a geothermal area associated with faulted Permo-Triassic sandstones of the coastal Kenya (Figure 3).

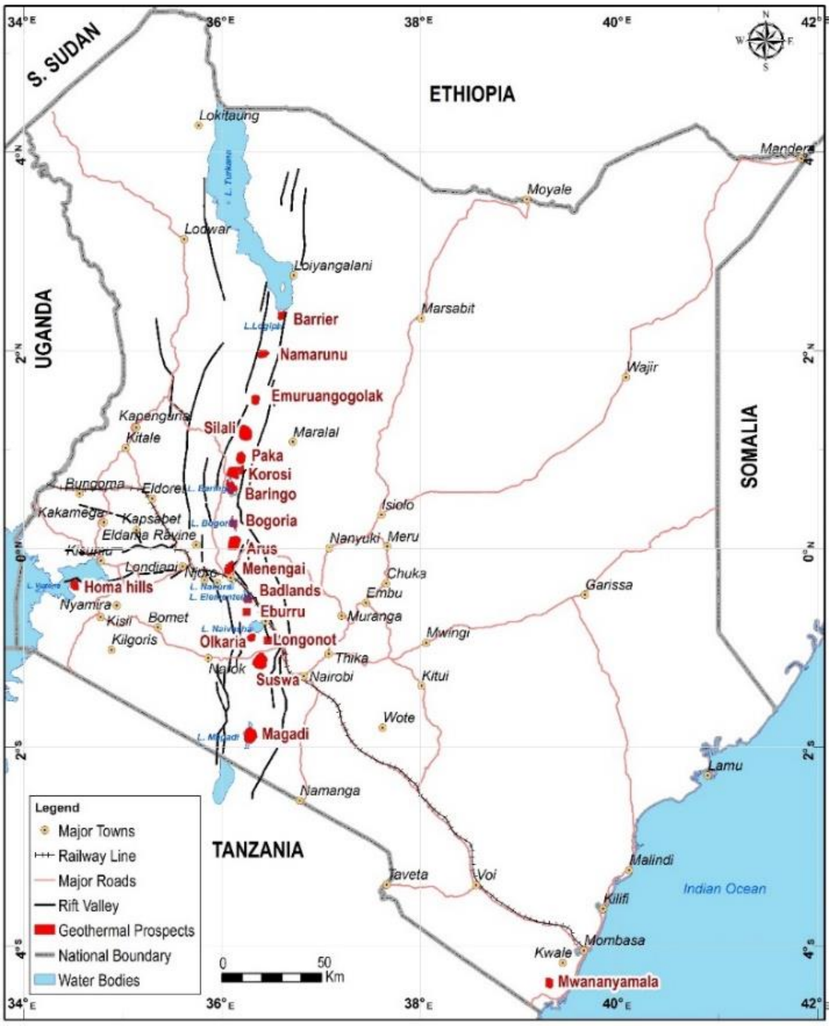

Figure 3: Map of Kenya showing locations of the geothermal fields and prospects.

4 GEOTHERMAL RESOURCES AND POTENTIAL

This section provides a short description of the prospects in Kenya and the development status to date. Exploration for geothermal energy in Kenya started in the 1950's with surface exploration that culminated in geothermal wells being drilled at Olkaria, Eburru and Menengai geothermal fields. The Greater Olkaria geothermal field has over 300 wells drilled producing 950 MWe, adjacent Eburru six wells, Menengai thirty wells, Paka seven wells and Korosi 6 wells. Geothermal development is currently being fast-tracked in Kenya with drilling ongoing in Menengai Olkaria geothermal fields (Table 2).

4.1 Olkaria geothermal field

The Olkaria geothermal prospect lies within the Olkaria volcanic complex lies on the axis of the rift but with a bias towards the Mau escarpment to the west. The rock outcrops is dominated by rhyolite flows and pyroclastics of which the youngest is the Ololbutot rhyolitic obsidian flow that erupted at 180 ± 50 yr BP, Clarke et al., (1990). The landscape is also dotted with volcanic centres (Figure 4). Fault systems at Olkaria are dominantly in three directions: NW-SE, N-S and NE-SW. The latter two are younger and have affected even the Holocene flows while the NW trending faults are older and often associated with the rift graben formation. They are more common in the west where the field merges into the Pliocene Mau escarpment. In the sub surface, the volcanic complex has been divided into the east and west with the divide being the fault zone that runs through Olkaria Hill, Omenda (1994, 1998). The lithology in the western sector is dominated by the Mau Tuffs but minor trachytes, rhyolite and basalt occur within the formation. The Greater Olkaria geothermal field has been divided into seven fields for ease of development and management, namely, Olkaria East, Olkaria West, Olkaria North-West, Olkaria North-East, Olkaria Central, Olkaria South-East, and Olkaria Domes (Figure 5). The field has capacity to generate more than 1,500 MWe and direct utilization of hundreds of MW_t.

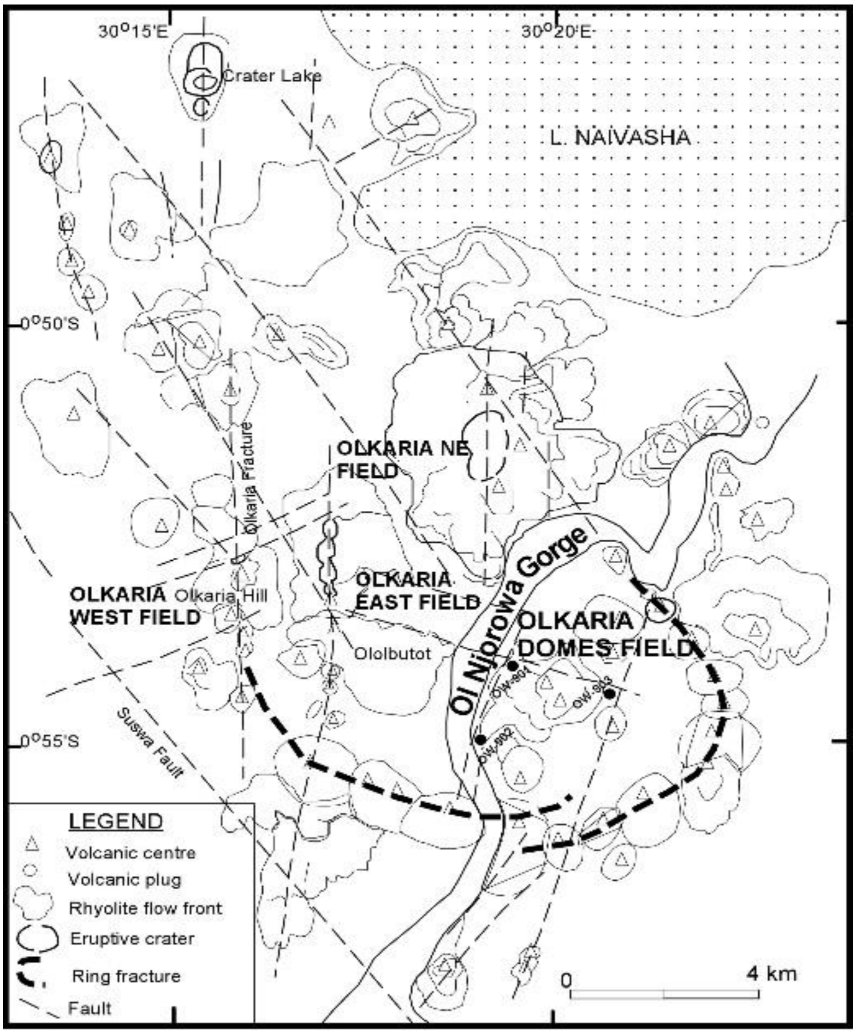

Figure 4. Structural map of Olkaria geothermal field

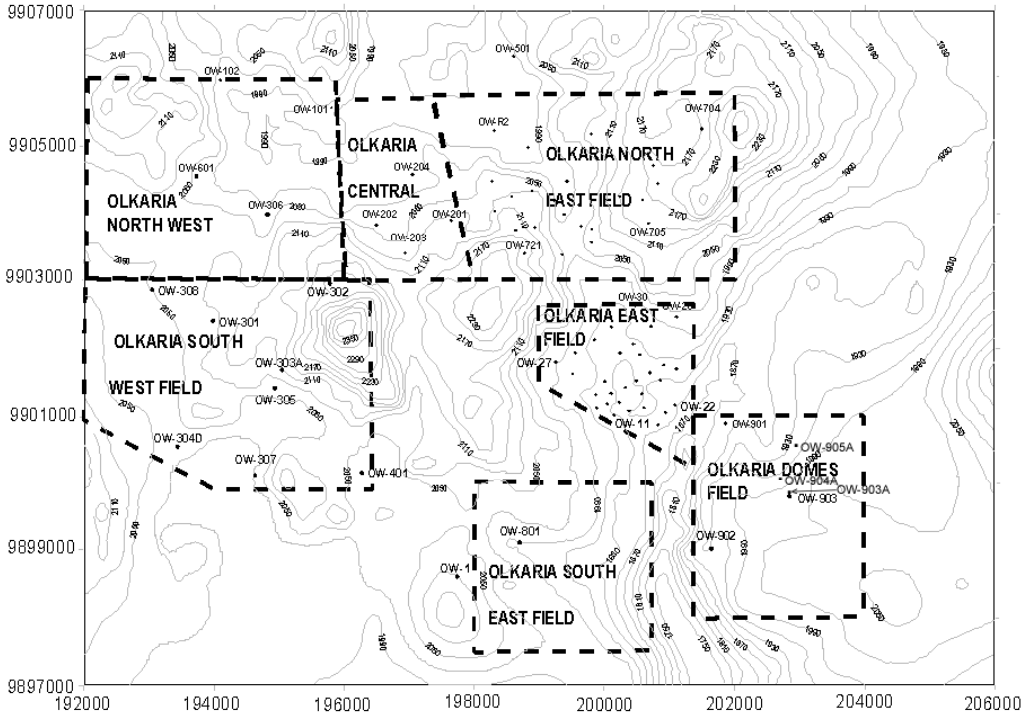

Figure 5: Map of the Greater Olkaria geothermal area showing the locations of the fields.

4.1.1 Olkaria East field

The Olkaria South West field is home to the Olkaria I power plant which was the first geothermal power plant in Kenya, the first unit (Olkaria I Unit 1) having been commissioned in 1981. The second (Olkaria I Unit 2) and third unit (Olkaria I Unit 3) were installed in November 1982 and March 1985 respectively. Each of the units is of 15MW each hence a total installed capacity of 45 MWe. The power plant is currently planned for decommissioning after operating continuously for 40 years since 1982. The power plant is owned and operated by KenGen. After decommissioning, the units will be redeveloped to 51MW and commissioned by 2028. To fully utilize steam realized after further appraisal drilling of the Olkaria East field, additional units (AU) consisting of 2x75 MWe (Olkaria IAU4 and Olkaria IAU 5) plants were developed and commissioned in 2014 and a further unit of 86 MWe (Olkaria IAU 6) power plant was commissioned in June 2022.

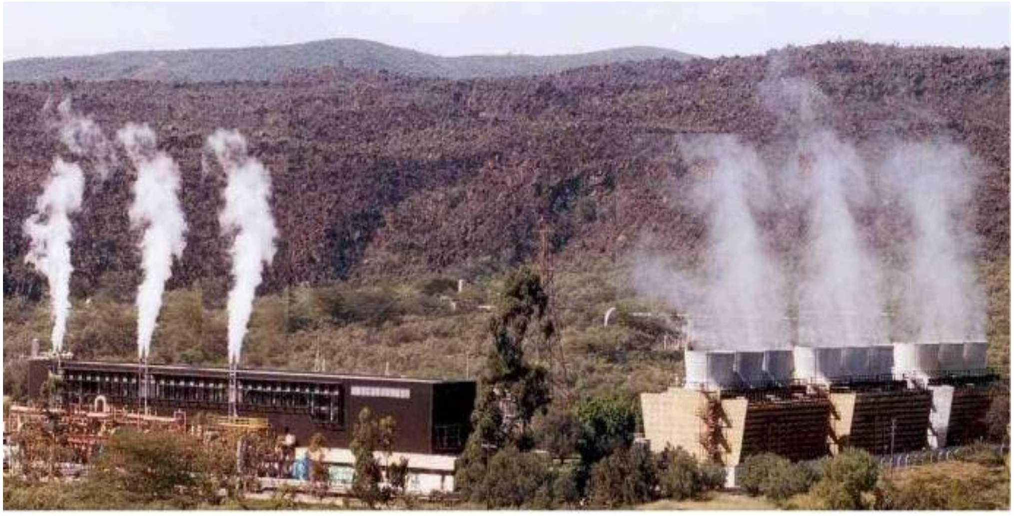

Figure 6: A view of Olkaria 1 power plant located in the Olkaria East production field

4.1.2 Olkaria North East field

This field hosts the Olkaria II power plant. The plant consisting of 2X35MWe units was commissioned in 2003. A third 35MWe unit was commissioned in 2010. The current total installed capacity at Olkaria II is 105MWe. Production drilling is ongoing in the field with intention of increasing the capacity of the field by 140 MW. Feasibility study for the expansion has been commissioned.

4.1.3 Olkaria Domes field

Surface exploration was carried out in 1993 and three exploration wells drilled in 1999. Appraisal drilling was undertaken in 2006 and 2007 and paved way for production drilling that has continued to date. 2x75 MWe Olkaria IV power plant was completed and commissioned in December 2014. 37.8 MWe wellhead units have been installed in Olkaria IV field. The eastern sector of the field houses the Olkaria V power plant. 173.2 MWe power station which was commissioned in 2019. At the field is also developed a geothermal hot bath and spa which is the largest in Kenya (Table 3).

4.1.4 Olkaria Central field

Olkaria Central field is located between Olkaria West and Olkaria North East fields. All the wells drilled in this field have relatively lower outputs resulting from lower reservoir temperatures and lower permeability. Oserian Development Company (ODC), a flower farm, constructed two power plants with installed capacity of 2.5 and 1.8 MWe utilizing Organic Rankine Cycle (ORC) and back pressure technologies respectively. The plants use steam from wells leased from KenGen. The plants which were commissioned in 2004 and 2006, respectively provide electricity requirements for private use. ODC also utilizes geothermal heat for greenhouses from a 1.28 MWe well also leased from KenGen. Plate heat exchangers are used to heat fresh water which is then used to heat the greenhouses and sterilize soil. Separated CO_2 is used to enrich the CO_2 levels in the green house (Table 3). The use of geothermal heat has resulted in drastic reduction in operating costs in the flower farm.

4.1.5 Olkaria West field

Host to the OrPower4 power plant owned by Ormat International. 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 150 MWe. OrPower4 uses the combined cycle plant technology to generate the 150 MWe, LCPDP (2021).

4.2 Eburru Geothermal Field

Eburru geothermal field is located to the north of Olkaria at the foot of the Mau escarpment. Detailed surface studies were concluded in 1990 and culminated in the drilling of six exploration wells between 1989 and 1991. One of the six exploration wells encountered high temperature geothermal system at >250˚, Omenda and Karingithi (1993); Onacha, (1990). A 2.52 MWe condensing pilot plant was constructed and commissioned in 2012 (Table 2). KenGen in 2022 commenced drilling of appraisal wells in the field with plans to expand the generation capacity to 25 MWe,

4.3 3.3 Menengai geothermal field

Menengai geothermal field is hosted in the Menengai Caldera which is a Quaternary caldera volcano located within the axis of the central segment of the Kenya Rift. The volcano has been active since about 0.8 Ma. The volcano is built of trachyte lavas and associated intermediate pyroclastics. Resurgent post caldera activity (<0.1 Ma) occurred inside the caldera with eruption of thick piles of trachyte lavas from various eruption centres.

Production drilling at the Menengai geothermal field has proved steam equivalent to about 170MW on the wellhead. Three IPPs have entered into a steam sales agreement with GDC for power generation of 35 MWe each. The IPPs are Quantum Power East Africa Ltd., OrPower 22 Ltd (a consortium of Ormat, Civicon and Symbion Power) and Sosian Menengai Geothermal Power Ltd (SMGPL). The development of Menengai geothermal power plant is under the Project Implementation and Steam Supply Agreement (PISSA) which 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. The Sosian Menengai Geothermal Power is under construction and it is expected to be commissioned in the first quarter of 2023, Figure 7.

Figure 7: Sosian Menengai geothermal power plant under construction

4.4 Suswa prospect

Suswa is the southernmost of a series of Quaternary caldera volcanoes in the Kenya Rift. The volcano has two nested calderas: outer and inner with diameters of 10 and 4 km, respectively. Volcanism at Suswa started during late Pleistocene and continued to less than 1,000 years ago, Omenda (1997). The volcanic products comprised trachytes, phonolites and their pyroclastic equivalents. Results from detailed surface studies suggest reservoir temperatures of >300˚C based on gas geothermometry. Seismic and gravity studies show that the heat source under the caldera is at about 6 km depth. Resistivity (MT) indicates an anomaly centered below the inner caldera and extending to the northeast out of the inner caldera. Exploratory drilling is expected to commence in year 2017. The prospect is licensed to GDC and will be developed under PPP arrangement.

4.5 Longonot prospect

Longonot is a large caldera volcano within the floor of the southern Kenya Rift adjacent to Olkaria Geothermal field. The volcano comprises of a large trachyte caldera of about 11 km diameter and a resurgent activity on the caldera floor that formed a central volcano with a crater at the summit. The caldera floor is filled, to a large extent, by trachytic ashes from the central volcano. The youngest activity (<300 years BP) at Longonot was of mixed Trachyte-basalt composition and erupted within the crater floor and on the northern flank of the central volcano. Geothermal surface manifestations are mainly fumaroles and hot grounds within the central crater. The geochemical survey revealed high radon and CO_2 gas discharges with gas geothermometry indicating geothermal reservoir temperatures of more than 300˚C, KenGen (1998).

Combined MT, gravity and seismic indicate that the heat source is at 6 km deep with the shallowest portion directly under the central volcano, Alexander and Ussher (2011). Geothermometry indicates that a high temperature geothermal system >250˚C exists under the volcano. The prospect was leased to African Rift Geothermal Limited (AGIL) for 20 years. The company plans to commence exploratory drilling in 2017 which would lead to staged development of 70 MWe power plants with full commissioning in 2019.

4.6 Korosi prospect

Korosi volcano is located in the northern part of Kenya Rift Valley and neighbors Lake Baringo to the south and Paka volcano to the north. Detailed surface studies were undertaken between 2005 and 2012. The latest volcanic activity associated with Korosi volcano was of basaltic composition and occurred a few hundred years ago while the last trachytic volcanism occurred about 100 ka. The MT resistivity surveys indicate an anomaly below the Korosi massif. Gas geothermometry indicates reservoir temperatures of more than 250˚C. Three exploratory wells have been completed.

4.7 Paka prospect

Detailed surface studies of Paka volcano was undertaken in 2006. Paka is a relatively small shield volcano constructed largely by trachyte lavas and pyroclastic deposits and located just to the north of Korosi volcanic complex. 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. Surface geothermal activity is widely developed at Paka particularly within the summit craters and the northern flanks where fumaroles at

>97˚C are common. GDC in 2019 commenced exploration drilling at the summit of the volcano within the caldera floor. Ten wells have been completed with and additional two progressing. So far, the drilled wells have a steam equivalent of about 38MWe.

4.8 Silali prospect

GDC completed detailed surface studies and well pads of the Silali geothermal prospect and is committed to undertake exploratory drilling in 2023.

4.9 Other geothermal Prospects

The other potential geothermal prospects in Kenya Rift that are under evaluation include Lake Magadi, Lake Baringo, Emuruangogolak, Namarunu, Barrier volcanic complex, Emuruapoli, Arus and Homa Hills. These prospects have been licensed to private developers.

5 DIRECT USE

5.1 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, Figure 8). 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 8: Photo of Eburru geothermal pyrethrum dryer

5.2 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.

5.3 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 (Figure 9).

Figure 9. Grain dryer at Menengai geothermal field in Kenya

5.4 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 35ºC. 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.

6 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, Olkaria V and Olkaria I Units 4, 5, 6 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.

7 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 1865 graduate experts were active in the country in 2022 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 2035. 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.

8 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, Capital Power Ltd for Homa Hills prospect and Emuruepoli prospect. Other prospects that have been licensed to private developers include Lake Magadi, Namarunu, Emuruangogolak, and Emuruapoli.

9 DISCUSSION

The number of drilled wells in Kenya have increased steadily from the 1950's and increased significantly during the last few years. The wells that were drilled for exploration, appraisal, production and injection vary in depth from 2,100 m to 3,650 m focusing mainly on the high temperature systems. In Kenya, exploration and development has focused mainly on the high temperature systems as shown by the over 340 wells that have been drilled into the high temperatures resources. The wells that recorded lower temperatures were drilled as high temperature wells but encountered low enthalpy. Kenya is currently the epicenter of geothermal developments in Africa with current installed capacity of about 952 MWe and a further ~18.5 MWt for direct use. Installed electric capacity has seen a growth of over 300% from 2010 when installed geothermal capacity was 167 MWe, Simiyu (2010). Part of the new generation comes from wellhead power plants having a total installed capacity of 83.5 MWe which KenGen has constructed to utilize idle steam from small isolated wells. The increase will be achieved through the additional plants under construction at Olkaria and new plants at Menengai field, Eburru and Baringo-Silali prospect. It is anticipated that the private sector will play an increasing role in new geothermal developments through both PPP arrangements and direct licensing of field. Direct use of geothermal energy has not grown significantly since 2010 and greenhouse heating remains the leader with installed capacity of 10 MWt, Lagat (2010). Pyrethrum drying still exists but amount of energy used is low. KenGen recently commissioned their equivalent of "the blue lagoon" at the Olkaria II plant where brine from production wells is channeled into the pool, Mangi (2014). The energy used at the hot pool is about 8.7 MWt.

10 CONCLUSIONS

It is clear that indirect utilization of geothermal energy for power generation in Kenya improved dramatically in the last few years and future outlook is even brighter with more projects lined up for development. Future developments will not only result in increased generation at Olkaria and Menengai geothermal fields but developments of new fields at Paka and expansion at Eburru will further enhance expansion of geothermal development in Kenya. Direct utilization increased marginally but growth is expected with both GDC and KenGen putting focus not only on electricity generation but also direct use.

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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 2022	942	7,839	720	4,080	837	4,397	0	0	436	1,337	212	724	3,147	18,377
Under construction in December 2022	35												35	0
Funds committed, but not yet under construction in	35	0											35	0
Estimated total projected use by 2024	1,012	8,421,864	720	4,080	837	4,397	0	0	436	1,337	212	724	3,217	18,377

TABLE 2. UTILIZATION OF GEOTHERMAL ENERGY FOR ELECTRIC POWER GENERATION AS OF 31 DECEMBER 2022

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

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

Electrical installed capacity in 2022

Electrical capacity actually up and running in 2022

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 20202 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	2022	1	Operating	1F	86.3	86.3	295,146	
Menengai	Menengai Unit 1	2023	1	Construction	1F				35
Menengai	Menengai Unit II	2024	1	Construction	1F				35
Olkaria	Olkaria IV Uprating	2025	2	Planned	1F				40
Olkaria	Olkaria 1 Rehabilitation	2025	3	Planned	IF				63
Olkaria	Olkaria Wellheads	2026		Planned	IF				58
Olkaria	Olkaria VII	2027	2	Planned	1F				140
Olkaria	Olkaria II Unit 4&5	2027	2	Planned	1F				140
Menengai	Menengai unit III	2027	1	Planned	1F				35
Total						952	950	6,633,165	546

TABLE 3. UTILIZATION OF GEOTHERMAL ENERGY FOR DIRECT HEAT AS OF 31 DECEMBER 2022 (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. (^{o}C) - outlet temp. (^{o}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. (^{o}C) - outlet temp. (^{o}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 (^{o}C) Inlet	Temperature (^{o}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]
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	

Laundromat, milk processing at pilot scale

TABLE 5. SUMMARY TABLE OF GEOTHERMAL DIRECT HEAT USES AS OF 31 DECEMBER 2022

1) Installed Capacity (thermal power) (MWt) = Max. flow rate (kg/s) x [inlet temp. (^{o}C) - outlet temp. (^{o}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. (^{o}C) - outlet temp. (^{o}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

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)]			
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**	

TABLE 6. WELLS DRILLED FOR ELECTRICAL, DIRECT AND COMBINED USE OF GEOTHERMAL RESOURCES FROM JANUARY 1, 2020 TO DECEMBER 31, 2022 (excluding heat pump wells)

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

Purpose	Wellhead Temperature	Number of Wells Drilled				Total Depth (km)
		Electric Power	Direct Use	Combined	Other (specify)	
Exploration[1)]	(all)	40	0	0		100
Production	>150^o C	299	0	1		750
	150-100^o C		2		18	50
	<100^o C				5	12.5
Injection	(all)	52				130
Total		**391**	**2**	**1**	**23**	**1042.5**

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 Progr
(6) Private Industry

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
2020	7	203	2	10	10	15
2021	6	203	2	10	10	15
2022	16	211	2	10	10	15
Total	**57**	**1,578**	**16**	**62**	**62**	**90**

TABLE 8. TOTAL INVESTMENTS IN GEOTHERMAL IN (2022) 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	16.0	84.0
2020-2022	5.32	399.85	0.1	160.85	17.6	82.4