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GEOTHERMAL EXPLORATION IN KENYA – STATUS REPORT AND UPDATES

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ABSTRACT

The need to meet world energy demands while preserving sustainable environment has resulted into a shift of focus to renewable energy sources. In Kenya, eelectricity consumption is expected to grow by 23% to a minimum of 3000 kWh by the end of 2018. To meet this demand, Kenya like many other countries, has shifted its focus to renewable energy sources mainly geothermal resource development. Kenya is well endowed with high temperature geothermal resources that are largely untapped. These resources are located within the axial of the Kenya Rift valley. The Kenyan Rift valley forms part of the larger East Africa Rift system (EARS) which runs from Afar triple junction in Djibouti to Beira in Mozambique. Some of the areas with geothermal resources are already developed and in production drilling stage. These are referred to as geothermal fields and they include Olkaria, Eburru and Menengai. In the other areas, surface exploration studies have been done but production drilling has not commenced. These are referred to as prospects and they include Suswa, Longonot, Arus-Bogoria, Lake Baringo, Korosi, Paka, Lake Magadi, Badlands, Silali, Emuruangogolak, Namarunu and Barrier. Geothermal research and development in Kenya began in early 1950's. The first drilling, which took place in 1956, yielded unsuccessful results. In 1972, with the help of UNDP, geothermal research was accelerated culminating in the commissioning of the first power plant in 1981. Currently, Kenya is number seven on the world geothermal energy producers with a total of 657 MWe. This power is generated by Olkaria I (45 MWe), Olkaria I unit IV&V (140 MWe), Olkaria II (105 MWe), Olkaria III (139.3 MWe), Olkaria IV (140 MWe), Wellhead generators (83.3 MWe), Oserian (2 MWe) and Eburru wellhead (2.5 MWe). Geothermal development in Kenya has relied on various financial partners to realise this success. They include Government finance, multilateral development banks, bilateral development agencies, special purposes finance (green funds), commercial banks and private equity. Kenya has made great strides in the direct utilization of geothermal resources. Some of the uses include heating and fumigation of green houses, drying of crop harvests, milk pasteurization, fish farming and recreational purposes among others. Like many other energy development projects, geothermal energy has had its fair share of challenges. They include financial challenges, technological and human capacity challenges, environmental and socioeconomic challenges and legislative and policy challenges. However, various measures have been put in place to address these challenges. Geothermal resource development has a great future with the Kenyan government focussing on having 2500 MWe from geothermal by the year 2025.

1. INTRODUCTION

Electricity consumption is expected to grow by 23% to a minimum of 300 0kWh by the end of 2018. The interconnected system installed capacity as per May 2017 was 2.312 GW (KPLC, 2017). Out of this, 677 MW is from geothermal energy, 823 MW from hydropower, 776 MW from total thermal, 25.5 MW from wind while cogeneration contributes 28 MW. The off-grid installed system as at May 2017 was 27.52 MW and consisted of diesel, solar and wind power plants in areas away from interconnected system. The off-grid thermal is at 26.33 MW, wind is at 0.5550 MW while solar is 0.64 MW. The percentage rate as per consumption is 47% geothermal, 39% hydropower, 13% thermal and 0.4% wind. In the past, Kenyan Government heavily relied on hydropower for electric power generation. Hydropower is highly dependable to climatic changes hence quite unreliable. For this reason, the government shifted focus and invested resources in the exploration and development of geothermal resources beginning 1970s. Table 1 shows the current installed capacity by mode, projects onto which funds have been committed and those under construction while Table 2 shows a breakdown of the projects under construction and those which have funds committed but not yet under construction.

TABLE 1: Present and planned electricity production

	Geothermal		**Fossil fuels**		**Hydro**		**Other renewables**		**Total**	
	C[1] MWe	GP[2] GWh/yr	C MWe	GP GWh/yr	C MWe	GP GWh/yr	C MWe	GP GWh/yr	C MWe	GP GWh/yr
In operation	677	5,927	776	6,798	823	7,209	56	491	2,332	20,425
Under construction	358	3,136	-	-	-	-	310	2,716	668	5,852
Funds committed but not yet under construction	185	1,620.60	1,000	8,760	-	-	120	1,051	1,305	11,432
Estimated total projected use by 2020	2,765	24,221	3,753	32,876	1,310	11,477	679	5,948	8,507	74,523

1: Capacity; 2: Gross production.

TABLE 2: A breakdown of projects under construction and those which funds have been committed

Project	**Mode of generation**	**Status**	**Company**	**Capacity**	
				C[1] MWe	GP[2] GWh/yr
Turkana	Wind	Under construction	Lake Turkana Wind Power Ltd.	310	2,716
Menengai	Geothermal	Under construction	GDC	100	876
Baringo-Silali	Geothermal	Under construction	GDC	100	876
Okaria	Geothermal	Under construction	KenGen	158	1,384.08
			TOTAL	**668**	**5,852**
Menu	Wind	Funds committed	KenGen	80	701
Lamu	Fossil fuel	Funds committed	Centum Investment / Gulf Energy	1,000	8,760
Gitaru	Solar	Funds committed	KenGen	40	350
Olkaria 1AU6	Geothermal	Funds committed	KenGen	70	613
Wellheads	Geothermal	Funds committed	KenGen	108	946
Olkaria 1 upgrade	Geothermal	Funds committed	KenGen	7	61
			TOTAL	**1,305**	**11,432**

1: Capacity; 2: Gross production.

Before power is generated, there has to be an efficient and well networked supply system. Kenya Power and Lighting Company (KPLC) has launched various projects aimed at ensuring efficiency in power connectivity and distribution (KPLC, 2017). Among the projects launched include; the Kenya Electricity Modernisation Project (KEMP) aimed enhancing the electricity network in readiness for the anticipated 5000+ MW generation by 2030, Last Mile Connectivity Project (LMCP) aimed at increasing electricity access to Kenyans especially the low income group, the Global Partnership on Output Based Aid (GPOBA) electrification project which is a partnership between World Bank and KPLC. GPOBA project is aimed at preventing commercial losses by reducing cases of electricity theft while providing convenient services to customers through prepaid metering. There is also the Boresha Umeme Network Upgrade Project. Under this project, networks serving major customers as well as areas with repeated poor supply quality issues are given a priority in a focused and thorough maintenance effort that pools resources to one locality. The last project is the Street Lighting Project.

Additionally, KPLC is undertaking several Network Expansion and Maintenance Programmes (KPLC, 2017). They include the Live Line Maintenance Programme, Underground Cabling Project and Rapid Response Team. The Live Line Maintenance Programme will see the maintenance of electricity distribution network without switching off. This will address revenue losses and customer inconveniences. The Underground Cabling Project is aimed at improving electricity supply in Nairobi through refurbishment of the existing network and building of additional lines and new substations. The Rapid Response Team was created in 2016 to deal with electric power emergencies. The team uses motorbike transport to reduce emergency response time.

The Least Cost Power Development Plan (2013-2031) prepared by government of Kenya indicates that geothermal plants have the lowest unit cost, hence suitable for base load (Ondraczek, 2014). The current Olkaria geothermal power plants have operated as base loads with more than 95% availability. This demonstrates the viability of geothermal energy in Kenya. Owing to its reliability and viability, geothermal energy stands to play a big role in realizing Kenya's vision 2030 objectives. The government targets a total of 5000 MW power generation from geothermal sources by 2030 (Micale et al., 2015). Hence, the government has embarked on an ambitious geothermal expansion plan in order to increase geothermal power share in the energy mix.

Kenya is well endowed with high temperature geothermal resources that are largely untapped. These resources are located within the Kenyan rift which forms part of the eastern branch of the East Africa Rift system (EARS). The eastern branch runs from the Red sea in Afar region to the North to Beira in Mozambique to the south. Geologically, the EARS is an intra-continental divergence zone where rift tectonism accompanied by intense volcanism has taken place from late Tertiary to Recent (Corti, 2011). The rift tectonism, intense volcanism and faulting associated with the formation of EARS has resulted in the formation of volcanic centers (Figure 1). Most of these volcanic centers, which occur in axial region of the rift are hosts to extensive geothermal resources.

Geothermal resources are divided into two groups; geothermal fields and geothermal prospect sites. Geothermal fields are those resources in which exploratory drilling has been done and the resource quantified while geothermal prospects are those in which only surface exploration has been done. There are twelve geothermal prospect sites and three geothermal fields identified in Kenya. The prospects include; Suswa, Longonot, Arus-Bogoria, Lake Baringo, Korosi, Paka, Lake Magadi, Badlands, Silali, Emuruangogolak, Namarunu and Barrier. On the other hand, geothermal fields include Olkaria, Menengai and Eburru (Figure 1). Studies carried out in these prospects and fields indicates a potential of over 7,000 MW geothermal resource exists in Kenya.

2. GEOTHERMAL JOURNEY IN KENYA

Kenya is the first African country to develop commercial Geothermal Energy Utilization. Exploration for geothermal resources in Kenya began in 1950's. Geothermal development in Kenya has typically encompassed six key steps; (a) project definition and reconnaissance evaluation, (b) detailed exploration, (c) exploration drilling and delineation, (d) resource analysis and assessment of feasibility of the resource, (e) field development and, (f) steam production and field management.

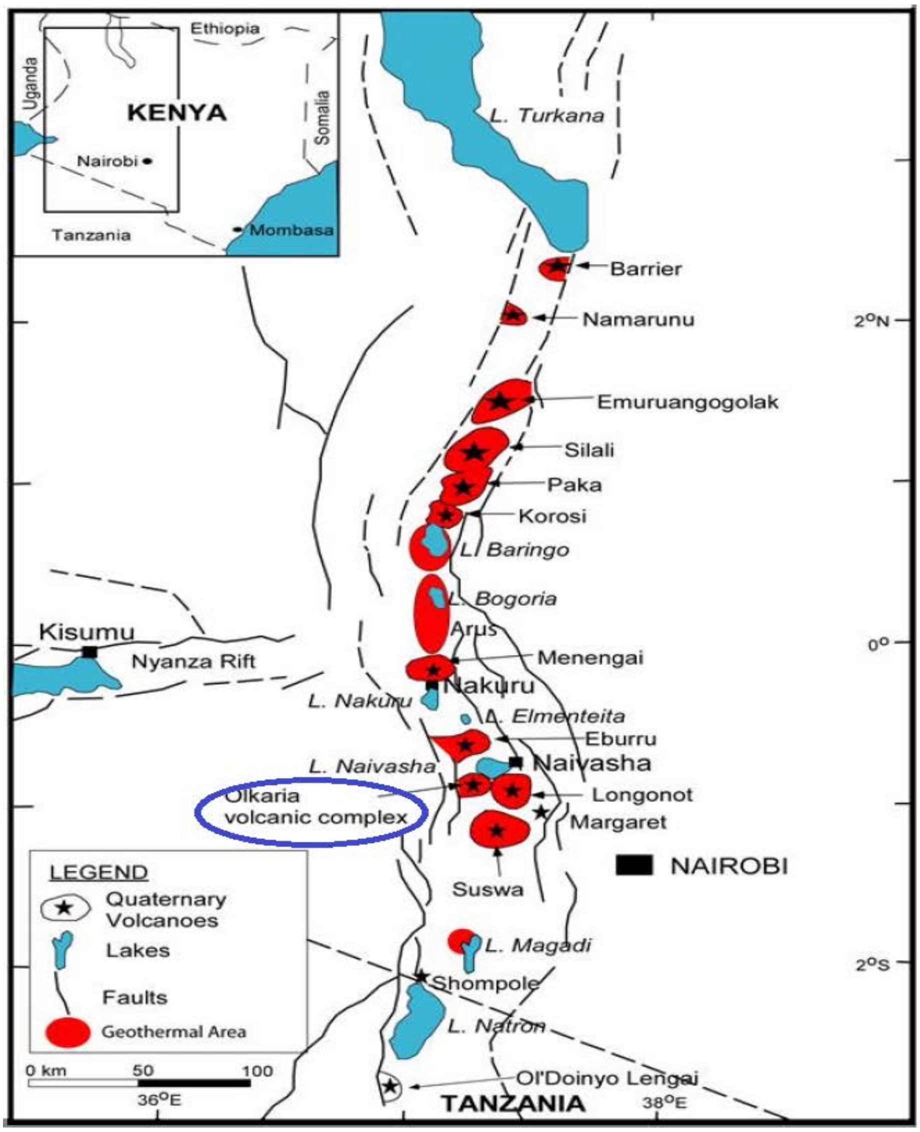

FIGURE 1: Location of geothermal fields and prospects along the axial region of Kenyan rift

Exploration for geothermal energy resources in Kenya started in the 1952. However, geothermal prospecting had started much earlier in 19th century. People like Fischer (whom Fishers' tower is named after) mapped and identified steam jets at Ol Njorowa Gorge in late 1890s. Surface exploration (geological and geophysical) was carried out within the Kenyan Rift between 1952 and 1956 (KPLC, 1992). It was done by a consortium of companies which included the East African Power and Lighting Company Ltd (EAPL), Power Securities Corporations Ltd, Associated Electrical Industries Export Ltd, and Babock and Wilcox Ltd. The study revealed that the central Kenyan Rift Valley, in particular Olkaria area, could contain geothermal energy resource. This findings resulted in the siting and drilling of two geothermal wells (X1 and X2) in 1956. The two wells were drilled to a depth 950 and 1200 m respectively and recorded a maximum downhole temperature of 235° C. The drilling operations were contracted to East African Drilling Company Limited. Attempts to discharge these wells proved futile and further work was finally stopped in March, 1959. This dented a blow to interest in geothermal development. Additionally, the 1960's intense development of hydropower kept the interest in geothermal resource at its low.

The high cost of hydropower development and its unreliability saw the shifting of power generation focus back to geothermal. In 1967, a Wenner configuration resistivity survey was carried out in the Rift valley from Lake Hannington (currently known as Lake Bogoria) in the North and Olkaria in the South. This work showed a number of resistivity anomalies and favored exploratory drilling. The search for geothermal resources was further compounded by the 1970’s world oil crisis. This crisis greatly affected the world economy at that time when there was overreliance on fossil fuel. Owing to this challenges, a joint Geothermal Project by the United Nations Development Program (UNDP) and the Government of Kenya (GoK), represented by East African Power and Lighting Company Ltd. (EAPL) was initiated in the early 1970's. This project led to more geoscientific work being carried out between Olkaria and Lake Bogoria, and Eburru in 1971 and 1972. The work mainly consisted of geological mapping, hydrogeological surveys, gravity studies and infra-red imagery surveys.

By 1972, the resource within Olkaria was the most prospective and hence a decision was taken to concentrate Geothermal Development at Olkaria area ($80km^2$). A technical review meeting at the end of 1972 recommended drilling of four deep (~ 2200 m) exploratory wells in Olkaria area. In 1973, drilling of the four wells commenced with funds from UNDP. By 1976, six wells (well OW-1 to OW-6) had been drilled. These wells were drilled by a rig owned by the East Africa Power Lighting company, a company owned by the then East Africa Community’s three countries (Kenya, Uganda and Tanzania). A feasibility study, done by SWESCO, Stockholm and VRKIR Consulting Group Ltd on reservoir assessment, steam utilization for power generation, effluent, disposal, by product use and environmental impact of the development provided promising results. The study recommended the development of a 2x15 MWe power station. After the completion of the feasibility study, UNDP pulled out of the project. Active drilling for a 30 MWe power plant continued. Geothermal Energy New Zealand Limited (GENZL) was engaged to supervise all drilling operations.

In late 1977, the EAPL evolved to Kenya Power Company (KPC) following the breakup of the East African Community (KPLC, 1992). KPC later assumed all the responsibility to develop geothermal resource in Kenya. Additional wells were thereafter drilled to provide enough steam for the generation of electricity, and in June 1981 the first 15 MWe generating Olkaria 1 unit 1 power plant was commissioned. This was the first geothermal power plant in Africa. By the end of 1984, a total of 33 wells had been drilled in the Olkaria East production field and a total of 3x15 MWe power plant commissioned by early 1985. The second 15 MWe unit was commissioned in November 1982 and the third unit in March 1985, raising the total to 45 MWe. Since then, exploration work has continued in the Olkaria geothermal field. The concession area has since been expanded and a total of about 294 wells have been drilled to date in the Olkaria geothermal field. In 1990’s, the field was divided into seven sectors for the purpose of geothermal management and exploitation. Below is a breakdown of the geothermal power plants' development in Olkaria geothermal field.

2.1 Olkaria Geothermal field

Currently, Olkaria and Eburru geothermal field are the only field being utilized for power production. However, Olkaria geothermal field is the most explored with a production capacity of 657 MWe being generated from the field. There is also direct utilization of over 30 MWt for heating flower farms and bathing in spa. This field has been divided into seven segments for the purpose of easy management (Figure 2). The proven resource at Olkaria geothermal field is more than 600 MWe. Due to the availability of this resource, accelerated expansion plans have been set in place by KenGen.

2.1.1 Olkaria I power station

The first unit with a generation capacity of 15 MWe was commissioned in June 1981. Later two units (unit 2 and 3) were added in November 1982 and March 1985 bringing the total installed capacity to 45 MWe (Figure 3). This project was financed by the World Bank. The power plant is owned and operated by KenGen. This plant draws its steam from the Olkaria East sector. A total of thirty three (33) wells have been drilled to supply steam to Olkaria I. Twenty four (24) of the wells are currently connected to the power station while two (2) have been retired. One (1) well is being used for re-injection and the others are standby wells. Currently the field has steam capable of generating an additional 25 MWe.

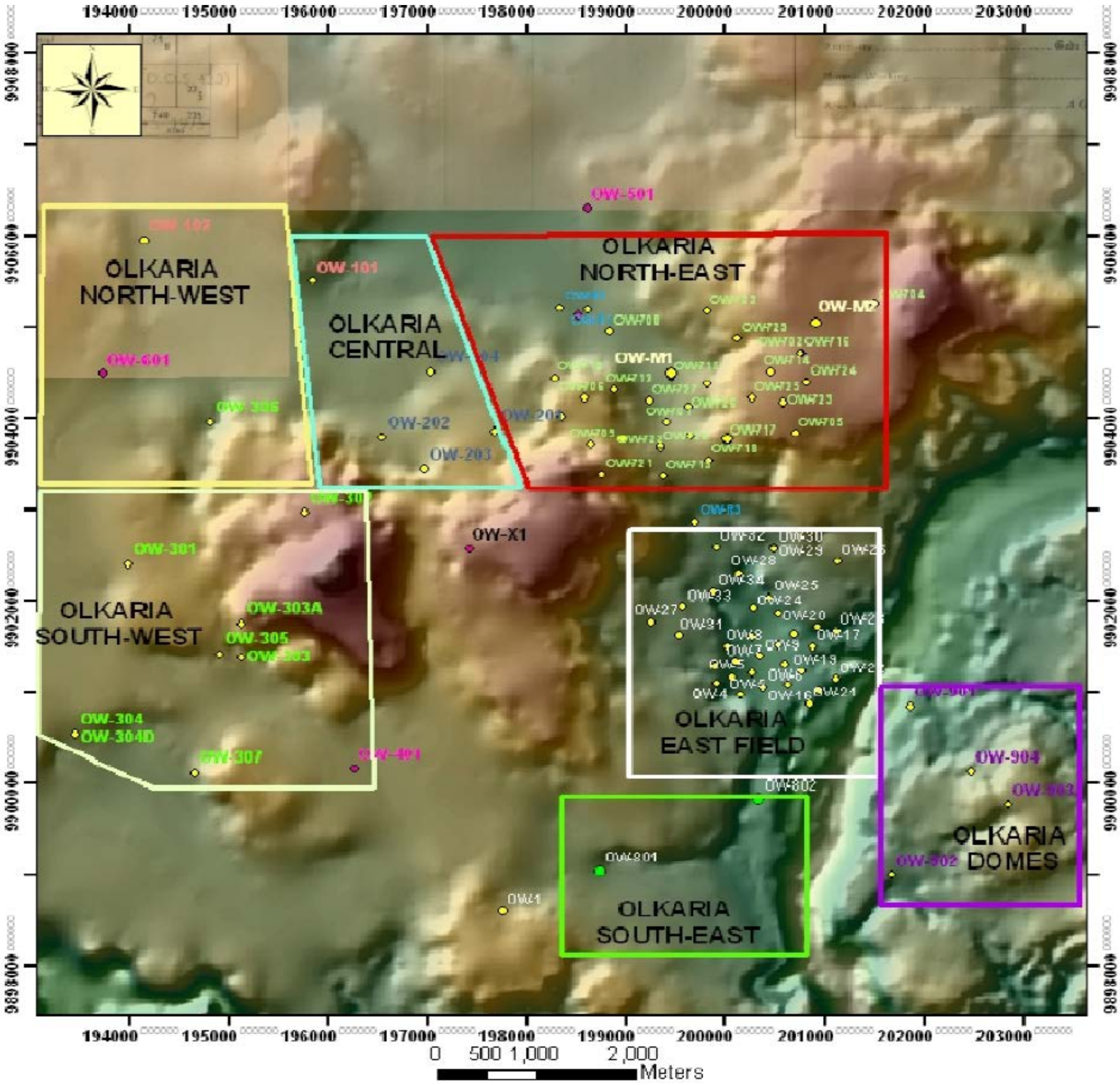

FIGURE 2: The seven segments of Olkaria geothermal field

2.1.2 Olkaria II sower station

Between the year 1986 and 1998 drilling continued in search of steam for Olkaria II power plant, located in the Northeast sector. A total of 30 wells were drilled by 1992 in the Olkaria Northeast sector. However, due to political instability and inflation experienced in the country in 1992 through to 1997, financiers pulled out and no major works were undertaken until 1999. In 2003, a 70 MWe Olkaria II (units 1 and 2) power plant was commissioned. Due to availability of excess steam, a third unit of 35 MWe was added to the national grid in May 2010, bringing the total installed capacity for Olkaria II power plant to 105 MWe (Figure 4). 22 wells supply steam to the three power generating units. The power plant is owned and operated by KenGen.

2.1.3 Olkaria III power station

In 1997, ORMAT International was licensed by the Kenya Government to generate 48 MWe from Olkaria III which lies in Olkaria Northwest sector. This was after the energy reforms of the 1996. In August 2000, ORMAT, through its local subsidiary OrPower 4, commissioned 8 MWe that was later increased to 12 MWe from a combined binary cycle pilot plant. This was the first geothermal plant to use binary technology. As part of its first phase of development, OrPower 4 drilled nine directional wells to further appraise the Olkaria Northwest sector.

In January 2009, a new plant was installed adding another 35 MWe to the plant's capacity. Later, 36 MWe production unit was installed in 2013. The fourth generation unit at Olkaria III, with capacity of 26 MWe was commissioned in 2014. The fifth unit with a capacity of 29.6 MWe was commissioned in February, 2016, bringing the total capacity at the plant to 139.6 MWe. This power plant draws its steam from the Northwest sector of the Olkaria geothermal field.

FIGURE 3: A view of Olkaria 1 Power plant located in the Olkaria East Production Field

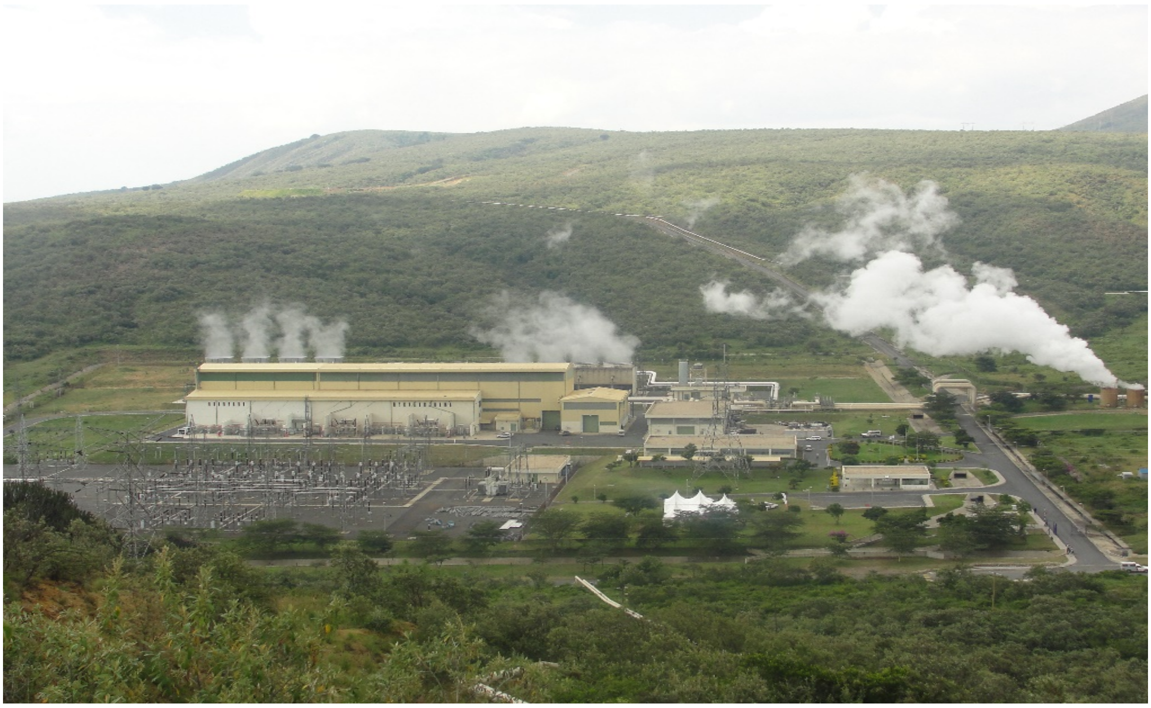

FIGURE 4: View of Olkaria II power station

2.1.4 The Olkaria 300 MWe Project: Olkaria IV and Olkaria 1 AU

The Olkaria 300 MWe project comprises the Olkaria IV (Figure 5) and the Olkaria I additional units 4 and 5. Each of the two power plants has an installed capacity of 150 MWe. Olkaria I units 4&5 draws steam from Olkaria East and partly Northeast sectors. In 1999, KenGen drilled three exploratory wells for Olkaria IV power plant, located in the Domes sector of the Olkaria geothermal field. The Government of Kenya, in 2006, funded appraisal drilling for this field. Production drilling commenced in 2007 by signing of a six well drilling contract with the Chinese owned Great Wall company (GWC). With more steam being realized and the field proving to be successful, more production and injection wells were drilled. With improved drilling technology, deeper and directional wells going down to a depth of 3 kms were drilled in Domes area. In 2009, the first optimization study for the Olkaria geothermal resources was done by WesJec. This confirmed the capability of Olkaria geothermal field to sustain additional production of 150 MWe for the Olkaria IV power plant and 150 MWe for the Olkaria I unit IV&V units. Construction works on the each of the 150 MWe power project for Olkaria I units IV&V and the Domes field began in March 2012 and on 23rd July 2012 respectively.

FIGURE 5: Olkaria IV power plant located in Domes area

Olkaria IV power plant was commissioned on 17th October 2014 while Olkaria I Unit IV and V was commissioned on 19th February 2015. They generate 150 MW each.

2.1.5 The wellhead technology

Wellhead technology is a new power generation technology pioneered by KenGen. The technology involves tapping steam from wells, which are undergoing tests or waiting to be connected to permanent plant. The main aim of this technology is to ensure revenue from early generation. Permanent power plants take between 24 to 36 months to construct and commission. The well head power plant on the other hand takes 6 months hence a quick return on investment. This move came in time when the country experienced an increase in electricity demand. The first wellhead generator was commissioned in Eburru in the year 2011. This was followed by the second wellhead generator which was commissioned in June 2012 in Olkaria East sector. The two wellhead generators generate 2.4 MWe and 5 MWe respectively. With the realization of the efficiency in terms of the time taken to have power on the grid, KenGen accelerated the installation of wellhead generators in 2014-2015. By mid-2017, KenGen was having 16 wellhead generators generating a total of 83.5 MWe. 15 of this wellheads are in Olkaria geothermal field while one is in Eburru field.

2.1.6 Oserian power plant

This is a binary power plant owned by Oserian flower farm. It was commissioned in July 2004. Its steam is leased from Kengen. It generates 4 MWe. It draws steam from Olkaria Central sector of Olkaria geothermal field.

2.2 Eburru geothermal field

Eburru volcanic complex is located to the north of Olkaria. KenGen carried out detailed surface studies between 1987 and 1990. These studies culminated in the drilling of six exploration wells in Eburru between 1989 and 1991. Further infill MT surveys done in 2006 revealed that Eburru field is able to support up to over 70 MWe power generation. The results from the exploration wells indicate that the field had experienced temperatures of over 300 °C, possibly due to localized intrusive. The maximum discharge temperature was 285 °C. The total output from one of the well that was able to discharge (EW-1), was 2.4 MWe. Based on data from the drilled wells, the estimated power potential of the field lies between 50-100 MWe. In 2011, KenGen commissioned a 2.4 MWe condensing pilot power plant (wellhead unit). Plans are underway to drill appraisal and production wells to build a high capacity power plant.

2.3 Menengai geothermal field

Detailed surface exploration in Menengai, Arus-Bogoria, Koros-Chepchuk and Paka began in 2004. Menengai caldera is the most recent discovered geothermal fields in Kenya. The detailed studies done in 2004 were the basis of siting and drilling of two exploration wells in Menengai field in 2011. The drilling was underateken by the Geothermal Development Company (GDC). GDC is a Special Purpose Vehicle (SPV), fully owned by the government and formed with main aim of speeding up geothermal development. The mapped potential area in Menengai is over 80 Km^2 with an estimated resource potential of 1600 MWe. So far, over 30 wells have been drilled successfully and 135 MWe proven. Production drilling is continuing in the field using seven high capacity drilling rigs.

GDC has contracted three IPPs to construct three power plants under phase 1 of Menegai development. The three Independent Power Producers (IPPs) will generate the first 100 MWe from Menengai. These are Quantam Power East Africa, Orpower 22 (a consortium of Ormat, Civicon and Symbion) and Sosian Energy. Each will install a 35 MWe power plant in Menengai. GDC and the IPPs have signed the Project Implementation and Steam Supply Agreement (PISSA). The agreement stipulates that the IPPs will finance, design, construct, install, operate and maintain the plants on a Build-Own-Operate (BOO) basis. The IPPs have also signed a steam sale agreement with Kenya Power who will off-take the power generated by the IPPs. To fast track development of the resources in Menengai, GDC has advertised for joint development of Menengai phase 2 with private sector on 40/60% equity arrangement.

The development of Menengai has been supported by different financial players. Key among them is the Government of Kenya (GoK). Of the financiers, African Development Bank (AfDB) has given GDC the largest financial support while the French Development Agency (AFD) was the first development partner to support GDC. Other partners in Menengai include the UK Government, World Bank, Scaling-up Renewable Energy Program (SREP), and others. This assistance has gone towards the purchase of drilling rigs and materials, consultancies, capacity building initiatives and infrastructural development.

2.4 The Arus-Baringo-Silali project

The Arus-Baringo-Silali block in this paper refers to the Arus-Bogoria, Korosi, Chepchuk, Paka and Silali geothermal prospects. This block has an estimated potential of 3,000 MWe. GDC has been tasked with the development of this resource in phases. Phase I targets to generate 100 MWe of electricity. This phase is funded by the Government of Kenya and KfW. The Government of Kenya is funding the construction of access roads and community engagement while KfW has given GDC a concessional loan of Ksh. 8 billion for the drilling of 15-20 wells. GDC has contracted Hong Kong Off-Shore Oil Services Limited (HOOSL) to drill the 15-20 geothermal wells under this phase. Additionally, it has already done a 70 km access road to open up the area for drilling.

2.5 Suswa geothermal project

The Suswa Geothermal prospect is situated at the intersection of Narok, Kajiado and Nakuru Counties. Detailed geoscientific studies carried out between 1992 and 1993 rated the field as having a good potential for geothermal development. The project has an estimated potential of over 750 MWe. There is a shallow heat source under the caldera at a depth of about 10 Km. Three wells have been sited on the main caldera floor. The caldera floor is estimated to have a potential of about 200 MWe. A 70 MWe power plant is programmed for development and commissioning by end of 2018. A private investor has been licensed to carry out further survey and subsequent development, subject to a specific time bound programme.

2.6 Longonot

The Longonot geothermal prospect lies east of the Olkaria Geothermal field. Geological, geochemical and geophysical surveys were carried out in the prospect in 1988. Results from these surveys were used to site two exploratory wells. The prospect is believed to be more than 60 km² and is capable of supporting a 200 MWe power generation. A 70 MWe power plant will be developed in Longonot and commissioned by 2018. An additional 70 MWe plant will be developed in the field for commissioning by 2020.

2.7 Akiira Geothermal prospect

Surface exploration studies were done in Akiira area in 1990s. The studies indicated a resource potential of over 70 MWe. In the year 2015, Marine Power drilled two exploratory wells. The wells could not sustain discharge due low pressure. However, temperatures of about 200°C were recorded in one of the wells. Plans are underway to carry out more detailed surface exploration before conducting further drilling activities.

2.8 Other geothermal prospects

Other geothermal prospects include Emuruangogolak, Namarunu, Barrier, Lake Magadi and Elementaita. Reconnaissance studies have been carried out in these prospects indicate temperatures of above 200°C.

3. PROGRESS MADE IN DIRECT UTILIZATION OF GEOTHERMAL RESOURCES

Direct application of geothermal energy has continuously gained popularity due to its economic, environmental and energy efficiency benefits. Its applications vary widely from agricultural applications, crop drying, space heating and industrial processes. In Kenya, direct utilization of geothermal resources was practised even before its application in electricity generation. The Maasai community are known to have used hot springs in Olkaria for bathing as early as 19th century. The red ogre associated with hot springs and altered grounds was also used in 19^{th} century for body decoration by the Maasai community.

The use of geothermal for drying farm products was first applied in 1930s. The Eburru geothermal drier, built by an English settler around 1939, was used to dry Pyrethrum flowers and maize (white corn). The drier was supplied with geothermal water from a well at 95°C adjacent to the building; however, due to leakage and lack of insulation around the pipes, the heat supplied in the building was only 43°C. Currently, Eburru residents gather and condense some of the geothermal steam from the fumaroles for consumption as drinking water.

In early 2000, Oserian Development Company Limited (ODCL) initiated a major investment program to utilize the geothermal energy in flower farming. In 2003, ODCL went ahead and leased well OW-101, one of the earlier drilled wells, from KenGen. This was in addition to other two wells, OW-306 and OW-202 which were leased for the main purpose of power production. Well OW-101 was to be used to heat the greenhouses and supply carbon dioxide required for photosynthesis. Under this application, through a system of loops (Figure 6), hot geothermal fluid heats fresh water which is used as a heat transport medium to the greenhouse. Greenhouse heating assists in controlling relative humidity within the greenhouse especially the early morning hours when humidity tends to rise to about 100%. Reducing relative humidity to below 85% eliminates fungal infection and hence eliminates the use of chemical fungicides. Heated water is also used to sterilise the fertilised water, reducing fertiliser wastage and hence reducing cost. Carbon dioxide from the well is piped to the greenhouses in order to enhance photosynthesis.

FIGURE 6: Oserian greenhouse heating using geothermal

In 2010, KenGen took the idea of direct geothermal utilization for bathing a notch higher. An idea to construct a geothermal spa was conceptualised. The spa utilizes natural geothermal water from a drilled well. The water is obtained from the well at 100°C. From the well, its pumped into a pool where its allowed time to cool to 70°C. It is again transferred to another pool where its cooled further to 35°C before flowing to the main pool where visitors enjoy warm bath (Figure 7). This spa started operating in 2013 and is the only natural spa in Africa. Lake Bogoria hotel have utilized hot springs for use in a swimming pool. The hot springs are directed into a swimming pool where residents and visitors enjoy their warm bath.

Plans for large scale direct utilization of geothermal resources were initiated in Menengai in 2015. GDC set up a direct-use demonstration project in Menengai to show how geothermal by-products can benefit communities through their use in green houses, leather tannery, dairy milk preservation, fish farming, meat processing and development of spas among others. Four demonstration projects have been set up in Menengai. They include geothermal powered dairy unit, geothermal heated aquatic ponds, geothermal heated greenhouse and geothermal powered laundry unit. To start off, a water bath has been constructed and stainless steel heat exchanger submerged inside the bath. Cold water is heated from 25°C to 85°C through counter flow movement. This hot water is supplied to various projects. A milk processing unit that uses heat from the geothermal heat exchanger for milk pasteurization has been set up as a pilot plant in Menengai. Hot water at 80 °C heats milk to a temperature of 65°C - 67°C for a period of 30 minutes. Milk is then cooled in two processes; using room temperature water and using ice water to temperatures as low as 4°C. Pilot plants have been set up for use in greenhouse heating, fish farming, milk pasteurization and laundry.

FIGURE 7: Olkaria Geothermal Spa

4. OTHER KEY PLAYERS IN GEOTHERMAL SECTOR OTHER THAN KENGEN

GDC was incorporated in December 2008 as a Government Special Purpose Vehicle (SPV) intended 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. The company commenced its operations in 2009. The creation of GDC was based on the government's policy on Energy as clearly articulated in Sessional Paper No. 4 of 2004, and the Energy Act No.12 of 2006 which unbundled the key players in the electricity sector to ensure efficiency. GDC is established as a limited company owned by the government of Kenya with the National Treasury and Ministry of Energy and Petroleum as the shareholders.

OrPower 4 Inc., a subsidiary of the Ormat Technology operates a Geothermal Power Station on the South western slopes of Olkaria hill through a 20 years Power Purchase Agreement (PPA) with KPLC. The Olkaria III geothermal resource occurs partly within Hell's Gate National Park (gazetted in 1984), and partly in Maiella - Ngati and Kongoni farms. It falls within the zone gazetted as a geothermal resource area in 1971. The company recently commissioned its 5th generator, hence achieving a total installed capacity of 139.6 MW. Other than OrPower 4 Incl., other licensed Independent Power Producers (IPP) include; WalAM Geopower Inc. (IPP) for exploration and development of Suswa geothermal field, AGIL (IPP) for exploration and development of Mt Longonot geothermal field, Olsuswa (IPP) for exploration and development of Barrier field and Marine Power Generation (IPP) for exploration and development of Akiira geothermal field.

5. BARRIERS TO GEOTHERMAL DEVELOPMENT AND THEIR REMEDIES

Geothermal resource, like many other renewable source of energy, has its own challenges. These challenges range from environmental and social, policy and legislative, technological and financial (Malafeh and Sharp, 2014). The challenges tend to slow down the utilization of geothermal resources. Kenya has also faced these challenges in its strides for geothermal energy resource development.

5.1 Financial challenges

Exploration, appraisal and production drilling in geothermal development requires large up-front financial investment and the long-term investment returns. This has been a great challenge considering Kenya's low income economy. Geoscientific surface studies and exploratory drilling funding is done by the government while appraisal drilling is funded by the government and partially by private sector. The huge capital investment required has resulted in overreliance to donor funding. With such overreliance, the speed of geothermal resource development in Kenya has relied on the availability of donor funds. For instance, the withdrawal of donor funding in the 1990's saw considerable slowdown of geothermal activities in Kenya as captured in the introductory part of this report.

However, the Government of Kenya has put forth measures to curb these financial challenges. Research and Development fund has been set aside to facilitate research in geothermal industry. Revenue generating activities, for example, offering consultancy services to private geothermal companies and other countries and steam sales have been adopted by KenGen and GDC. Adoption of policies like retention of the differential in interest on on-lent funds from the government, risk credit fund and utilization of the fuel levy fund for geothermal development has created the platform for raising revenue. Grants from research proposals written by geothermal development companies have also been used to raise funds for exploration. Moreover, the government has sort to raise funds through offloading its share in KenGen and offering competitive bidding to local and international private and public institutions. Carbon credit and wellhead units also provide cash stream to expand geothermal development.

5.2 Technological and human capacity challenges

During the early times of geothermal development, Kenya lacked the required expertise to handle this new technology. Inadequate human capacity slowed down geothermal development. This was compounded by the overreliance on foreign experts which raised the cost of development. Technological challenges negatively affected geothermal development. A reduction in drawdown pressure resulted in the decline of the early drilled production wells. Low capacity drilling rigs which couldn't drill to greater depths (i.e. 2000+ m) hence leaving much of the resource untapped. Technological challenges like the low capacity rigs have been addressed through purchase of high capacity rigs with the ability to drill deeper wells (3000+ m). Modeling of re-injection plan has aided in stabilizing the reservoir drawdown pressure as well as the well output. The government has taken great effort in capacity building through sending engineers and scientist to geothermally advanced countries like Iceland, New Zealand and USA.

Experts have also been brought in the country to offer training using the local geothermal resources. This has enhanced in-house expertise. KenGen and GDC in conjunction with United Nations Environmental Program (UNEP) are in the process of jointly setting up a geothermal training school (popularly referred to as Africa Geothermal Centre of Excellence) to train both local and international geothermists.

5.3 Environmental and socioeconomic challenges

Kenya's geothermal resources, like most of the geothermal resources, are located in remote scenic, wild and protected areas. The key socioeconomic impact associated with developing these resources include opening up of these areas, loss of wildlife habitat and visual intrusion in scenic tourist areas. Communities living within these areas also have to be displaced due to unconducive environmental conditions that come with geothermal power development. For example, Olkaria geothermal field is located in Hells Gate national park. Development of this field has led to great loss of the Hells Gate national park. However, there are also social benefits associated with this development to the local community.

Socioeconomic challenges have been dealt with through enacting set international environmental policies that addresses such challenges. The Environmental Impact Assessment (EIA) regulations policy, National and donor emission standards for air, noise and water quality requirements, Local and international legislation in relation to biodiversity conservation, national and international policy on resettlement/relocation and compensation are among the legislation adopted by the Kenyan government to address these challenges. Geothermal development companies have environment sections which deals with rehabilitation and restoration of the affected habitat. Unlike in the past, KenGen has set up Social Corporate Responsibility (CSR) programs which provide social amenities for example, schools, hospitals and animal watering points for the local communities, like in the case of Olkaria.

5.4 Legislative and policy challenges

Before 1998, electricity generation and distribution was tasked to Kenya Power Company (KPC). KPC was a state owned corporation under the Ministry of Energy. This made the development of geothermal resource a solely government affair. Owing to the limited government resources, this monopoly considerably slowed down geothermal development. The government set up on a fundamental reform process within the energy sector in 1996. A policy paper on economic reforms set out the governments intentions to separate the regulatory and commercialise 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 Electricity Regulatory Board (ERB). This rationalization and unbundling redefined the scope of Kenya Power and Lighting Company (formerly known as KPC) such that it was limited to transmission and distribution of electricity.

KenGen was formed through an act of parliament enacted in 1996. It was established in 1997 and its mandate was to generate electricity. This 1996 act also opened up for Independent Power Producers (IPPs) to enter electricity generation industry. Formation of the state owned Geothermal Development Company (GDC) through an act of parliament in 2008 enhanced geothermal exploration. GDC was mandated with exploration of geothermal resources before handing them over to KenGen or other private developers for development. The government is to source for the exploration funds.

6. FUTURE DEVELOPMENT PLANS

To meet the growing energy demand, alongside mitigating environmental degradation, development of geothermal resource must be prioritized. The government, together with state owned electricity generating companies have put in place measures that will help in realizing this. The 2nd optimization studies done in Olkaria between 2011 and 2015 indicated the capability of Olkaria geothermal field to support extra 560 MWe power generation. This resulted in more drilling at Olkaria to acquire steam for the development of Olkaria IAU6, Olkaria V, VI & VII power plants. Olkaria IAU6 is expected to generate 70 MWe while the rest 140 MWe each. EXIM bank financed drilling of 89 wells which form part of the wells to supply steam to these power plants. Some of these plans are well documented in Omenda (2014).

More of the future plans include:

- Enhancing the public-private partnership. Steps have been taken by the government to attract greater private investment. The formation of GDC to undertake geothermal well exploration and drilling then lease out steam to IPPs is one of such measures.
- The recently enacted mining act sets up the maximum period a lease can be held with no geothermal exploration or development work going on. This will open up geothermal prospects to able investors who are otherwise locked out by lease holders who lack the financial capability of developing these prospects.
- The plans to set up a Centre of Excellence in the country is aimed at enhancing local capacity building.

7. FINANCING OF GEOTHERMAL PROJECTS IN KENYA

Contradictory as it may appear, it is true that in financing of projects, money is not the main problem. There is a lot of money chasing after very few promising projects. The issue is mainly whether the projects are bankable. Both investors and financiers put their resources into a project with the hope of recovering their investment at a profit over the life of the investment. Geothermal projects have long economic life of at least 20 years and typically 25 to 30 years with payback period of about 10 to 15 years. Geothermal development in Kenya has relied on various sources of funds in financing geothermal projects. The sources include Government Financing, Multilateral Development Banks, Bilateral Development Banks, Special Purpose Financing, Commercial Banks and Private Equity.

7.1 Government financing

Kenya Government financing plays a very crucial role to open up and prepare project for financing by other entities. Resource exploration and appraisal are most difficult development phases to be financed by other parties as the phases bear the highest risk exposure. Kenyan experience shows that multilateral, bilateral, private entities are unwilling to invest in these phases.

The Kenyan Government has assumed high upfront risk of exploration and appraisal and is now providing financing for these development phases. These phases are being financing through taxes, ordinary and infrastructure bonds.

7.2 Multilateral development banks

World Bank through its various entities and the European Investment Bank (EIB) are the two multilateral development banks at the international arena. The International Development Agency (IDA) arm of the World Bank is aimed at financing credit to low income countries. International Bank for Reconstruction and Development (IBRD) serve the middle-income and creditworthy poorer countries' market while International Finance Corporation (IFC) serve the private sector. There exist also regional multilateral development banks that include African Development Bank for African region, Asian Development Bank for Asia region and Inter-American Development Bank (IDB) for the American region. Geothermal development has greatly benefited from this institutions.

7.3 Bilateral development agencies

Besides the multilateral financing institutions, there are many bilateral development financing institutions that both specialize with funding governments and often times, private organizations. In Kenya, Japan International Cooperation Agency (JICA), Agency for French Development (AFD), KfW of Germany, China Export-Import Bank and United States Export-Import Bank are active in financing geothermal development through the Kenyan government. In addition, Japan Bank of International Cooperation (JBIC), PROPACO of France, DEG of Germany and United States Export-Import Bank are actively involved in financing private sector projects.

7.4 Special purpose finance (green funds)

With the advent of realities of global warming, many bilateral, multilaterals and other financing institutions are increasing engaging in green projects. Various funds exist including clean development mechanism (CDM) and scale-up renewable energy program (SREP) for Low Income Countries. KenGen has been a great beneficiary of this project. Olkaria II power plants earns KenGen carbon credits as a result of mitigating against release of non-condensable gases into the atmosphere.

7.5 Commercial banks

Kenya has a dynamic banking sector comprising of both local and foreign banks totalling to a number of 39. In the energy sector, the banks have been engaged in syndicating for financing as wells being avenues for mobilizing capital for bonds and share. The banks have in recent times been intermediaries for overseas institutions seeking to fund green energy projects within the private sector. Early power generation using modular units that Kenya is popularizing among the local private entities will see the local banks playing a greater role.

7.6 Private equity

The Government recognizes that it will be impossible to finance the Vision without the participation of both the public and the private investors. The Government has given a mandate to facilitate entry of IPP into the geothermal sector by accelerating resource exploration and appraisal. This is well explained under ‘Other players in geothermal sector’. The entry of the IPP will be through international competitive bidding.

8. CONCLUSION

Geothermal power has proved to be cheap and reliable source of energy to the Kenyan power consumer. Development of geothermal power has seen a reduction in the price of electricity. Some of the benefits of geothermal energy include:

- Reduction in the cost of power through shutting down diesel generators.
- Creation of employment opportunities with geothermal sector employing more than 10000 people directly and indirectly.
- Regional development of the communities around the geothermal areas.
- Reduction in emission of greenhouse gases that could have been emitted through burning of fossil fuel.

There is great focus on geothermal development by both the Kenyan government and private sector. The government aims at having more than 50% of power supply coming from geothermal by the year 2025.

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