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GEOTHERMAL POTENTIAL IN EAST AFRICA – HOW TO REALISE IT

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ABSTRACT

The East Africa Rift System is an example of a continental rift system associated with the world-wide mid ocean rift systems. It is divided into two rift systems; the Eastern and Western branch. The Eastern branch straddles southwards from Afar triple junction through Ethiopian highlands, Kenya, Tanzania and Malawi to Beira, Mozambique in the south. The western branch transects through Uganda, DRC and Rwanda while the nascent south-western branch runs through Luangwa and Kariba rifts in Zambia into Botswana. The volcanic and tectonic activity in the rift started about 30-45 Ma ago and in the eastern branch the activity involved faulting and eruption of large volumes of mafic and silicic lavas and pyroclastics. The western branch, typified by paucity of volcanism, is younger (12 Ma) and dominated by faulting that has created deep basins currently filled with lakes and sediments. Geothermal activity in the rift is manifested by the occurrences of Quaternary volcanoes, hotsprings, fumaroles, boiling pools, hot and steaming grounds, geysers and sulphur deposits. The manifestations are abundant and stronger in the eastern branch that encompasses Afar, Ethiopian and Kenya rifts while in the western branch, the activity is subdued and occurs largely as hotsprings and fumaroles. Detailed studies of geothermal potential in Eastern Africa indicate that the region has potential > 10,000 MWe. Geothermal exploration in East Africa began in 1952 in Kenya, 1969 in Ethiopia, early 1970's for Uganda and 1949 for Tanzania. The estimated geothermal potential in the East Africa Rifts system is over 10,000 MW. Currently, Kenya is at an advanced stage of geothermal development with the generation of about 692 MWe. On the other hand, Ethiopia has an installed capacity of 7.28 MWe, while Tanzania, Uganda, Eritrea, Rwanda, Zambia, Malawi, and Djibouti are still either in exploration or drilling stage. To accelerate and realise the full geothermal potential of the East Africa region, there is no doubt that adequate measures need to be put in place by the respective governments.

1. INTRODUCTION

The East African Rift System (EARS) is considered as the classical example of the continental rift system which is part of the Afro-Arabian extending from the Red Sea to Mozambique in the south. The evolution of the EARS is believed to be structurally controlled (Achauer and Mason, 2002) by exploitation of the weak collisional zones at the contact between the Proterozoic oregenic belts and the Archean Tanzanian Craton by the rift faults. Evolution of the rift dates back 30-45 Ma (Ring, 2014).

As the rift extends from the Ethiopian segment southwards it bifurcates at about 5°N into the Eastern and Western branches (Figure 1). The two branches are endowed with vast high temperature geothermal resources. The Eastern branch that comprises the Ethiopian and Kenya rifts is older and relatively more volcanically active. By contrast, the Western branch that comprises the Albert-Tanganyika-Rukwa-Malawi rifts is considered younger and less volcanically active.

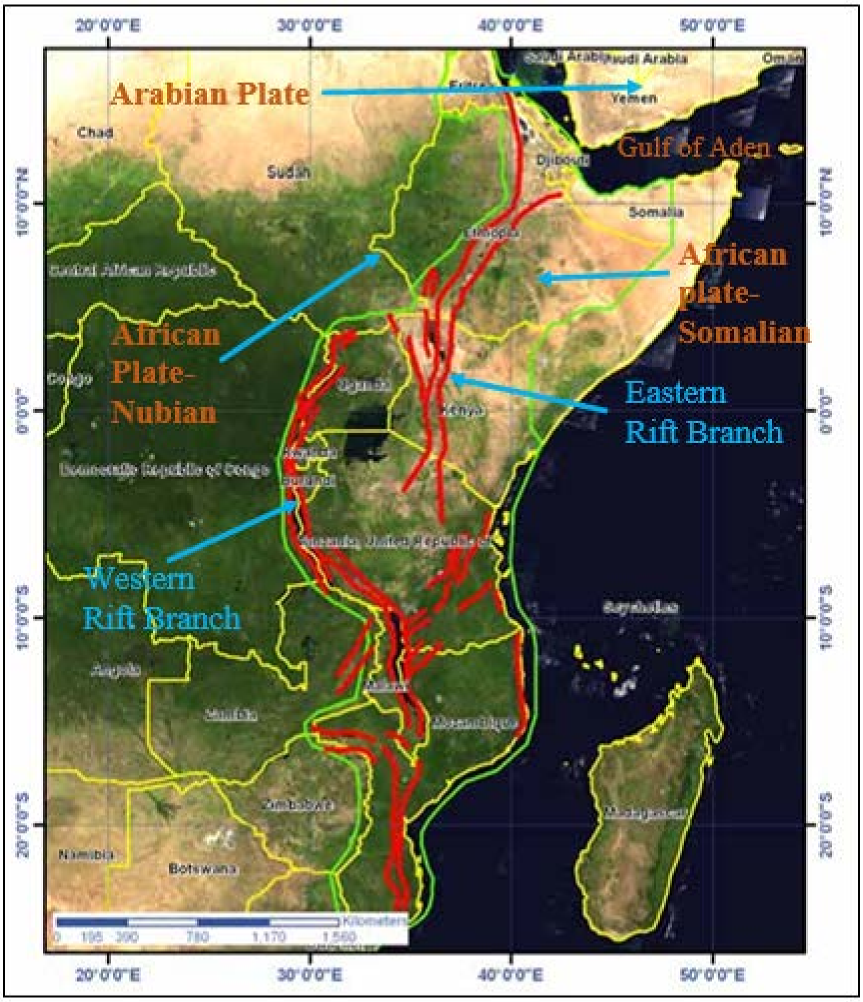

FIGURE 1: Location of the EARS showing the Eastern and Western branches. Also shown are the various micro-plates. Modified from (Chorowicz, 2005).

Smith and Mosley (1993) suggested that rift tectonism, intense volcanism and episodes of faulting associated with the formation of the EARS is culpable for the formation of the numerous central volcanoes of Quaternary age. The latter are particularly pronounced on the Eastern branch of the EARS. The shield volcanoes are built predominantly of intermediate and the associated pyroclastic products, hence signifying presence of shallow hot bodies underneath (magma chambers). Domal uplift and extension has caused the brittle crust to fracture into a series of normal faults giving the classic horst and graben structure of the rift (Chorowicz, 2005). The Western branch, on the other hand is characterized by paucity of volcanism along the entire stretch of the rift with notable volcanic areas being Virunga and Rungwe. Hydrothermal activity in the EARS is manifested in the form of hot and altered grounds, fumaroles, hot springs, mud pools, geysers, silica sinters, etc. and are closely associated with the Quaternary volcanoes in the rift axis. The association can be related to shallow hot magmatic bodies under the massifs, which are interpreted to be the heat sources.

Despite the enormous potential of geothermal resources in the EARS capable of generating > 10,000 MW most of the resources remain largely untapped. Only Kenya and Ethiopia have active geothermal generation of 692 MWe and 7.2 MWe, respectively. Varying degrees of geothermal exploration and research have been undertaken in Djibouti, Eritrea, Uganda, Tanzania, Rwanda, Zambia and Malawi. According to Omenda (2007) the potential to use grid-connected electrification is greatest in Kenya, Djibouti, Ethiopia, Uganda and Tanzania. However, all the countries have the potential to use geothermal energy for grid connected electrification.

2. GEOTHERMAL ACTIVITY OF THE EAST AFRICAN RIFT

2.1 General information

East African rift system (EARS) is a succession of rift valleys that extend from Beira in Mozambique in the south to Afar triangle in the north; a total distance of more than 4,000-km (Chorowicz, 2005). The EARS is a continental branch of the worldwide mid ocean rift system that corresponds to the third arm of the Afar-Red Sea – Gulf of Aden triple junction. The rift is assumed to mark the incipient plate boundary between the Somali and Nubian micro-plates and linked to the Afar- Red Sea – Gulf of Aden rift systems (Figure 2). The EARS splits into two at about 5°N to form the Eastern and Western branches. As mentioned earlier, the Eastern branch comprises the Afar, Ethiopian, Turkana and Kenya Rifts while the western branch comprises Albert, Kivu, Tanganyika, Rukwa and Malawi Rifts. The SW branch comprises Luangwa-Kariba-Okavango rifts.

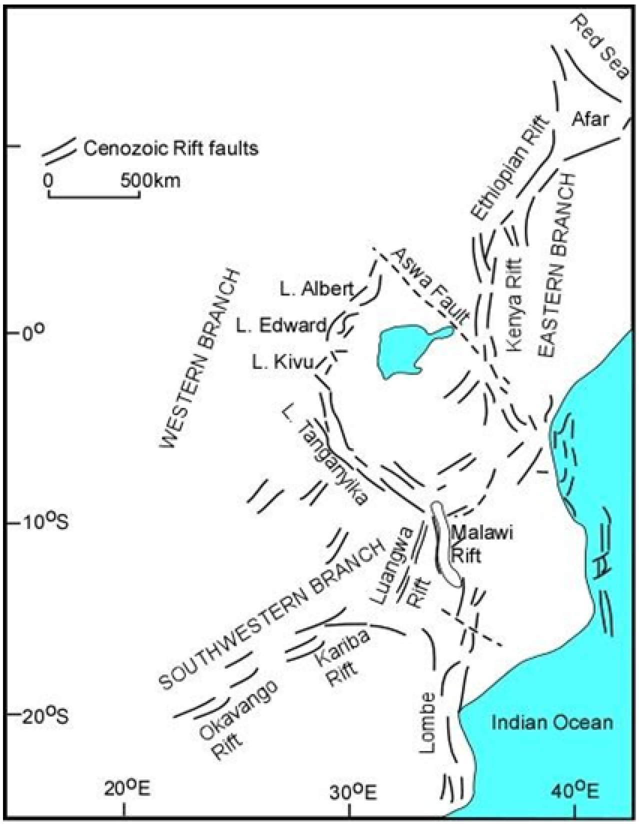

FIGURE 2: Structural map showing the East African Rift System. Modified from (Atekwana et al., 2004).

During the inception of the EARS, overstretched zone of weakness opens up along pre-existing faults and basalt intrudes into them at depth (dyking). Fissure eruptions may occur depending of magma supply. The caldera (central) volcanoes of the rift are underlain by crustal magma chambers during some stages of their active periods. They erupt silicic magma when overpressure breaks their roof – either as large volume pyroclastics or smaller volume domes and flows. A variety of central volcanic activity is long lasting eruptions or lava lake activity of basaltic lava at their central crater. Spreading slows down from north to south from more than 2 cm/yr in the Red Sea to about 1 mm/yr in the Main Ethiopian Rift and further less than 1 mm/yr combined in the Western and Eastern Rifts across the Kenya Dome and gradually decreasing from there to the south (Ring, 2014). For comparison: North-Atlantic has a spreading rate of 2.3 cm/yr and Iceland 1 cm/yr. Those are half-rates. In response to the increased extension in the EARS, the Moho is at between 5 and 35 km along the rift axis (Omenda, 2007).

2.2 Geothermal potential of the Eastern branch

2.2.1 Geothermal potential in Ethiopia

Geothermal resources in Ethiopia are widespread in the Main Ethiopian Rift (MER) and Afar Rift (Figure 3). The latter is the most active segment of the entire EARS with Erta Ale volcano being presently active (last eruption in 2006). Surface geothermal expressions include steaming grounds, hot springs, altered grounds, fumaroles, most of which are associated with young volcanic fields in the rift valley. The heat sources for the geothermal systems are related to shallow magma chambers associated with young rhyolitic volcanoes and upper mantle intrusion/upwelling associated with the thin crust (averaging 5-20 km). Geothermal exploration in Ethiopia started in 1969. The geothermal potential of the Ethiopian rift has been estimated to be between 4,200-10,800 MWe. Over the years a good inventory of the possible resource areas has been built up and a number of the more important sites have been explored in the Ethiopian Rift Valley. Out of the 120 geothermal prospects within the Ethiopian rift system, about 16 have been judged to have potential for high temperature steam suitable for conventional electricity generation (Kebede, 2016).

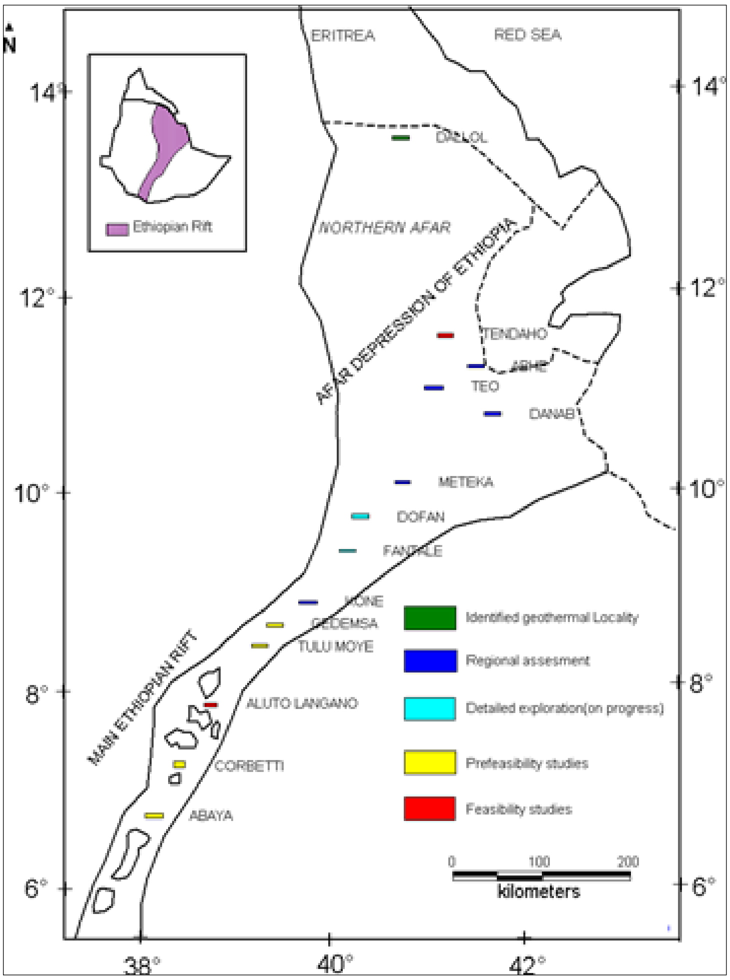

FIGURE 3: Location of geothermal prospects in Ethiopia

The remaining prospects have potential for diverse direct use applications ranging from agricultural, industrial, mineral extraction, recreation, amongst others. Earlie exploration activities from south to north covered prospects such as Abaya, Corbetti, Aluto-Langano, Tulu Moye and Tendaho. Exploration work peaked in 1980's culminating to the drilling of 8 exploratory wells to a depth of about 2500 m in Aluto-Langano prospect. Of the 8 wells, 5 were productive with maximum bottom-hole temperatures of about 350°C.

During the early 1990s exploration drilling was also carried out at Tendaho (Northern Afar) where three deep (2100 m) and three shallow wells (500 m) confirmed the existence of a high temperature (270ºC) reservoir (Kebede, 2016). The Aluto-Langano geothermal field was handed over to the Ethiopian Electric Power Company (EEPCo) for development in the year 1996 but utilization was delayed until 1998 when the first 7.2 MWe pilot power plant was built. Apart from the Aluto-Langano field, there are also various exploration works going on in other prospects. Some of these prospects include Doubti, Alallobeda and Ayrobera which fall under the Tendaho prospect. Surface exploration at Doubti and Ayrobera has been finalised and analysis completed. This was conducted under the framework of ARGeo project. As regards to future geothermal development plans, the Ethiopian government has put in place both medium- and long-term plans. The former targets to have about 675 MWe of geothermal power on the grid by 2025, whereas, the latter aims to have 5000 MWe by 2037 (Kebede, 2016).

2.2.2 Geothermal potential in Djibouti

Djibouti lies at the Afar triple junction of three active, major coastal spreading centres: (a) The Eastern Africa Rift zone; (b) The Gulf of Aden Rift; and (c) and the Red sea Rift (Figures 1 and 2). In Djibouti, areas of strong manifestations are located within the Asal and Hanle rifts in the Afar Depression (Mohamed, 2003). According to a recent study by the Geothermal Energy Association (GEA, 1999), the geothermal potential in Djibouti is between 230-860 MWe from a number of prospects including: Lake Abbe, Hanle, Gaggade, Arta, Tadjourah, Obock and Dorra. Much effort has been expended in Djibouti since the 1970's, in view of the country being deficient of indigenous energy resources. Djibouti's current energy production is by fossil fuels. The first concerted effort to assess and explore Djibouti's geothermal resources took place in the Assal area from 1970-83 and funded by the French government. About six exploratory wells were drilled in the Assal geothermal fields.

While a very high temperature system has been successfully located, problems related to high salinity of the discovered fluids, which is due to the close proximity of the field to the Gulf of Aden, has delayed resource development and exploitation (Teklemariam and Beyene, 2005). The high salinity of the fluids would impose serious challenges in the utilization of the field. In 2015, the Geologica Geothermal Group Inc., (GGG) and its consortium of geothermal industry experts were selected by Electricité de Djibouti (EDD) to review historic well information, regional geology, geophysics and geochemistry and propose drilling targets for four exploration wells. The objective of the proposed exploration drilling is to prove a commercial geothermal resource capable of supporting a 20-50 MW electric power generation project for 30 years. The review has seen the successful drilling of well Fiale-1 in the Fiale caldera between August and October, 2018. Drilling of well Fiale-2 commenced on 15th October, 2018 and is still in progress.

2.2.3 Geothermal potential in Eritrea

Eritrea is characterised by two main geothermal prospects, namely Alid (Figure 4) and Nabbro-Dubbi. The two prospects are both located within the Danakil depression, the structural axis connecting the EARS and the Red Sea. In 1973, the United Nations Development Programme (UNDP) sponsored a reconnaissance survey study which was carried out by the Geological Society of Ethiopia. The study surveyed thermal springs along the Asmara-Massawa road and identified potentially significant exploitable geothermal resources in Eritrea. In 1995 with the help of the United States Geological Survey (USGS), Eritrea identified the Alid geothermal prospect, located approximately 120 km south of Massawa for follow up detailed investigations. Alid volcanic centre is the best studied of all geothermal areas in Eritrea. The geothermal prospect is characterized by a rhyolitic domal intrusion which is considered to be the main heat source for the geothermal system. Manifestations occur in the form of boiling pools, hot springs, and fumaroles (Woldegiorgis et al., 2003). Detailed geoscientific investigations revealed a reservoir temperature of about 250° C.

FIGURE 4: Map showing Alid geothermal prospect in Eritrea

2.2.4 Geothermal potential in Kenya

Kenya has more than thirteen geothermal prospects located within the Kenya Rift System (KRS). The latter expends from Lake Turkana in the north to Lake Magadi in the south, and continues all the way to northern Tanzania. The entire length of the Kenya rift from Lake Turkana in the north to northern Tanzania has young volcanoes dominantly of silicic composition in its axis. The youthfulness of the volcanoes attests to active magmatism under the rift. Similarly, geothermal manifestations are more abundant and stronger within the rift and in many cases they are associated with the young Quaternary volcanoes (Figure 5). Three geothermal fields, namely Olkaria, Eburru and Menengai have successfully been identified within the KRS. Studies carried out in these prospects and fields indicate a geothermal resource potential > 10,000 MWe.

Geothermal manifestations in the Kenya rift include fumaroles, hot springs, spouting springs, hot and altered grounds and solfatara (sulphur deposits). The occurrence of fumaroles is common on the mountains while hot springs and geysers are common on the lowlands. Sulphur deposits have been observed at several geothermal areas including Olkaria, Paka and Barrier volcanoes where it is indicative of the presence of a degassing magma body at depth. Extinct manifestations in the form of travertine deposits, silica veins and chloritized zones are common in the Lakes Baringo – Bogoria regions indicating long-lived geothermal activity in the rift.

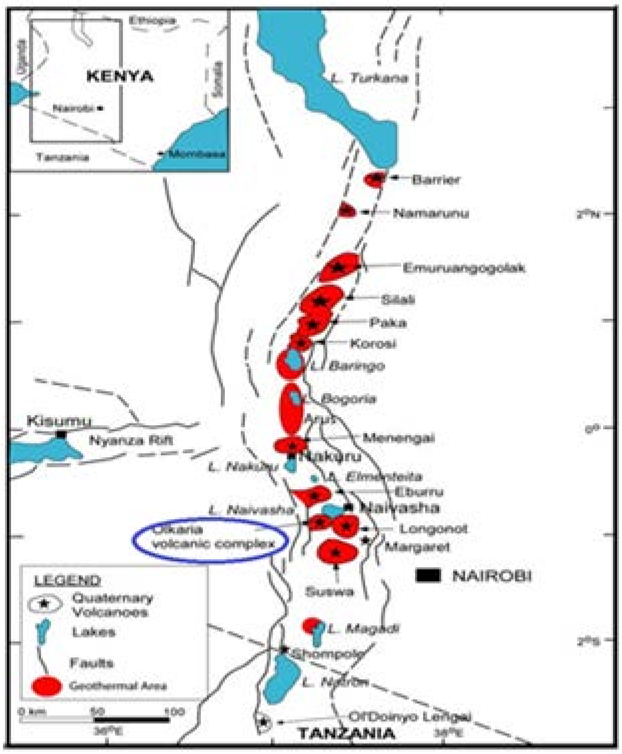

FIGURE 5: Map of the Kenya Rift System showing the geothermal prospects

Kenya is the first country in Africa to develop commercial geothermal energy uutilisation. Geothermal development in Kenya began in 1952. It began with surface exploration which was carried out within the Kenyan Rift valley between 1952 and 1956. The exploration activities were mainly geological and geophysical (KPLC, 1992) and were done by a consortium of companies which included the East Africa Power & Lighting Company Ltd, Power Securities Corporation Ltd, Association Electrical Industries Export Ltd, and Babock and Wilcox Ltd. The exploration findings indicated geothermal resource potential within the rift valley with greater potential at the central Kenyan rift, particularly Olkaria. Presently, the Olkaria geothermal field generates an aggregate capacity of about 692 MWe from three players namely, KenGen PLC, Orpower 4 and Oserian Development Company (ODC). In addition, the geothermal field has about 30 MWt installed capacity for direct utilisation, mainly for heating flower farms and bathing in the Olkaria geothermal spa. Eburru geothermal field, located approximately 40 km north of Olkaria produces 2.4 MWe from a modular power plant. Production drilling in Menengai geothermal field has proved steam equivalent to about 135 MWe. Three Independent Power Producers (IPPs) have been contracted to generate 105 MWe, with each IPP expected to produce 35 MWe. The remaining prospects have either undergone detailed exploration with exploratory wells sited or plans are underway to conduct surface exploration studies.

2.3 Geothermal potential of the Western branch

The western branch extends over a distance of about 2100 km from Lake Albert in the north, to Lake Malawi in the south (Figure 6). The rift bisects the western side of Lake Victoria and along the edge of East African Plateau (Ebinger, 1989). Despite the western branch being characterised by subordinate volcanism in relation to the Kenyan and Ethiopian rifts, geothermal activity is still evident in many localities. Whereas, the volcanism and tectonic activity in eastern branch commenced about 30-45 Ma ago in the eastern branch of the rift, it has generally been argued that volcanic activity in the western branch is relatively young and commenced about 12 Ma in the north near Lake Albert and about 7 Ma in the Tanganyika rift (Ebinger, 1989). The Western Rift of deep lakes and few volcanoes bends about the eastern edge of the Kenya dome from Uganda to Tanzania continuing south to Malawi. The floor of that rift is filled with sediments (which contain hydrocarbons) and lakes, elongate in shape, occupying depressions up to 4.5 km deep (Tanganyika, lake depth over 1400 m) (Ebinger, 1989).

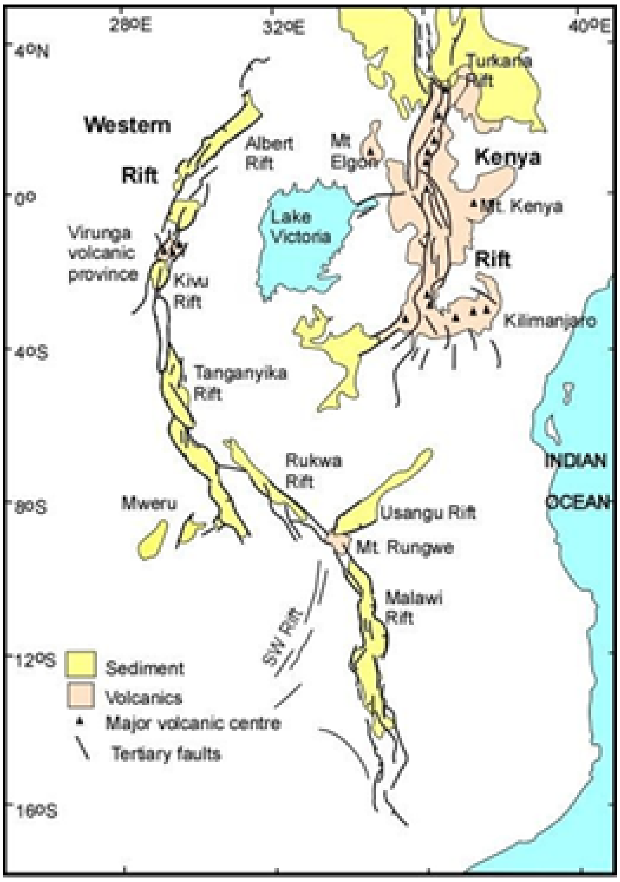

FIGURE 6: Map showing the structural relationship between the Eastern (Kenya) and the Western branch of the EARS

According to Omenda (2007) the western branch is characterized by the abundance of potassic alkaline rocks that consists of carbonatites, ultra-potassic mafic rocks and potassic mafic-felsic lava. Volcanic activity is more intense in the Virunga volcanic field where, Africa's most active volcanoes namely; Nyiragongo and Nyamuragira in the DR Congo erupt basaltic lavas.

Geothermal manifestations in the Tanganyika-Rukwa-Malawi Rift comprise hot springs and fumaroles at temperatures of up to 86 °C have been observed in Mbeya. The fumaroles are closely associated with the Quaternary Rungwe volcanic field (Roberts et al, 2012). The area is also characterized by high seismicity signifying that the area is still tectonically and magmatically active. Other hot springs occurring in Malawi, Zambia and Mozambique are predominantly fault controlled and are associated with the border faults (Roberts et al., 2012). The hotsprings are probably due to deep circulation of ground waters through the rift structures.

2.3.1 Geothermal potential in Uganda

In Uganda, the geothermal energy potential has been estimated at about 1500 MWe (Bahati, 2016). Geothermal activity is restricted primarily to the areas within the western rift valley. The three key geothermal prospects are Kibiro, Buranga and Katwe-Kikorongo (Figure 7). Kibiro and Buranga are characterised by fault-controlled manifestations and are located at the foot of Ruwenzori massif and Lake Albert, respectively. Additionally, geothermal manifestations at Buranga discharge at boiling point. Travertine deposits have also been noted in several localities within the geothermal prospect (Bahati, 2003). Hot springs have been observed in Katwe-Kikorongo and Virunga volcanic field, where their occurrence has been attributed to the to the young volcanoes. According to Bahati and Tuhumire (2002) geothermal manifestations located outside the western rift in Uganda are characterised by lower surface temperatures (30-60°C).

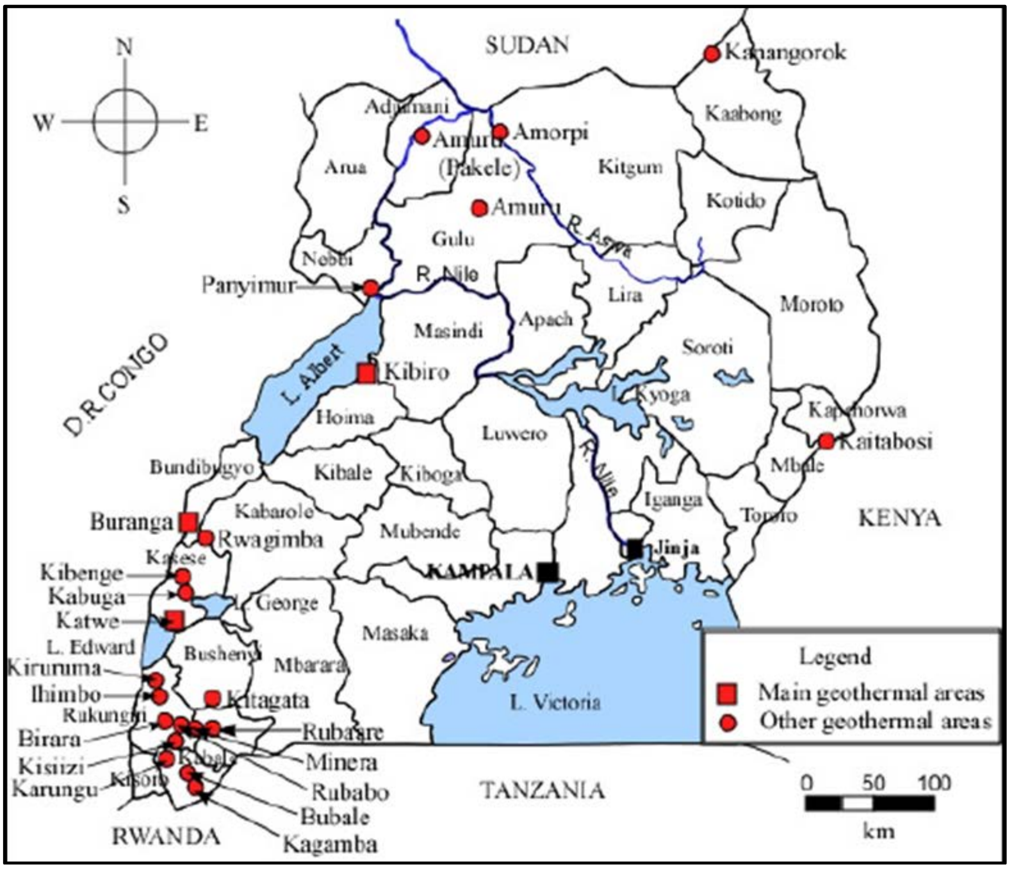

FIGURE 7: Map of Uganda showing the geothermal prospects

2.3.2 Geothermal potential in Tanzania

The geothermal potential in the United Republic of Tanzania has been estimated at about 500 MWe (Mnjokava, 2015). This value has been derived from the natural heat flow discharge from hot springs and is based on integrated geoscientific techniques without test drilling. Geothermal prospects are mostly located in the Gregory (southern extension of the Kenya rift) and Albert (Western) arms of the Great East African Rift Valley (Figure 8). The volcanic provinces of Kilimanjaro and Meru, located in Northern Tanzania close to the border with Kenya are associated with the Eastern arm. The volcanic province of Rungwe is associated with the triple junction (Rukwa, Ruaha and Lake Nyasa rift branches) in the south western Tanzania, near the border with Malawi and Zambia (Mnjokava, 2015). In the Western arm, hot springs have been encountered in Mtagata in Karagwe, Uvinza in Kigoma and Majimoto in Mpanda near the border with DRC and Zambia. Other low temperature manifestations occur in central and south east Tanzania in Singida and Rufiji areas.

Surface exploration studies began in Tanzania in 1949. This went into a lull until 1970's when there was a shift to geothermal after the oil crisis. Between 1976 and 1979, the Swedish Consultant Group SWECO, in cooperation with VIRKIR, Iceland carried out detailed exploration studies in northern Tanzania and Mbeya region. The study was able to establish hot springs measuring about 86°C. This project was funded by the Swedish International Development Agency (SIDA). Based on these studies, SWECO recommended further studies in Mbeya region, Ngorongoro and Manyara. These studies indicated a possibility of the presence of a high, intermediate and low temperature reservoir in northern and southern Tanzania, respectively.

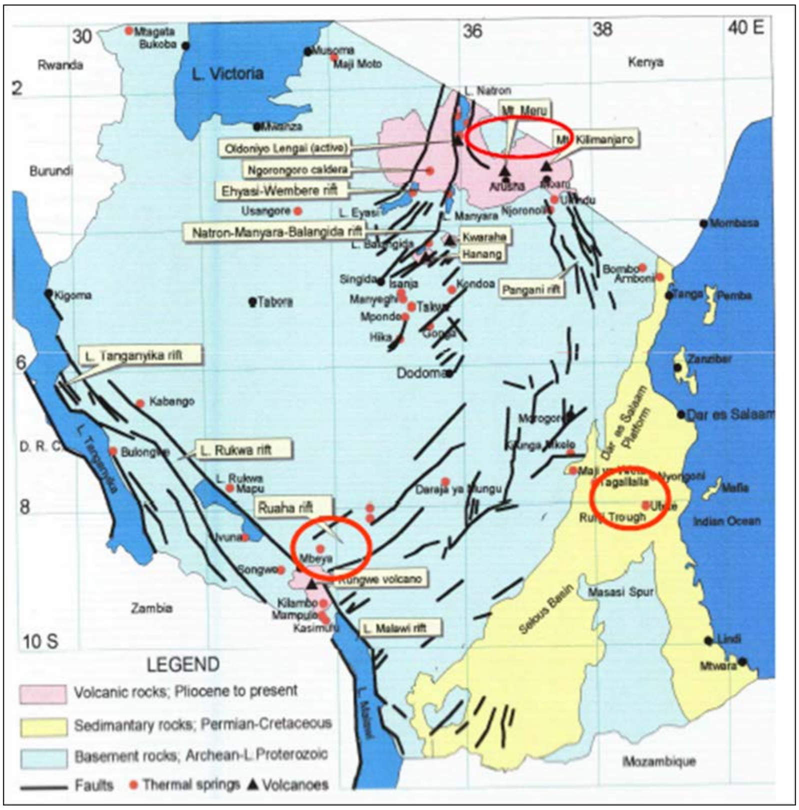

FIGURE 8: Map of Tanzania showing the geothermal areas

2.3.2 Geothermal potential in Rwanda

Geothermal prospects in Rwanda are located along the western border of the Western branch of the Great East African Rift Valley. The prospects include; Gisenyi, Karisimbi, Kinigi and Mashyuza (Figure 9). The geothermal potential of Rwanda has been estimated at between 170-300 MWe by the Geothermal Energy Associates (GEA, 1999). Hot springs, measuring between 54-74°C have been identified in Gisenyi and Mashyuza prospects (Rutagarama and Abdallah, 2007). In 2006, preliminary assessment was carried out in Gisenyi and Mashyuza by the American company Chevron. In 2009, KenGen acquired additional surface studies (geochemistry and geophysics) and carried out a baseline environmental impact assessment (EIA) on the southern slopes of the Karisimbi Volcano. Findings recommended drilling three exploration wells in the Karisimbi prospects (Mariita et al., 2010).

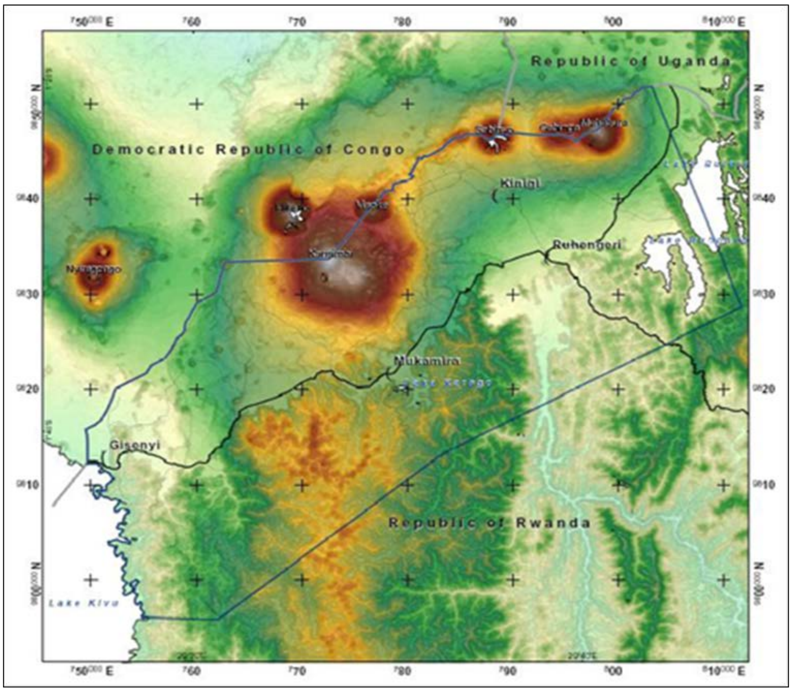

FIGURE 9: Map showing geothermal areas in Rwanda

In 2011, an additional geothermal survey was done by the Institute of Earth Science and Engineering (IESE) through Auckland UniServices, New Zealand aiming at developing a conceptual model for the entire western region and locating a site for exploration drilling in the three prospects, Karisimbi, Kinigi and Gisenyi (Shalev et al., 2012). Drilling of two exploration wells, i.e. KW-01 and KW-02 to a depth of 3003 m and 1367 m, respectively was carried out in the Karisimbi geothermal prospect in 2013. However, the wells did not show evidence of the existence of a geothermal system in the area. This led to the decision to halt drilling activities in March, 2014 and concentrate the focus in review of all the existing data in the geothermal sector to establish the gaps.

2.4 Geothermal potential of the south-western branch

The south-western branch of the western rift follows geological structures along mobile belts from Lake Tanganyika into southern DR Congo and Zambia then south-westward into the Okavango rift system in northwest Botswana (Omenda, 2007). The rift is amagmatic in its entire length, with faults oriented along the entire length of the rift. However, rift structures in the Okavango have been identified only through geophysical techniques (Atekwana et al., 2004). Geothermal activity in the form of low temperature springs occur in Zambia, southern DR Congo and Malawi. Deep circulation of the springs is through fault zones. Hot springs occur at Kapisya that discharge at 85°C near Lake Tanganyika and also near Lake Mweru.

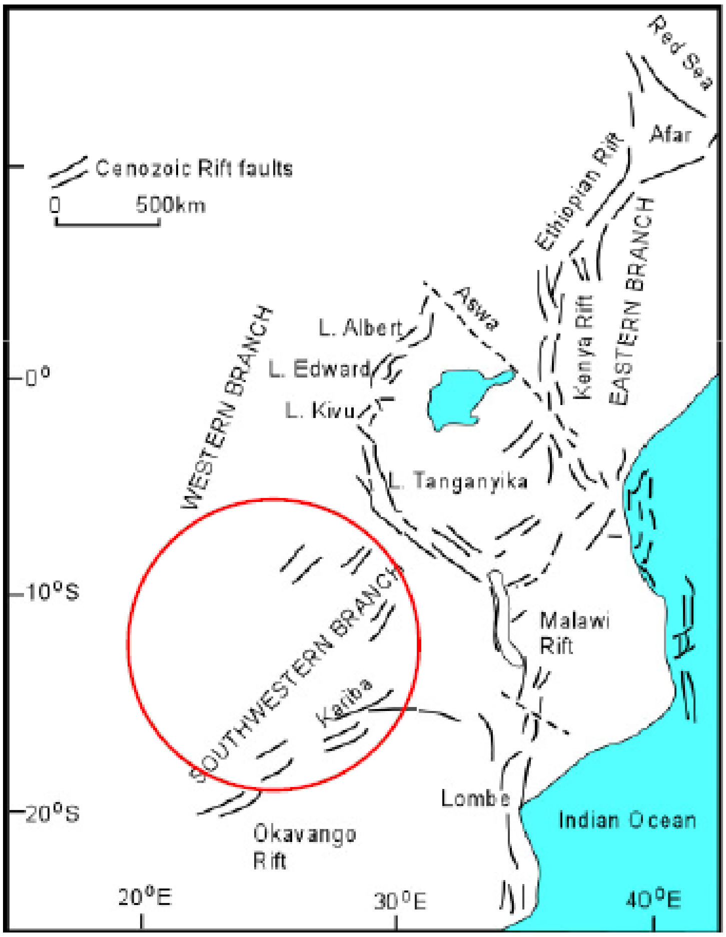

FIGURE 10: Map showing the location of the south-western branch of the Gregory East African Rift Valley

Other springs occur at Chinyunyu (60°C) near Lusaka (Atekwana et al., 2004). The Italian government in 1987 funded a mini geothermal pilot power plant (200 KW) at Kapisya hot springs located at the shores of Lake Tanganyika. The plant was installed on the basis of limited exploration work, and it never became operational (Omenda, 2007). In attempts to revive the power plant, ZESCO signed an MOU with KenGen to assist in refurbishing and commissioning of the plant after being idle for more than 20 years. As part of the agreement, KenGen and ZESCO carried out detailed scientific investigations at Kapisya and Chinyunyu which revealed that the geothermal systems follow the fault plane model where the heat is due to deep circulation along the rift structures. It was estimated that each of the prospects can generate up to 2 MWe using binary technology (Omenda, 2007).

3. BARRIERS TO GEOTHERMAL DEVELOPMENT IN THE REGION

3.1 Financial challenges

The initial phases of geothermal development are capital intensive and requires up-front financial investment. During Exploration, appraisal and production drilling, the project consumes money with no returns. The low-income economy of these countries makes it difficult for them to carry out these initial phases. In Kenya for instance, 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. Overreliance on donor funding considerably slows down the speed of geothermal development since it solely depends on the availability of this funds.

However, most of the countries have put forth measures curb these financial challenges. Countries like Kenya have set up Research and Development to facilitate research in geothermal industry. Other countries for example Uganda, Tanzania and Ethiopia have formulated legislation to fund geothermal exploration and development. In Kenya, KenGen and GDC have adopted revenue generating activities, for example, offering consultancy services to private geothermal companies and other countries. 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 by the Kenyan Government 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. Sale of Carbon Credits (CDM) from the clean Wellhead technology by KenGen has also helped the government raise finances to use for geothermal development.

3.2 Technological and human capacity challenges

During the early times of geothermal development, most countries lack the expertise needed in this field. The inadequate human capacity and technological challenges slows down geothermal development. Additionally, overreliance on foreign expertise raises the cost of development. For instance, the low capacity drilling rigs that were used to drill the early drilled wells in Olkaria, Kenya could only drill to a depth of 2000 m. These left a 1000 m depth of untapped resources. However, these challenges have been addressed through the purchase of high capacity rigs with the capacity to drill down to a depth of 3000 m as well as directional wells. The decline in drawdown pressure has been addressed by designing a re-injection model.

To address the inadequate human capacity challenges, the government has taken great effort in capacity building through sending engineers and scientist to geothermally advanced countries like Iceland, New Zealand and USA. Additionally, experts have also been brought in the country to offer training using the local geothermal resources. This has enhanced in-house expertise. Furthermore, plans are an advanced stage to set up the Africa Geothermal Centre of Excellence (AGCE) in Kenya to address the geothermal training needs for the East Africa countries. This Centre is being hosted by the Government of Kenya and coordinated by the Africa Union Commission with the UN Environment through ARGEO providing the technical backstopping. The AGCE will have campuses at KenGen and GDC. Currently, an Interim Project Coordination Unit has been set up at UN Environment that coordinates training under the auspices of AGCE until AGCE becomes fully operational.

3.3 Environmental and socio-economic challenges

Most of the world geothermal resources are located in remote scenic, wild and protected areas. Development of these resources means disruption of the wildlife habitat, opening up this areas and visual intrusion in scenic tourist areas. Moreover, communities living in this area have to be displaced to create room for the infrastructural development. For example, Olkaria geothermal field is located in Hells Gate national park.

To address the socio-economic challenges, environmental policies and legislation have been enacted. These policies are in line with the International Environmental laws. The Kenyan government, for instance has enacted 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 legislation to address these challenges. Geothermal development companies have also established environment sections which deals with rehabilitation and restoration of the affected habitat. KenGen and GDC have also set up Social Corporate Responsibility (CSR) programs which provide social amenities for example, support to schools, hospitals and animal watering points for the local communities, like in the case of Olkaria.

3.4 Legislative and policy challenges

Since mid-1990, the East African countries have initiated reforms in their energy sectors aimed at addressing legislative and policy challenges hamper the development of geothermal resources. Most of these reforms are addressed in the above write up. Before 1997, electricity generation and distribution were tasked to Kenya Power & Lighting Company (KPLC). The countries have formed companies or departments whose sole aim is to explore, drill and develop geothermal. For instance, KenGen was separated from Kenya Power & Lighting Company in 1997. It was tasked with the generation of power with main focus on geothermal. In 2008, GDC was formed and mandated with the exploration of geothermal resources before handing the field to KenGen or other private developers for geothermal development. TGDC was also formed in Tanzania in 2013. It was mandated to develop geothermal resources in Tanzania. Uganda has formed a Geothermal Development Department to handle all matters related to geothermal development in the country.

3.5 Institutional barriers

Institutional barriers arise as a result of general lack of direction within the government as regards to geothermal resources. Some government institutions are out of synchronization on geothermal issues. In certain cases, some concessions for virgin prospects are granted only after a lengthy approval process, long beyond the period stipulated in the geothermal laws. This usually causes delays in obtaining the respective licenses. It is instructive that many governments do not have laws and regulations governing geothermal development in their countries. As a result, a clear vision of the role that geothermal energy will play in every county’s future energy mix should be clearly outlined.

4. WAYS TO REALISE GEOTHERMAL POTENTIAL OF EAST AFRICA

Geothermal, despite being clean and renewable energy source, is faced by several challenges that hinder its development. Some of these challenges include; the high capital that cost associated with geothermal development, inadequate human resource capacity to develop and manage resource, lack of proper legislative and policy framework, among others. Various measures have been undertaken in Kenya and a few other countries in Africa to address these obstacles and increase the share of geothermal power in the energy mix in East Africa as outlined below.

4.1 Formulation of geothermal energy policy and legislative framework

Geothermal energy development requires clear policies and legal framework in order to break even with other conventional sources of power and increase investors interest in East African countries-initiated reforms in their energy sector starting mid-90s. For example, Kenya initiated reforms in 1996 that saw the unbundling of the power sector into the generation and transmission utility. This was further followed by more reforms in 2006 that opened doors for geothermal development to Independent Power Producers. Under these reforms, the IPPs are offered fixed and guaranteed price for generated electricity as stipulated under the Power Purchase Agreement entered between the IPP and the off-taker. Furthermore, to reduce the risk associated with exploration of geothermal resources, the government of Kenya formed Geothermal Development Company (GDC) in 2009.

GDC was formed and mandated with the exploration of geothermal resources before handing the field to KenGen or other private developers for geothermal development. Similar legislative changes have been adopted in Uganda, Tanzania and Ethiopia. In Tanzania, they have formed the Tanzania Geothermal Development Company to undertake similar assignments like Kenya's GDC. Ethiopia and Uganda have autonomous departments under their Ministries of Energy tasked with geothermal development. East African countries have also adopted the Renewable Portfolio Standards (RPS) policy for geothermal. This policy is designed to increase the contribution of geothermal energy to the energy mix. Under this policy, the government has set targets of the total amount of geothermal power expected to be on the grid after every set chosen number of years. Kenya developed the Least Cost Power Development Plan (LCPDP), reviewed after every 2 years and lately established the National Geothermal Strategy.

4.2 Strengthening of the African Rift Geothermal Facility (ARGeo)

The idea to form the Africa Rift Geothermal Facility (ARGeo) was born in 2003 in an East African Market conference organised by United Nations Environment Programme (UNEP), the Business Council for Sustainable Energy (BCSE), the US Trade and Development Agency and a number of other US agencies and international organizations in Nairobi in 2003 (Mwangi, 2009). This conference was informed by Kenya´s plans to accelerate development of geothermal resources and the growing interests in other African Rift countries to do so. The conference involved high ranking Ministry of Energy and Industry officials from Tanzania, Uganda, Eritrea, Djibouti, Ethiopia, Zambia, Malawi, Rwanda and Kenya as well as representatives from bilateral and multilateral organizations and private financing agencies.

The main aim was to explore commercial opportunities for geothermal development in the region and overcome financial, regulatory and institutional barriers. ARGeo became operational in 2005. Through ARGeo, funds have been availed through grants by various International organizations to tackle the various challenges that face geothermal development, for example capacity building. ARGeo also organises a one-week conference after every two years where member countries are able to share their geothermal development updates, challenges and various ways in which these challenges can best be tackled. The latest of such conference was held in Kigali, Rwanda between 29th October - 2nd November, 2018. Strengthening the capacity and providing financial support to ARGEO will go along way in promoting the development and use of geothermal resources in the region.

4.3 Enhanced capacity building in the region

Geothermal development requires well trained personnel to handle aspects associated with its development. In the initial years of geothermal development in East African countries, there was inadequate human capacity. For example, to address the inadequate human capacity challenges, the government of Kenya, which was the first country to develop geothermal, took great effort in capacity building through sending engineers and scientists to geothermally advanced countries like Iceland, New Zealand and USA. Through these studies and research works, the employees have been able to address problems associated with geothermal development and offer timely home-based solutions.

Additionally, experts have also been brought in the country to offer training using the local geothermal resources. This has enhanced in-house expertise. Currently, plans are an advanced stage to set up the Africa Geothermal Centre of Excellence (AGCE) in Kenya to address the geothermal training needs for the East Africa countries. This Centre is being hosted by the Government of Kenya and coordinated by the Africa Union Commission with the UN Environment through ARGEO providing the technical backstopping. The AGCE will have campuses at KenGen and GDC. Currently, an Interim Project Coordination Unit has been set up at UN Environment that coordinates training under the auspices of AGCE until AGCE becomes fully operational. The center will be tasked with promoting capacity building in countries still in their early stages of geothermal development for example Rwanda, Uganda, Burundi, Zambia and Ethiopia, among others. The instructors will be mainly drawn from within East Africa with a few internationally experts. An Interim Project Coordination unit (IPCU) has been set up at UN Environment with support from Iceland International Development Agency (ICEIDA) to coordinate trainings under AGCE before full operationalisation of AGCE. A number of programmes have already been conducted, including the training of geothermal technology held in Kenya from 22nd May 2018 to 8th June 2018 sponsored by the Africa Energy Commission and the short courses during the ARGEO C6 in Ethiopia in 2016 and ARGEO C7 in Rwanda from 29th October to 30th October 2018.

4.4 Adequate government funding

Investing in geothermal energy is defined by initial higher capital cost. Moreover, geothermal projects involve long time investment periods before electricity is supplied to the grid. Therefore, financial support is an important factor in influencing the successful development of geothermal resources. Financial support seems to be highly correlated with both political and technological supports. Public funding for geothermal resources development in the initial exploratory stages helps to stem the risk involved in its development. For example, the Government of Kenya announced KenGens IPO on stock market in 2006. This offloaded 30% shareholding to the public and was aimed at raising money to fast track financing of geothermal development. The government also provided a time-framed subsidy on the recently developed 280 MWe geothermal plants electricity sales. Additionally, the Kenyan government as well as the other East African governements fund for the scientific mapping of geothermal resources through the parent Ministries.

4.5 Strengthening the Geothermal Risk Mitigation facility (GRMF)

The Geothermal Risk Mitigation Facility (GRMF) was established on 15th December, 2011, by the African Union Commission (AUC) with financial support from the German Federal Ministry for Economic Cooperation and Development (BMZ) and the EU-Africa Infrastructure Trust Fund via KfW Entwicklungsbank (KfW) for Eastern Africa Rift System countries with total amount of 50 million EUR.

The GRMF is a grant program designed to share cost for geothermal surface exploration work, exploratory drilling program as well as grants for infrastructure costs and a continuation premium. The objective of the facility is to encourage public and private sector investors to accelerate the development of geothermal resources of the Eastern African countries for power generation by providing grants for surface exploration and drilling. As a result, strengthening ties with GRMF will accelerate development of geothermal resources in the region.

4.6 Strengthening Africa Geothermal Centre of Excellence (AGCE)

The African Geothermal Centre of Excellence (AGCE) to be established in Kenya will be used to train skilled manpower to handle the massive geothermal resources in the continent and help the continent power its vision through clean energy. A skill gap analysis done by UNEP in the region exposed a lack of critical expertise in the geothermal sector including scientists, engineers, and other skilled manpower. Out of the 14 East African Rift Valley Countries, Kenya is the only country with geothermal power plants currently up and running. This centre will, therefore train all the required manpower at an affordable cost and member countries which have been spending billions of shillings to send their employees abroad for similar trainings will have a big saving in their training budget.

4.7 Building networks of competence through collaborations in the region

Currently, the knowledge of how to develop geothermal energy is limited to a few countries, in particular Kenya. To spread expertise on geothermal energy and raise awareness of its potential, networks and partnerships at all levels for knowledge and technology transfer need to be strengthened. This implies not only knowledge transfer, but even more important, regional initiatives such as collaborations. The latter will play a central-role in achieving the East Africa region's near and longer-term objectives in geothermal development. Collaboration will encourage the member states to develop and implement cost effective clean energy programmes which is fundamental for socio economic growth. Areas of collaborations may include providing attachment/internship opportunities, exchange programs between various organizations and institutions and geothermal exploration, drilling, reservoir management, and power plant operations and maintenance and environmental management.

4.8 Supporting the New-Zealand-Africa Geothermal Facility (NZ-AGF) partnership

The partnership targets countries in Africa that have geothermal potential and which are eligible for GRMF funding. The NZ-AGF is designed to provide responsive and flexible geothermal technical assistance and capacity building for East African countries to develop their geothermal energy. Supporting the NZ-AGF partnership will assist in overcoming technical capacity barriers to geothermal development.

4.9 Stakeholder management

Stakeholder management is important for successful development of geothermal resources. Fair engagement procedures help to build and sustain society's trust in geothermal projects and their owners both at local and national levels. For new projects, it is important for the sites to be examined not only with regard to the characteristics of the reservoir, but also with respect to the social context. By means of qualitative interviews and media analyses, the public's hopes, fears, questions, concerns, and perceptions around the topic of geothermal energy can be obtained and contained. Stakeholder management involves a comprehensive mapping of the project stakeholders and establishment of constant contacts with the stakeholders so as to keep them informed of any development. The social buy in is even more critical in areas that are populated or where environmental issues may arise.

4.10 Establishing Geothermal Associations

In recognition of the importance of the role of geothermal energy as a renewable and clean energy, and to promote energy mix in order to meet National Energy Supply there is need to establish Geothermal Associations in countries endowed with geothermal resources. The main function of Geothermal Associations is to provide a forum where members share experiences and seek solutions to common problems or barriers that may impede both individual and corporate progress. The association also helps to create awareness of the crucial role geothermal resources play in socio economic development both through direct and indirect uses. For example, the Geothermal Association of Kenya (GAK) was registered in April, 2010 to encourage, facilitate and promote coordination of activities related to local and worldwide research, development and application of geothermal resources. Apart from bringing together professionals to advance interests in tapping of geothermal resources in Kenya through the Annual General Meetings (AGM), GAK advocates for geothermal policies, laws and regulations. Another critical example is the Indonesia Geothermal Association (INAGA). The latter was established in early 1991 and has since accelerated development of geothermal resources in the country.

4.11 Promoting technology / innovation

New advanced technologies are important for promoting and accelerating the geothermal development energy utilisation in developing countries. For example, advancement of new technologies has seen Kenya, and in particular KenGen invent the concept of wellhead technology, otherwise popularly referred to as the modular power plants. The latter, apart from being early revenue earner also have the advantage of maximising resource utilisation as money is sourced for putting up the conventional power plants. Through innovation, Kenya has made tremendous strides in direct use applications of low-medium enthalpy geothermal resources. An outstanding example is the Olkaria Spa and Demonstration Centre which attracts thousands of both local and international tourists, hence a source of revenue to KenGen. With new advanced technologies like Enhanced Geothermal Systems (EGS), geothermal energy is expected to be used almost everywhere.

4.12 Sound governance structure

To promote rapid development of geothermal resources in a country, systematic governance structure is highly recommended. A properly constituted structure has a long history of encouraging participation of all the key players in the sector. Each player has clearly spelt mandate and vision. A sound governance structure can have an effect on a player’s performance, such as profitability or speed in adopting productivity or enhancing innovations. Effective governance structure is fundamental to the growth and profitability of a particular sector.

4.13 Establishment of Memorandum of Understanding (MoUs)

The purpose of MoUs is to establish a framework for mutually beneficial cooperation and various forms of collaborations geared towards achieving shared geothermal energy goals amongst various countries. For example, the Ministry of Energy (Kenya) and Ministry of Energy (Djibouti) have signed an MoU that will see Kenya support Djibouti in the development of her vast, untapped geothermal resources. Kenya will send experts (Scientists and Engineers) to assist Djibouti explore, exploit and utilise her geothermal resources. Furthermore, the long-standing MoU between KenGen and United Nations University-Geothermal Training Programme (UNU-GTP) has supported geothermal development in Kenya through training and consultancies. KenGen sends at least five scientists/engineers for the six months geothermal technology course in Iceland. There are also students from KenGen pursuing Masters and Doctor of Philosophy (Ph.D) degrees in Iceland under the KenGen-UNU-GTP initiative. Other countries have also benefited from a working relationship with the UNU- GTP where staff from Ministries and other Government agencies have been accorded training either through the annual short course held in Kenya since 2006 supported by the UNU- GTP and KenGen or through the training programmes offered at the UNU- GTP in Iceland.

5. CONCLUSION

- The geothermal activity in the Gregory East African rift system is closely tied to the occurrence of Quaternary volcanoes located within the axis of the rifts. The shield volcanoes are largely made of trachytes, rhyolites and associated pyroclastics.

- The presence of the silicic products attests to the occurrence of shallow magma (fossil) bodies that are considered the most important heat sources for the associated geothermal systems.

- Evidence for the occurrence of shallow magma bodies has been demonstrated at Olkaria, Suswa, Longonot and Menengai geothermal areas in Kenya where seismic waves show “gaps” at shallow levels.

- Geothermal reservoirs in the Ethiopian and Kenya Rifts are mainly hosted within the faulted and layered Plio-Pleistocene rift volcanics. The permeability in such systems is due to fractures/faults and lithologic contacts.

- For the geothermal resources in the Western branch of the rift, the reservoirs are largely hosted within the Precambrian metamorphic rocks where secondary permeability associated with faults and fractures plays a pivotal role in fluid circulation from depth.

- Geothermal resources in the Southwestern branch is non-magmatic and predominantly fault controlled. Hot springs of medium temperature are the key surface geothermal expressions.

- Every country has demonstrated efforts to develop their geothermal resources. However, more efforts are still required to realise the full potential. Adequate measures should be put forth by the different governments to realise the full potential.

- Governments should enact laws and regulations that promote development of geothermal resources. In addition, governments should promote regulatory environments that encourages private sector participation.

- More cooperation and partnerships among countries is strongly recommended. Kenya, being the pioneer in geothermal development in Africa should provide subsidized technical support to other countries in the region. This can be realised through Government to Government partnerships/cooperation.

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