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Barriers and Opportunities in Harnessing Geothermal Energy: A Case Study of East Africa

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This paper examines geothermal energy applications and development in East Africa. With a large geothermal power potential of 30,000MW, about 5% of this potential has been developed in the region. This study uses secondary data to review source documents, empirical literature and archival information, which was triangulated to obtain greater truths. The findings are that geothermal energy is mainly used for power generation and other direct uses. The outstanding barriers are mainly political, economic, socio-cultural, technological environmental and legal regulatory that should be overcome to achieve robust industrialisation among member countries.

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The prospects include Reliable Power generation, Diversified clean energy source, employment and direct uses. The concluding remarks include suggesting a policy shift to geothermal power as a clean energy option that is a credible source for sustainable industrialisation. There should be a renewable effort to train human resource, set up geothermal policy to fast truck power development options. This study investigates and brings forth the developments in the geothermal power development. It also highlights the drivers and barriers to geothermal development. It also brings possible policy measures to the social and economic planners in expanding the renewable energy sector.

Keywords: Geothermal energy; renewable energy; electricity; East Africa.

1. INTRODUCTION

1.1 Background and Motivation

Geothermal energy, plays an increasing role in economic growth. It is a key pillar for sustainable development (Bhattacharya et al. 2016, Mutumba et al. 2022b). Geothermal energy is a hub for manufacturing processes, information and communication, transport, agriculture and business (Singh et al. 2021). East Africa has a huge geothermal energy potential (Li et al., 2015). However, geothermal energy, has unique upfront cost and risk structure, different from conventional energy generating technologies (Noorollahi et al. 2019).

Developing geothermal power fosters the achievement of the sustainable development goal (SDG) 7 which seeks to provide affordable reliable modern energy for all. This calls for deliberate efforts to develop clean energy alternatives within the region. Though the role geothermal energy plays in the sustainable development agenda is not clearly known. The controversial debate can be understood by focusing on drivers and strategies to drive economic growth in the long run (Mutumba et al. 2021a).

Global geothermal power systems generate electricity (Nasruddin et al., 2016). Global geothermal electricity stands at 15,599.99 MWe. The USA generates 3700 MWe, Indonesia 2289 MWe, Philippines 1918 MWe, Turkey 1549, Kenya 1,193, New Zealand 1,064 MWe, Mexico 1,005 MWe, Italy 916 MWe, Iceland 750 MWe and Japan 550 MWe (Hossain et al. 2020). East Africa constitutes the region with the lowest electrification rates in the World. All efforts to increase Electricity generation and supply capacity would spur economic growth and development in this region (Mutumba 2022a). What is common with this region is ambitious renewable energy targets and the efforts to forge 100% renewable energy in the energy mix is high.

The motivation of this paper is to provide a systematic analysis of drivers and barriers of geothermal energy developments in East Africa. Previous studies focus on geothermal developments in the developed world. This paper highlights geothermal applications in East Africa. It seeks to review existing literature on the drivers and barriers with the view of assembling strategies that can overcome those bottlenecks to enhance geothermal power. The increasing carbon emissions on a global scale has become an urgent and important matter that both developing and developed countries must address by reviewing their energy investments, generation and consumption to focus on renewable energy development (Mutumba et al. 2022b, Chingoiro and Mbulawa 2017).

Earlier studies done (Lund et al. 2015, Mugagga and Chamdimba 2019, Mutumba et al. 2021b, Odongo 1993, Bahati et al. 2010, Jianchao et al. 2018) have laid greater emphasis on the deep seated geothermal resource and utilisation strategies in specific countries. Other studies have focused on a few drivers of geothermal energy (Taghizadeh et al. 2020). This study will concern itself with East African countries as a way of understanding and appreciating a regional energy markets, and the possible synergies or possibilities of greater cooperation in energy resources utilisation and development. This paper will explore the geothermal applications, drivers and barriers within East Africa. This will be useful to policy makers in devising evidence based strategies to overcome these barriers.

1.2 Overview of Eastern Africa's Geological Structure

Geothermal potential exists in the great East Africa Rift valley system (EARVS) with over 30,000 MW. The EARVS is the largest, most preserved and conserved continental rift with a stretch of 6500 Square KM (Mugagga et al. 2020). The choice of East Africa is mainly because it has some of the fastest growing geothermal energy development in the world in the last decade (Benti et al. 2023). This however, is only noticed in Kenya and the region has lessons to learn jointly on translating this success across the entire region. It comprises a volcanic system with tectonic plates subdivided into three, namely the Ethiopian rift, The Eastern and Western rift valley arm. All these have useful implications for this study.

Geothermal power projects are in Kenya and Ethiopia geothermal areas namely Olkaria, Ngurumani escarpments, L. Naivasha, Lake Magadi in Kenya, Katwe- Kikorongo (Katwe), Sempaya- Buranga and Kibiro, Panyimur in West Nile in Uganda, Karisimbi in Rwanda. Other sites are in Madagascar, Malawi, Eritrea, Tanzania and Djibouti where exploration and resource assessment is still ongoing are shown in Fig. 2. It is barriers standing in the way of developing these geothermal resources, this is shown in Table 1.

Geological evidence of deep seated volcanic material exists. Magmatism evidenced from the floats of gabbro and dolerite exist in the Kenyan Dome and in selected places with the Eastern African rift valley in general. Geothermal energy potential was first estimated in the 1963 by (McCall 1967) and (Thompson and Dodson 1963) in 1967, on the eastern arm of the Great African Rift valley (Odongo 1993), while 1982 geological studies were done on the western arm (McNitt 1982) Geological and geochemical works were done in 1994 for instance the exploration stage began as early as 1993 with over 43 sites were studied and gave spectacular geophysical properties like temperature gradient, micro-seismic and earthquake. This brought the total number of known sites with prospects to 73. The great Olkaria geothermal reservoir is on a deep seated Geological structure of a volcanic complex known as a ‘Kenya Dome’ (Baker and Wolenberg 1972, Naylor 1972). To date most geothermal power development has occurred in Kenya and Ethiopia.

“Geochemical exploration studies were also carried out, isotope hydrology studies to delineate flow characteristics of geothermal waters and identify their recharge areas. The geothermal fluids for Katwe-Kikorongo are rich in carbonates and sulphates, and salinity of 19,000 -28,000 mg/kg total dissolved solids. The source of high concentration of hydrogen sulphide is both volcanic and hydrothermal. Kibiro is depleted in sulphates with 35ppm and its interaction with hydrocarbons produces hydrogen sulphides (H_2S); salinity levels of 4000-5000ppm. Geological surveys revealed magmatic source of heat for Katwe, Buranga and Kibiro. It has explosion craters, ejected pyroclastics, lava flows tuffs with a lot of granites and gneissic rocks” (Bahati et al. 2010).

1.2.1 Kenya

Kenya is the largest producer of geothermal power in Africa. It has some of the most well developed geothermal power resources in the region. With a geothermal potential of about 10,000MWe, it has been able to harness 1193 MWe and is among the top ten global producers (Alam et al., 2020). It has been actively involved in geothermal exploration and development from 1963, however, by 2010 only 198MW was got from geothermal energy.

Table 1. Geothermic properties of Major geothermal Resources in East Africa

No	Location	Max. Water temp (^{0}C)	Surface Temp (^{0} C)	Hydrogen Sulphide (ppm)
1	Olkaria(Kenya)	260	100	25
2	Kibiro (Uganda)	250	86	35
3	Katwe-Kikorongo(Uganda)	200	70	40
4	Sempaya- Buranga (Uganda)	150	98	30
5	Panyimur (Uganda)	200	60	12
6	Ngonzi (Tanzania)	232	76	26
7	Karisimbi (Rwanda	120	74	28
8	Bwengwa (Zambia)	150	100	20
9	Rusizi (Burundi)	160	72	30
10	Chiwenda (Malawi)	132-157	75	34

The main geothermal power stations are at Olkaria I-V with capacities of (215,103,140,140,153MWe) respectively Olkaria central with 43MWe, Akiiro Geothermal with 70MWe, Eburru Pilot with 2.52MWe, Menengai with 105MWE at a cost of USD 108million a loan facility from the African Development Bank (AfDB). Menegai power project shown in Fig. 1, has 3 independent power producers (IPPs), namely; Orpower22 Limited, Sosian Menegai Geothermal power limited (SMGPL) and Quantam East Africa Power Limited. Menengai geothermal power was able to connect over 500, 000 households. Others include Baringo Silali, Homa hills, Magadi and Namarunu (Ngounou, 2020).

Kenya through M-Kopa was able to raise USD 80 million in 2017 in equity financing. This is as a result of attracting investment in the energy sector that spans for decades. What is important to note is the unit cost of installing 1KWe is US $1028.7 computed from the Menengai geothermal project. This is cheaper than most clean energy sources like solar which is US$760 per KW (Alinda et al. 2021), Hydroelectricity at US$ 2600 per KW and Nuclear at US$4000-6000 per KW (Mutumba 2022a).

1.2.2 Ethiopia

Ethiopia with a geothermal power potential of 17,000MWe and geothermal potential of 7000MW. It produces over 607.3MWe it has concentrated on hydroelectricity in its energy mix. Its overall energy generation is over 4500MW. It has been actively involved in geothermal activities from 1969, with over 23 geothermal areas. The major active areas are in the Great Rift Valley including Aluto-Langano with 7.2 MWe, Tendaho-Alalobeda 100MWe, Corbeti with 500MW with over U.S. $ 2billion invested in the development of the Corbeti well alone. Financing is from World Bank, Iceland, Japanese International Cooperation and Assistance (JICA) and Government of Ethiopia.

Ethiopia's political structure is so centralized, that the space between the energy sector players and business is so interwoven. However, since 2017 there is a renewed interest by Government to support the development of renewable energy. With an ambition to higher electrification and focus on green growth, it has started courting investors into the energy sector. It has opened up space to private investors who would feed power to the grid (Oxford Institute for Energy studies 2018).

1.2.3 Democratic Republic of Congo

Its prospects are on Mt. Virunga and 0.2MWe binary plant was installed in 1952 in the Belgian Congo, the present day Democratic Republic of Congo (D.R. Congo) to support mining activities at Kiambukwa. The greatest challenge has been high upfront and maintenance costs, human and technical capital to develop more geothermal resources in the D.R. Congo. The deep seated geothermal potential in the D.R. Congo is yet to be tapped to greater use.

1.2.4 Rwanda

Rwanda, Just like D.R. Congo relies on Mt. Virunga volcanic complex. It has an estimated underlying potential of 300MWe. It mainly has low and medium temperatures. Preliminary exploration efforts done at Karisimbi, yielded minute results. What is left now are other areas of Gisenyi and Mashyuza. A deeper analysis shows more geothermic regions around Bugarama, Kiningi, Kilwa, Muti, Kanzanza. Gisenyi north of L.Kivu shows a geothermic region with sub surface temperatures of about 250^0C in a depth of 2000meters while at the surface is about 73.6^0 C (Mugagga et al. 2020).

The Investment climate in the geothermal sector has instituted a geothermal Feed-in-Tariff (FiT) which is necessary but not a sufficient condition for bringing in sufficient investment s into the sector. Government has limited investments in upstream geothermal activities It must therefore streamline its institutional framework to attract private investment into the sector.

1.2.5 Tanzania

Tanzania is blessed with both the eastern and western arm of the great East African Rift Valley systems. Its potential is estimated over 500MWe. The main prospects are in Ngonzi, Songwe, Kiejo-Mbaka, Kasimulu, Kilambu, Mampulo, Ivuna, Bulongwe, Kabango, Mapu, Luhoi and Natron. Tanzania's electricity generation is 1565.72MW with a plan to develop about 100MW of geothermal energy (Mugagga et al. 2020) for greater electricity access. From the climate investment fund US$21.7 Million has been invested into the Ngozi geothermal plant in the Rungwe Volcanic province.

1.2.6 Uganda

With an estimated geothermal potential of 1500MW in over 24 sites, Uganda is still undertaking final exploratory phases. The major geothermal sites are Kikorongo- Katwe, Kibiro, Sempaya- Buranga and Panyimur. With a view of increasing energy security, Uganda plans to develop about 150 MW in the medium term. It has a FiT of US cents 0.087 which is adequate to attract private investment into the sub sector. Its greatest short coming is the weak regulatory and institutional framework. Uganda has not yet finalised with a geothermal energy policy. Uganda's energy policy (2022) is silent on many pertinent issues of geothermal energy development.

1.2.7 Burundi

With over 14 geothermal sites Burundi has large untapped geothermal potential. At the same time it has a low access to electricity with about 89% of the population lacking access to electricity. This makes geothermal energy development a timely innovation to solving Burundi's energy challenges. The potential sites are located at Rusizi. Kamunyange with surface geothermometry of 39-40^{0}C, Rahagarika at 48^{0}C, Mugara at 48^{0}C and Ruhwa at 68^{0}C (Sinzinkayo et al. 2015). Therefore geothermal power development is possible with use of low enthalpy technology.

1.2.8 Djibouti

Djibouti is part of the great African Rift valley system. As such it has a geothermal potential of about 1000MWe with initial plans to drill 30MW from the Lake Assal region. There are overwhelming challenges to do with financial and technological barriers that stand in the way of geothermal energy development in this country.

1.2.9 Eritrea

There exist an active crust in the North West with fissures and volcanic fault lines at the Alid volcano. Detailed exploratory studies of 2015 were halted due to extreme field conditions. Eritrea is a new member of the region form Ethiopia and establishing a strong energy sector itself is challenging. The exploratory phase would therefore give a clear picture of geothermic potential.

1.2.10 Zambia

With over 80 occurrences of geothermal spots in Zambia including Kafue, Kapisya, Mwembeshi. Kalahari project limited is undertaking Bwengwa river project. The overwhelming challenges include the absence of a clear geothermal energy policy financial and human resources constraints.

1.2.11 Malawi

Malawi has an installed electricity supply capacity of 445MW most of which is hydroelectricity, with a need to diversify to geothermal energy development. It has deep circulated geothermal system with low and medium temperatures of 40-80^{0} C. In in the Malawi Rifted Zone (MRZ), Neogene Malawi rift and Permo-Triassic. The areas deep seated with geothermal resources include: Kasitu, Chiwondu, Chiweta, Marrupa, Unango, Niassa, Nampula, Ocua, Rukwa, Luangwa, Mawila, Mkhotakota, Luwonde, Shire, Tuhuhu, Karoo, Maniamba and Zambezi rift (Njinju et al. 2019). Chiwenda and Kasita have had their feasibility studies done with power potentials of 13.5 MW and 5.6 MW respectively.

1.3 Why this Paper is Important

This paper is important to geothermal energy literature by providing both theoretical and empirical underpinning on geothermal energy development as explained.

In the theoretical perspectives there is an extension of the energy stacking theory that supports addition of a new energy type alongside other already existing energy types. According to this theory there is evidence of a new energy sources attracting new demand without the consuming agents abandoning old energy sources. This gives useful prospects that investment into geothermal guarantees new demand within the regions.

It provides a detailed analysis of prospects and challenges that influence geothermal energy development in the context of a developing world. This is with an intention of laying a clear ground for expanding the existing regional power pool for which these countries poses varying capacities to generate geothermal energy by tapping the vast geothermal endowment within the region

The road map for rest of the paper is arranged as follows: the second section reviews empirical literature, the third section is on methodological framework while section four is results and discussion. The final section is on conclusions and recommendations.

Fig. 1. Menengai Geothermal power plant of 105 MWE giving Kenya overall Geothermal power of 672MWe

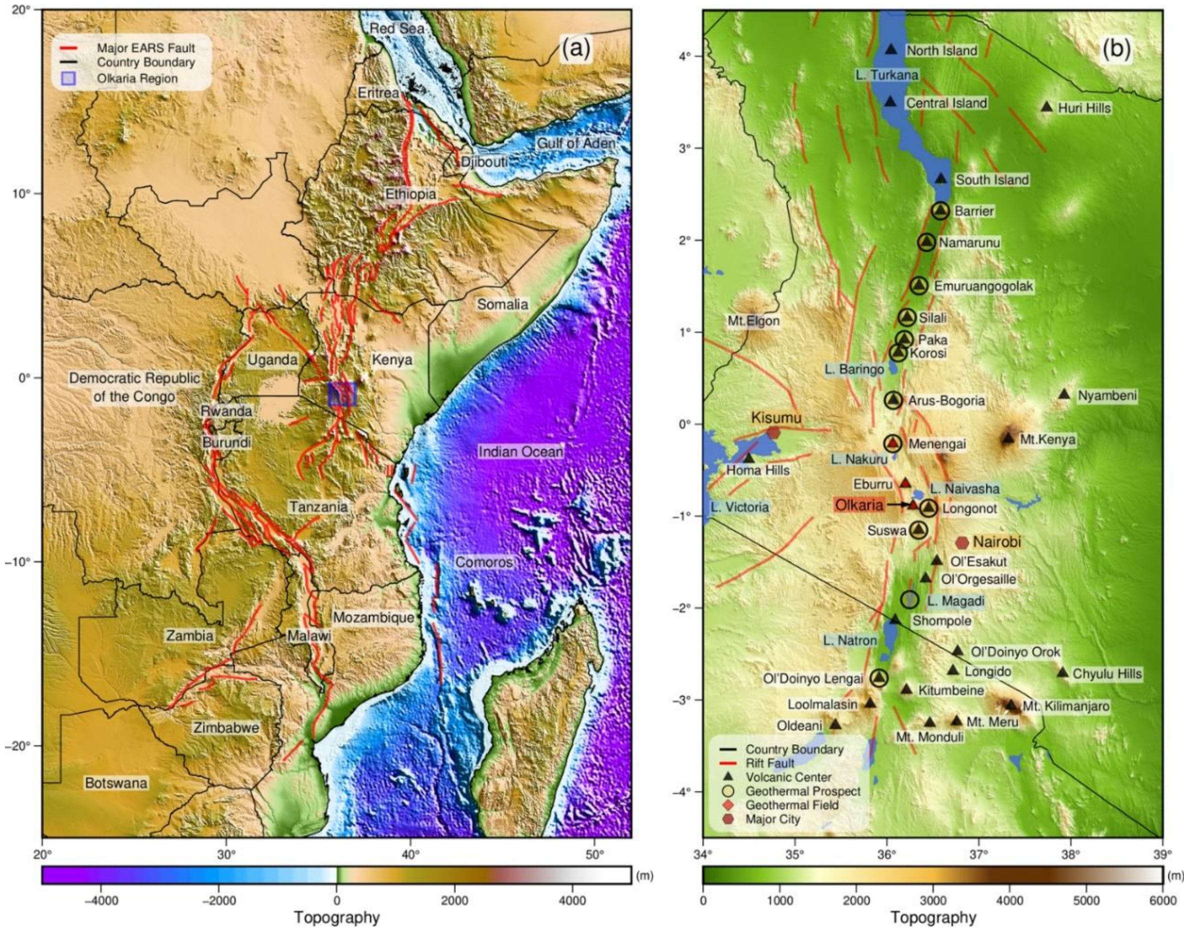

Fig. 2. Map of Eastern Africa locating geothermal energy resources.

2. EMPIRICAL LITERATURE

The review of relevant literature has been summarised in Table 2 (Mutumba et al. 2021b) investigated drivers and barriers of geothermal energy with evidence from Uganda, study findings showed prospective uses for both power generational and direct uses, further a number of challenges were enumerated ranging from land wrangles to socio-cultural and environmental challenges. (Kombe and Muguthu 2019) found that financial, institutional, technical, social and environmental barriers are the leading impediments to geothermal power development. [(Jianchao et al. 2018) used "PESTEL to analyse prospects and challenges in which he highlighted political economic, social technological environmental and legal challenges to analyse geothermal energy development in China”. (Colmenar et al. 2018) studied ways to “remove challenges to geothermal energy in European Union (EU) and classified geothermic resources as low, high enthalpy and renewable energy mix his finding were that in low enthalpy geothermal power the barriers were mainly social, economic and financial barriers while in Agricultural sector barriers were lack of technical knowledge, social, technical, financial and normative or institutional barriers, in the high enthalpy geothermal power financial and economic barriers the overriding”. (Kubota et al. 2013) investigated obstacles of “developing geothermal power development in Japan, it advocated for mind set change by players in hot springs and identified financial and economic barriers, development risk, societal barriers and local acceptance as the most prominent barrier”. (Taleb 2009) examined obstacles impeding the use of geothermal resources in Saudi Arabia he identified non-technical barriers as political economic, social and educational barriers.

Table 2. Summary of relevant empirical studies

Author (year)	Title	Approach and key finding
(Mutumba et al. 2021b)	Prospects and challenges of geothermal energy in Uganda.	It Examined the geothermal applications for power and directs uses, Barriers included land wrangles and competing land uses, upfront and operational costs, ignorance of geothermic resources, weak policy and institutional framework, inadequate skills, low levels of research and development, shortage of financial resources, Socio cultural and financial resources
(Taghizadeh et al. 2020)	Role of energy finance in geothermal power development in Japan.	It analyses social, legal economic, social and technical barriers of geothermal power development in Japan
(Mugagga et al. 2020)	Review of Geothermal Development in the Western Branch of the East African Rift System	Financial and economic, Legal, Institutional and regulatory drivers
(Young et al. 2019)	An Analysis of Non-Technical Barriers to Geothermal Deployment and Potential Improvement Scenarios	In-depth analysis of all barriers except technical barriers and measures for overcoming them.
(Kombe and Muguthu 2019)	Barriers and strategies for Geothermal development in East Africa	Financial, institutional, technical social and environmental barriers
(Jianchao et al. 2018)	Geothermal development in China	PESTEL as the overriding barriers
(Moya et al. 2018)	Geothermal energy: Power plant technology and direct heat applications.	Considers advantages and challenges of binary geothermal technology applications
(Ambumozhi 2018)	Overcoming Barriers to Geothermal Energy Development in Indonesia.	Analyses technical and non-technical barriers to geothermal development in Indonesia
(Pan et al. 2018)	Establishment of Enhanced Geothermal Energy Utilization Plans: Barriers and Strategies	It reviews barriers and strategies to adopting geothermal resources in respect of Institutional, regulatory, technological and financial aspects.
(Colmenar et al. 2018)	Measures to Remove Geothermal Energy Barriers in the European Union	It examines the market barriers that make it, difficult to use low enthalpy, high enthalpy and electrical use of geothermal resources in EU.
(Iwayemi	Crossing the Barriers: An	Analyse Land access challenges to including tribal

Author (year)	Title	Approach and key finding
2008)	Analysis of Land Access Barriers to Geothermal Development and Potential Improvement Scenarios	and cultural resources, environmentally sensitive areas, biological resources, land ownership, federal and state lease queues, and proximity to military installations.
(Rolffs et al. 2017)	Innovative risk finance solutions: Insights for geothermal power development in Kenya and Ethiopia	Examines drivers and barriers of geothermal power in Kenya and Ethiopia with emphasis of technical-financial, cost and geothermal risks.
(Pan et al. 2018)	Potential of geothermal energy for electricity generation in Indonesia: A review	Indonesia makes up 40% of global potential at 258,617MW
(Bai et al. 2013)	A review of Geothermal energy Resource applications and development in China: Current status and prospectus.	Focus on developing Geothermal energy technology, Low cost power plants, Hybrids systems and sustainable use of geothermal energy.
(Zhu et al. 2015)	Comparison of geothermal with solar and wind power generation systems.	Benefits of using renewable energy resources are analysed. Social and government barriers are also considered for each.
(Matek 2015)	Flexible Opportunities with Geothermal Technology: Barriers and Opportunities	Flexible opportunities with emphasis ancillary services from organic Rankine cycle (ORC).
(Kubota et al. 2013)	Determining barriers to developing geothermal power generation in Japan: Societal acceptance by stakeholders involved in hot springs	Examined financial, economic and societal acceptance, development risk as the underpinning barriers
(Bai et al. 2013)	Identification of Growth Barriers for Exploitation of Geothermal Energy in China	Discusses barriers and proposes ways of overcoming them
(Thorsteinsson and Tester 2010)	Barriers and enablers to geothermal district heating system development in the United States	It analyses barriers and enablers to utilising Geothermal district heating systems for space and water heating.
(Taleb 2009)	Barriers hindering the utilization of geothermal resources in Saudi Arabia	It identifies obstacles and enablers to geothermal development in Saudi Arabia
(Hughes 2008)	Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers	Barriers and strategies of overcoming them, emphasis lay on Geothermal Heat Pumps (GHP) technology and costs
(Tester 2007)	The Future of Geothermal Energy	Highlighted dimensions of Hydrothermal and enhanced geothermal Systems (EGS)

3. METHODOLOGICAL FRAMEWORK

3.1 Theoretical Framework

The overarching theoretical model is the energy stacking hypothesis (Kowsari and Zerriffi 2011). According to there is slow adoption to the development of new energy sources. The power users do not entirely abandon the traditional energy alternatives, when their incomes increase. They adopt newer and modern alternatives while sticking to the traditional ones hence the stacking effect. The switching from one electricity source to another is not done perfectly which results into multiple fuel use. This therefore means it is not possible to entirely substitute the traditional energy sources entirely to undertake the geothermal electricity as a key priority energy source (Masera et al. 2000).

The household that sticks to the using multiple energy sources along the energy ladder have been bound in social cultural attributes within the community in which they live. The existing stoves and the convenience of use. They are readily available for instance the three stone stove is flexible and could be mounted easily and cheaply in any space to allow for use of clean energy sources. Significant economic progress is believed to diffuse energy stacking (Kang et al. 2019). This therefore means incomes as well as energy prices will feed into the speed of transition. Where incomes grow and energy prices are constant transition can go on. While increasing household incomes and declining real energy prices cause energy transition and welfare gains. Biomass energy in Uganda is becoming tradable with distinct charcoal and even firewood markets. The fungibility of these commodities causes more energy stacking as the prices of these items are often increasing. The real incomes are static if not decreasing, this perpetuates energy stacking hence a stumbling block to energy transition. The indiscriminate extraction of biomass is leading to increased global warming and increased climate variability through increased CO_2 as carbon sinks in green cover is substantially reduced (Velvizhi et al. 2023). This therefore explains in part the delayed development of geothermal energy development in the region.

3.2 The Methods and Materials

The study used complex data sets from source documents mainly obtained from electronic academic sites like google scholar, Mendeley. The acquisition of data was maily papers available on digital platforms. These were mainly articles from peer reviewed journals that were accessible. Empirical works and archival information (O'leary 2017) on geothermal developments was read and profiled in the themes of study. Documentary review was done by reading different sets of documents and triangulating facts therein. The important aspects to be considered in this study to maintain a high level of validity and reliability, was handled through using measures like triangulation; the researcher's position or reflexivity, variation in observations included in the study, groups and providing a detailed description about the research process (Merriam 2002). In-depth exploration under a qualitative framework helped best answer the research questions.

4. RESUTS AND DISCUSSION

4.1 Prospects of Geothermal Energy

4.1.1 Reliable power generation

Geothermal power has an overriding benefit of providing load base power that is of a stable quality overtime (Noorollahi et al. 2019) (Noorollahi 2019). The power stations at Olkaria I-V, Olkaria central, Akiiro Geothermal, Eburru Pilot, Menengai power and Langano in Ethiopia. This creates a great opportunity for geothermal power for industries and running commercial enterprises. Small scale electricity uses given the subsurface temperatures electricity generation has potential for clean energy alternative Lund et al. (2011). The overarching electrical-grade hydrothermal systems depending on the contemporary technology can develop a number of plants of about 20 MW that can power a number of areas not currently connected to the main grid.

4.1.2 Diversified clean energy source

Though pollution from fossil energy sources has had irreparable damage on human health, it has also immense damage on the environment and the associated ecological system. Geothermal therefore, comes in handy to mitigate this problem as it’s clean with less greenhouse gas emissions.

4.1.3 Employment opportunities

With geothermal projects located in the hard to rich areas provides an opportunity to reduce this rural unemployment which has always sprawled as an open urban problem. With about 1200 jobs for skilled workers and another 1300 for semiskilled workers for every 1000MW of geothermal (Noorollahi et al., 2019). Forging livelihoods for these rural folks would stabilise these households in gainful employment and hence increases their incomes.

4.1.4 Direct uses

Geothermal is used for combined heat geothermic for commercial use, where hot water and quick dishes are prepared using hot water got from hot springs in the giant East African Rift valley system. Therefore geothermal can provide a reliable and sustainable heat source causing savings of up to 80% in emissions. This therefore is a clean and safe energy alternative.

Tourism both local and foreign visitors frequent who come to enjoy the beautiful and spectacular sites hence earning revenue to the country. Swimming and bathing mainly in the warm waters folks in the area often spend time swimming and bathing so it gives immense recreation value. And enhances recreational value of the revelers visiting the site.

Balneological Value. People appreciate the medicinal value associated with hot springs. They often get a healing from skin diseases and rush (Rolffs et al. 2017). Possibly the presence of aqueous Sulphur compounds may lower bacterial and fungal infections hence overcoming their health challenges. Although, the medicinal components of the hot springs has not been empirically studied. It is an alternative to curing certain complications and disorders that people around this area suffer from.

Drying crops especially annual crops like maize and beans are often dried using geothermal energy. This increases food availability as it checks post-harvest losses by ensuring quicker drying of cereals preserves its value and increases its price. This has increased food security in the region (Lund et al. 2015).

A critical learning point from Kenya that overcame these challenges and added 358MW of geothermal power in 2014 putting their total at 600MW, which constituted 50 % of global geothermal increase for that year (Rolffs et al. 2017). The gaps in funding, human resource and technology were overcome by sourcing for funds from development partners like the African Development Bank (AfDB). This provides some lessons to other members in the region to draft a clear geothermal policy and committing to clear rules of engagement in the power purchase agreements (PPA).

The electricity generation matrix for selected countries as well as their population is given in Table 3 to provide the clearly show the extent to which these governments need to work on the bottlenecks in order to provide more electricity to its people.

4.2 Barriers of Geothermal Energy Development in Eastern Africa

Governments have exhibited interest in improving the welfare of its people by promoting an energy mix that is rich in renewable energy, however, to achieve this a number of challenges have to be addressed. These are the challenges to geothermal energy development and its utilisation within the region.

4.2.1 Policy and legal barrier

“Land wrangles due to archaic land laws. Accessing land for geothermal energy development is complicated due to unclear property, worse still the intending project to be sited on such land, not necessarily public land. It is tribal and cultural land whose development requires wider and inclusive consultations” (Young et al. 2019). “Geothermal energy projects adversely affect land for agricultural development through construction of power plants and transmission lines. Geothermal energy projects on a large scale will involve distortion of biodiversity and ecosystems, construction activities is associated with destruction of certain plant and animal species, interference with breeding and migratory patterns. The habitat quality will be adversely affected this is a great threat especially to the endangered species”

Table 3. Showing selected Electricity statistics for selected East Africa

Country	Pop (mill)**	Elec Gen (MW)
Burundi	10.5	41
Kenya	48.5	2962
Rwanda	11.92	211
Tanzania	55.57	2113
Uganda*	45.9	2002
Average	33.56	1075.6

*Source: Adapted from IEA (2023), *ERA 2023, **World Bank (2023)*

(Iwayemi 2008). “Most geothermal sites are located in environmentally sensitive areas that are part of Queen Elizabeth national park that is conserved and would require de-gazetting to fully exploit the geothermal resources. The biodiversity and ecological value of the land, has in it species of biological value that must be preserved including Guerrillas, white rhinocerous and other bird species. All these make geothermal power development difficult” (Levine and Young 2017).

Ignorance about access to correct and meaningful information in the public arena that would promote geothermal development has not been done adequately. The Masses are ignorant about geothermal energy technologies, and benefits that accrue, they remain conservative about their old ways which are obsolete and ineffective. The deficiency of technical knowledge is a hindrance to quality decision making as far as accepting geothermal technology is concerned. This ignorance would lower social acceptance of the geothermal projects within the Eastern African region.

“Government policy, incentives and institutional challenges. Precisely, there is no policy on geothermal energy development, an alternative renewable energy policy of 2007 has a weak implementation machinery. Government policy activates an enabling framework for geothermal resource development” (Kombe and Muguthu 2019). The insufficient funding of geothermal energy entities leaves room for institutional weakness. In 2014, the geothermal resources, limited public finances create competition of financial resources among different sectors, this further restricts the availability of funds for geothermal energy resource assessment, carrying out feasibility studies. With such financial challenges it becomes difficult to efficiently and quickly achieve geothermal energy development.

At the institutional level the geothermal energy unit has been too underfunded to implement its mandate. The weak institutional machinery is a great blow to proper coordination and consultations with relevant stakeholders coupled with low budgetary allocations, prevents the development of synergies and linkages needed for geothermal energy development. Clear energy policies must be designed by these countries independent of the energy policies that are silent about the salient features unique to the geothermal sector.

On monumental institutional failure is the high rates of corruption that riddle the energy sector in East Africa. Despite efforts to attract foreign investment, corruption tendencies exist and Table 4 makes a comparison for selected East African countries. This causes delays in signing contracts and timely delivery of quality services. Since there is a possibility of diverting public resources to private gain. State companies given special treatment are expected to partner with the ruling political party, wherever possible. Other forms of favouritism occur to secure investment into the energy sector. Anticorruption efforts must be stepped up to foster increased accountability and transparency.

There is still a felt need to fight this vice and increase the level of transparency, well-enforced ethical and professional conduct, strong financial record keeping, and deliberate whistleblowing policies within the energy sector, this will open up the geothermal energy power development to the fullest.

4.2.2 Economic and financial barrier

Large investment costs for geothermal energy development is the high installation and operational costs of geothermal energy equipment. For instance it cost about U.S $ 5million to drill one well test (Kombe and Muguthu 2019). “The high initial costs of investment makes the start-up process of the geothermal projects more difficult to undertake. It also contributes to overall inadequacy of financial instruments. Therefore the high upfront costs of geothermal energy projects remain a challenge to its development. While operational and Maintenance costs Geothermal Energy Development is considered as alternatives for all urban, rural and even remote areas including island communities, however, the high operational and maintenance costs prohibit the widespread use of RE devices. There are a few public and private player engaged in the provision of RE devices. Worse still is the lack of expertise and limited institutional capacity all that have reduced the participation and the ‘fruits’ that accrue to use of RE devices. Other costs could include costs of connecting to the grid, interconnection and transmission costs” (Young et al. 2019).

The high levelised cost of energy (LCOE) of geothermal at us $0.087 as compared with other renewables in the region like the weighted-average levelised cost of energy (LCOE) of

Table 4. Corruption in East Africa

Country	Score	Rank	Rank in sub-Saharan Africa
Ethiopia	35	107	18
Kenya	28	143	28
Uganda	26	151	33

Source: Transparency International, 2019.

utility-scale Solar PV plants was US$0.068/kWh, and hence, current FiT for geothermal in Uganda might not be attractive for investors (IRENA 2020) while Hydro is estimated at US$0.3/kWh (Katutsi et al. 2021). This makes geothermal fairly cheap and affordable in terms of costing and feasibility of newer clean energy alternatives. The East African countries have partnered with the Chinese government for provision of most of the financing and equipment with in the energy sector projects. This has led to the formation of the East African power pool. What remains to be seen is how these countries are able to tap the benefit of joint workmanship within the region.

Financing Geothermal Project is a critical challenge for this region. According to (Ji and Zhang 2019) “one of the greatest challenges to geothermal is shortage of green energy finance. The shortages arise from both from public and private investors needed to carry out geothermal energy resource assessment. The exploration, drilling, Environmental impact assessment, appraisal and operation will require heavy funding which is still a barrier geothermal for energy development”. The green energy financing schemes have ushered the Feed in Tariffs (FiTs) and power purchase agreements and Renewable portfolio schemes with no packages to develop geothermal power (Noh 2019).

4.2.3 Socio-cultural barriers

Communities do not easily take on new innovations as regards the uptake of new forms of power. It’s still worse when they perceive the project as that will benefit other industrialised areas yet it is their land and heritage to be lost in the development of this geothermal power station in their area so this creates resistance as was the case in Oromia, Amhara in Ethiopia, In Uganda protests also occurred in the development of power dam at Bujagali. Geothermal projects starts with dispossessing locals of their land with infamous and clandestine resettlement schemes. Land is a source of all livelihood yet land is a cultural asset with heritage of these people. This quickly brings the locals on a collision path with any ongoing geothermal energy developments.

4.2.4 Technical barriers

(a)Geothermal energy Resource Data: Although resource data research has been done for several decades, some areas still require further explorative work. There is still need to overhaul and turn this data into geothermal power development.

(b)Institutional support through- quality and standards: Institutional, legal and regulatory mechanisms for developing geothermal power has remained weak throughout the region. Most countries in the region have not developed a credible geothermal energy policy which leaves sceptic investors with no choice but to wait until proper institutional and regulatory framework is developed.

(c)Technical capacity- research and development: There is little focus on research and development (R&D), there is not a visible plan or budget given to research institutions or universities, more still has to be done in stepping up budgets and doing coordinated research in RE development especially geothermal energy. Working systems must be promoted to tap into international R&D collaborations. Native technical knowledge on Solar and wind technologies are still low and without a convincing technical direction, this leaves related technologies to be imported at a very high cost, expatriates also cost the country yet a sustainable indigenous pool of workers need to be developed.

(d)Technological capacity - Technological Limitations: The technological challenges are mainly in the dimensions of drilling technologies whether hydrothermal or enhanced (engineered) geothermal systems (EGS), the power conversion systems and reservoir technology are still an obstacle (Tester 2007). Although these in the long run become tractable, scalable and affordable here seed capital is lacking to acquire this technology.

(e) Skills development- human capacity and training: Specialised training in Geothermal has been through sponsorships into the Auckerland University in New Zealand and United Nations University collaborating with University of Iceland (Hochstein 2005). There is a need to forge a critical mass of workforce to operate geothermal energy projects. However, geothermal energy projects call for a wide variety of skills in fields of Geoscience, Engineering (renewable energy, electrical, mechanical, mechatronics, chemical), material science, geophysics, geochemistry, energy management, social sciences all that cannot be easily acquired in large pools. This remains a barrier for geothermal energy development (Rubino et al. 2021).

4.2.5 Inadequate infrastructure to support geothermal energy development

Poorly built transport and communication network to support geothermal energy projects. Most roads are murram roads that become impassable in the wet season, the few tarmacked roads are poorly maintained. These are vital for transportation of technology and staff to develop the geothermal energy projects. Worse still, the geothermal infrastructure including the drilling technology, power conversion and reservoir equipment are all lacking. All these become a challenge to geothermal energy development.

4.2.6 Environmental barriers

Geothermal power development impact on the natural environment and the pre-existing ecosystem, surface distortions as well as displacement occurs. Households may need resettlement. The production of brine may also leave societies devastated (Colmenar et al. 2018, Mariita 2003). This may also not be easily accepted by the locals who may resist this development.

4.2.7 Geo-political and governance risks

Political and sovereign risks exist to private investors. There is an inherent risk of nationalisation for which private investors would lose in mining rights in the medium and long run. Non armed state groups exist like in Ethiopia and pose an immense risk to investment and installation of geothermal plants. There were risks of violent protests in Oromia, Amhara in Ethiopia in 2018. Physical asset risk also exist in countries where the potential of political upheavals exist. Investors must factor in the potential risk, before they undertake investment into the geothermal energy, grievances associated with human rights, land, labour are ripe in many of these countries (Mutumba 2023).

Other existent risks include financial risks including shortage of currency to finance geothermal energy projects. Further investment into geothermal exposes these countries to an unfavourable terms of trade. The Africa Energy Guarantee facility has been designed to respond to mitigation of such risk.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

This study has taken a keen interest in exploring the geothermal resources located in East Africa. The potential for geothermal energy has been known for a long time. The policy shift from the traditional biomass to clean energy highlights the need to actualise the use of geothermal energy development as renewable energy to meet her energy demands. Therefore prospects as well as challenges that constrain geothermal development thus far are briefly explained. The greatest challenge being the absence of a geothermal policy and regulatory framework to guide exploration and development of geothermal resources.

5.2 Policy Recommendation

Diversification of Eastern Africa’s energy mix. There is need to fast track the development of a geothermal energy policy to guide the exploration and development of geothermal power in the energy mix (Mutumba et al. 2024). This would increase the renewable energy mix as advocated by the renewable energy policies. This would also promote the current development agenda that is sustainable growth and development (Mutumba et al. 2024). This would also mitigate the climate change problems as there would be reduced encroachment of forest biomass to use of better and clean energy sources (Mbaabu et al. 2020).

Specialised manpower training with skills and knowledge on geothermal energy technology, financial support for research in geothermal data collection and analysis. Geothermal speciality training institutions should be established in preparation of the vast potential resources in addition to the existing energy training. This would equip workers with competences to develop this subsector. This would overcome the challenge of limited skilled man power to develop the geothermal energy projects, Economic subsidy reform program to individual, communities as well as private organizations to sink in geothermal energy projects, financial reimbursements and training for individual and communities that have been dispossessed of land to be utilised by government and/or investors for the development of the geothermal energy project and community participation/ ownership of geothermal Energy projects for security and infrastructure. Loan facilities are available and can be requisitioned from African Development Bank (AfDB) as well as global environmental facility (Colmenar 2018). Concessions and more friendly terms. Land evaluation reservations for key energy infrastructure projects for potential investors upon expression of interest to develop geothermal resources. Land would be availed with numerous friendly terms to create a conducive investment climate.

Proper and recurrent environmental systems audits, reinforcing and streamlining to ensure proper use of existing ecosystem services. Those ecosystems that have been tampered with as a result of power project can be reworked for restorative equilibrium. A budget for environmental restoration and clean energy planning should be established (Mariita 2003).

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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