AFREPREN/FWD

Success Story – Geothermal Power Generation in Kenya

EXECUTIVE SUMMARY

Using technology available today, Africa has the potential to provide 9,000 MW of power generation capacity from hot water and steam based geothermal resources, not including the additional potential of heat and ground source heat pump applications (BCSE, 2003).

The geothermal potential for selected African countries is shown in Table 1. These estimates of existing geothermal power generation potential do not include direct thermal use of geothermal energy, which is widely practiced in North Africa and parts of eastern and southern Africa, nor do they include the potential of geothermal technologies such as ground source heat pumps.

Table 1: Geothermal Potential of Selected African Countries

Country	Potential Generation in MW
North Africa	
Algeria	700
Sub Saharan Africa	
Kenya	3,000
Ethiopia	>1,000
Djibouti	230-860
Uganda	450
Tanzania	150

Source: Karekezi and Kithyoma, 2008

Kenya has registered significant progress in exploring geothermal energy for power generation. It has an installed capacity of 127 MW, equivalent to about 11% of the country's installed electricity generation capacity. Kenya's power investment plan envisages a major increase in geothermal power in current projections indicating that the resource's contribution to the country's installed capacity would increase to about 30%.

Varying levels of geothermal exploration and research have been undertaken in Djibouti, Eritrea, Uganda, Tanzania, Zambia, Malawi and Madagascar, but the potential for electricity generation is highest in Ethiopia, Kenya, Uganda and Tanzania, which are all part of the Great Rift Valley. Government representatives from Ethiopia, Uganda, Tanzania and Eritrea are interested in the use of small-scale geothermal plants for rural electrification mini-grid systems, although this has not yet been attempted. Based on its extensive expertise in geothermal power, Kenya's principal power generation company, KenGen, has assisted neighbouring countries, including Rwanda, Eritrea and Zambia in the assessment and development of their geothermal resources.

Geothermal power has also been successfully exploited in northern African countries, using geothermal fluid for irrigation of oases as well as heating and irrigation of greenhouses. In Kenya, a flower company is exploiting geothermal heat for use in its greenhouses, with good results[1].

This document summarizes the successful development of geothermal in Kenya, and consists of the following sections:

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[1] The value added from using waste steam in greenhouses could be useful in marketing the flowers as carbon neutral.

1. What is geothermal energy?
2. Why use geothermal energy?
3. Stages of geothermal energy development
4. Geothermal in Kenya – what has been the experience?
5. Lessons Learned – Why is Geothermal Power in Kenya a Success?
6. References and key contacts

1.0 What Is Geothermal Energy?

Geothermal energy is formed deep within the earth's crust, and is exploited for electricity generation and other direct uses. The medium of this energy transfer is geothermal fluid. On the surface, these are manifested as hot grounds, fumaroles, geysers, mud-pools and hot springs. Some of these are shown in Figure 1.

Figure 1: Some Surface Manifestations of Geothermal Resources

Source: Mariita, 2006

2.0 Why Use Geothermal Energy?

Geothermal energy is likely to become a major contributor to Africa's electrical power, especially in those countries that are endowed with this resource. Other countries may benefit by means of high voltage direct current (HVDC) lines Geothermal potential exists in east Africa, the Horn of Africa, and parts of north and southern Africa.

Key benefits of geothermal energy include the following:

I. Geothermal energy is competitive in terms of cost. Estimates indicate that it can even compete with large-scale hydro power (Stefansson, 1999).
II. Geothermal power plants have near zero emissions, (true for modern closed cycle systems that re-inject water back to the earth's crust) and very little space requirement per unit of power generated (Karekezi and Kithyoma, 2008). This makes geothermal energy an attractive option compared to fossil fuel alternatives.

III. Geothermal energy is not susceptible to seasonal fluctuations, and is available all year round. This is in contrast to hydroelectric power, which is affected by low rainfall and oil fired power plants, which can be prohibitively expensive to operate when oil prices are high.
IV. Geothermal energy has other direct uses such as space heating and heating of greenhouses for horticultural farming (Lund *et al*., 2005).
V. The knowledge base on geothermal energy is growing rapidly, with a sizeable expert team present in Kenya.

3.0 Stages of Geothermal Energy Development

Geothermal development typically consists of several key steps. The prospective geothermal fields undergo systematic investigation and evaluation processes from their initial exploration and development until steam production mechanisms have been implemented. These studies and evaluation processes are fairly similar worldwide with corresponding modifications and innovations to suit the particular geothermal area of interest in each country. From the perspective of the resource, a geothermal project can be divided into the following phases (Mariita, 2006):

- Project definition and reconnaissance evaluation
- Detailed exploration
- Exploratory drilling and delineation
- Resource analysis and assessment of development potential
- Field development
- Steam production and resource management

Upon confirmation of a resource for development, a complete feasibility study undertaken on the project would also consider the corresponding geothermal power plant to be set up for converting the energy from steam to power. The power plant will undergo the following phases, in parallel with geothermal field development: bid tendering, design, manufacturing and delivery, construction, commissioning and operation. For more details on key stages of geothermal power development, see Appendix A.

4.0 Geothermal in Kenya – what has been the experience?

As mentioned earlier, Kenya was the first country in Sub-Saharan Africa to exploit geothermal based power on a significant scale. Exploration for geothermal energy in Kenya started in the 1960's with surface exploration that culminated in two geothermal wells being drilled at Olkaria. In the early 1970's, more geological and geophysical work was carried out between Lake Bogoria and Olkaria. This survey identified several areas suitable for geothermal prospecting, and by 1973 drilling of deep exploratory wells commenced, with funds from UNDP. Additional wells were thereafter drilled to provide enough steam for the generation of electricity, and in June 1981 the first 15 MWe generating unit "Olkaria" was commissioned. This was the first geothermal power plant in Africa. The second 15 MWe unit was commissioned in November 1982 and the third unit in March 1985, raising the total to 45 MWe.

Olkaria 1 is owned and operated by KenGen, a state-owned power generation utility. Since 1997, private companies have shown interest in the generation of electricity using geothermal resources. Currently Orpower4 Inc. is generating 12 MWe with plans to generate a total of 64 MWe in the next few years in the Olkaria West field (Mbuthi, 2005). Kenya has so far exploited 127 MW of its total potential and plans are underway to increase geothermal generation capacity by 504MW by 2019 (KPLC, 2002).

Both the private and public sectors are involved in the development of geothermal energy in Kenya (BCSE, 2003). So far, 103 geothermal wells have been drilled in Kenya for exploration, production, monitoring and re-injection, with depths varying between 180 and 2,600m. Of these, 97 wells are in the Olkaria area and the rest in the Eburru Field (Mbuthi, 2005). A feasibility study carried out to evaluate Olkaria's potential for generating electricity found that the geothermal field covered 80km^2 and steam for at least 25,000 MW years. The present area covering 11km^2 has steam for an estimated 400 MW years and possibly more if re-injection proves to be effective.

Table 2: Geothermal Power Exploitation in Kenya

Country	**Kenya**
Potential generation (MW)	2000
Installed Capacity (MW)	127
Available (MW)	127

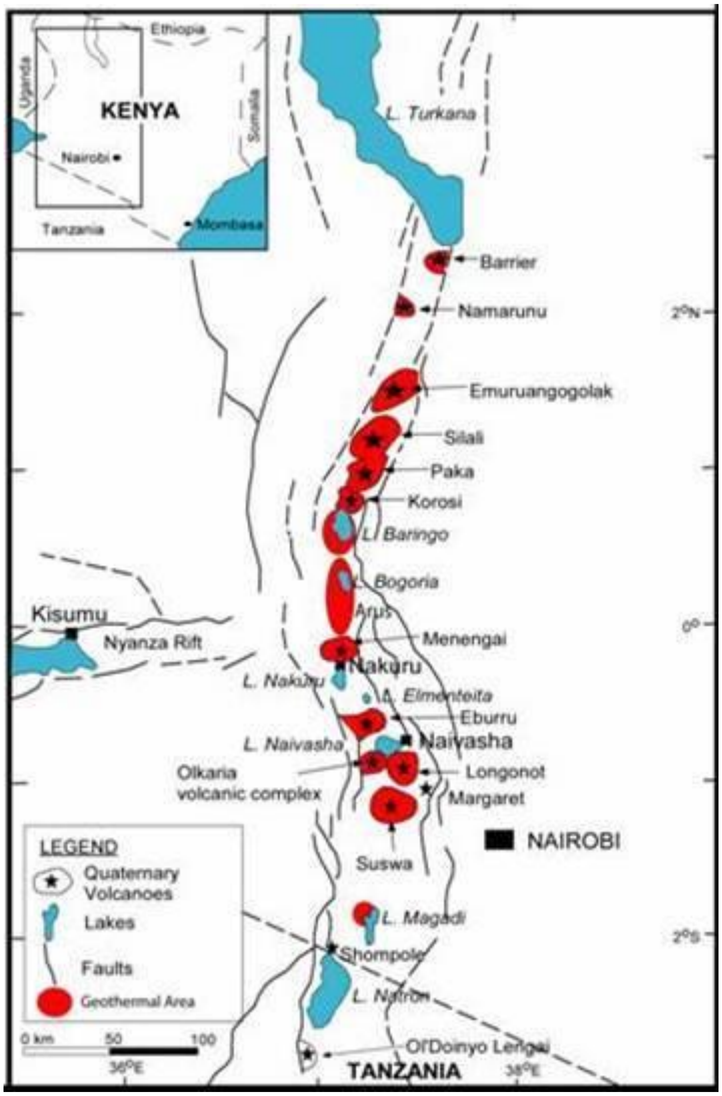
Source: MoE, 2007; BCSE, 2003; Fridleifsson, 2001.

Out of the total 127 MW installed capacity, Kenya Electricity Generating Company, KenGen - a public utility – has an installed capacity of 115 MW and OrPower Inc.; an independent power producer has installed 12 MW commissioned in 2000. Currently, the plants meet 11% of the total national electricity supply (MoE, 2008). In addition, geothermal has boosted energy security, as it is available 100% of the time and at one time constituted an important alternative to hydropower during the 1999 – 2000 drought experienced in Kenya.

Geothermal energy use in Kenya has led to significant socio-economic benefits for the country. Currently, a workforce of 493 persons is deployed at the Olkaria power stations. This corresponds to about 4 jobs per MW. A crude estimate of additional jobs related to geothermal energy was made on the basis of generating 504 MW by 2019. Assuming that geothermal development creates on average four jobs per MW in plant and infrastructure construction and 1.7 jobs per MW in operation and maintenance, it was estimated that 2,016 construction jobs would be created in fifteen years. A further 856 jobs would be created in operation and maintenance (Mbuthi, 2005).

Geothermal energy use has also contributed to poverty reduction, although there is significant unexploited potential for increasing the positive impact of geothermal on poor communities, especially in the areas where geothermal is harnessed. For instance, a geothermal heat resource is being used on a pilot basis in a horticultural farm near Lake Naivasha to control night-time humidity levels in order to reduce the incidence of fungal diseases. Geothermal power has also been successfully exploited in northern African countries, using geothermal fluid for irrigation of oases as well as heating and irrigation of greenhouses.

Figure 2: Geothermal resources in Kenya



Source: KenGen, 2002

3. Lessons Learned – Why is Geothermal Power in Kenya a Success?

The strong policy support for geothermal power in Kenya was a key factor that led to its successful exploitation. Kenya's Least Cost Power Development Plan (LCPDP) instituted in 2000 recognizes geothermal as an important low cost energy option for the future (see table 3) compared to other forms of electricity generation – especially conventional ones. The Kenyan government has been aware of the fact that, for accelerated development of the country's geothermal resources, joint efforts were required from both the public and private sectors. However, it recognised the risks associated with initial geothermal exploration, drilling and the assessment of the resource as being a disincentive to private sector investment, and the fact that this could lead to unsustainablly high electricity tariffs. To avert this outcome, the government financed these pre-development activities jointly with the utility KenGen prior to liberalisation of power generation in 1996. KenGen has since withdrawn from funding these activities and the government has taken full responsibility. Government commitment to exploration showed that it was willing to bear part of the risk of developing the resources, which attracted private developers and investors (Mbuthi, 2005).

Table 3: Summary of Additional Planned Power Generation in Kenya (2004 – 2019)

	MW			
Fiscal year	**Hydro**	**Geothermal**	**Diesel**	**Total**
2004	60	56		116
2005				
2006			40	40
2007		64		64
2008	80.6		20	100.6
2009		64		64
2010	140			140
2011		64	20	84
2012			80	80
2013		64	20	84
2014			100	100
2015		64	20	84
2016			100	100
2017		64	40	104
2018			150	150
2019		64	60	124
Totals	280.6	504	650	1434.6

Adapted from KPLC, 2002

Kenya is now a global leader in geothermal energy development, with experts from Kenya offering their expertise in developing geothermal power plants in other countries in the region, and even developed countries (Mariita, 2002).

The success of geothermal development in Kenya can be linked to several key factors, with the main driver being long-term commitment by both the private and public sectors. Kenya has made significant and long-term investments in developing local skills and expertise. Local champions have also played a crucial role in ensuring sustained local support for the initiatives.

The main lessons learned are:

- Long-term Focus: There is need for a long term commitment from the government and the donor community. Long-term commitment by both the private and public sectors in Kenya led to the success of geothermal electricity generation. Government commitment to exploration showed that it was willing to bear part of the risk of developing the resources, which attracted private developers and investors. Consequently, geothermal power generation is now fully integrated in the national power master plan.

- Specialization: Commitment to geothermal energy development in Kenya spans three decades, and substantial resources were used to train a large pool of geothermal experts in Kenya who now form the core of KENGEN specialized unit on geothermal power. Currently, Kenyan geothermal experts are providing technical assistance in the region and even outside Africa.

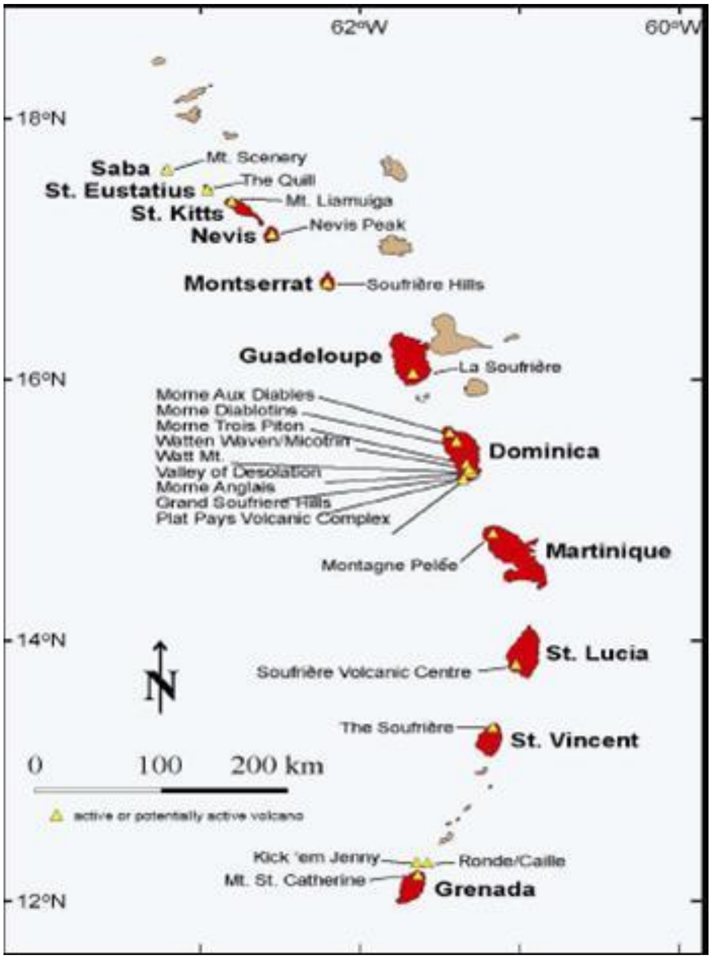
KenGen has the capacity in terms of equipment, staff and experience in undertaking geothermal assessment and development.

- Local Champions: The Government has been instrumental in building support for geothermal development both locally and internationally, with development partners such as the World Bank, the European Investment Bank and KfW of Germany who co-financed geothermal development in the country. The most important local champion, KenGen, played a crucial role in ensuring sustained local support for geothermal development.

- Phased development: This provided the opportunity to exploit existing wells, thus reducing upfront costs and producing revenue to finance future phases of the project. It also contributed to building confidence in the resource and in the ability of the country to implement geothermal projects. As shown previously in table 3, geothermal development is expected to continue in phased stages, increasing capacity by 64MW every other year.

Geothermal Potential in Other Regions

Another ACP region with strong geothermal potential for commercial power generation is the Caribbean. The map below shows active volcanoes with geothermal potential in the Eastern Caribbean islands, with estimated generation potential in the following table.



Source: Joseph, 2008.

Geothermal Potential in the Caribbean region

Country	Potential (MWe)
St. Kitts and Nevis	50
St. Lucia	680
St. Vincent and the Grenadines	890
Montserrat	940
Grenada	1,110
Dominica	1,390
Netherlands Antilles	3,000
Guadeloupe	3,500
Martinique	3,500

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APPENDIX A: KEY STAGES OF GEOTHERMAL ENERGY DEVELOPMENT

a. Project Definition and Reconnaissance Evaluation Phase

This phase involves collecting information from previous geological, geo-chemical and geophysical studies made in the area with a particular emphasis on mapping of young volcanic activity, thermal manifestations such hot springs, steam jets, groundwater boreholes and even known traditional utilisation of geothermal resources. The existing scientific information is re-interpreted to determine the more detailed investigations that need to be conducted. This review may reveal what methods of interpretation previously employed need refinements and may show the existence of a more attractive resource than previously envisaged.

b. Detailed Exploration Phase

The detailed surface exploration program usually includes the geology, geophysics, geochemistry, heat flow measurements, hydrogeology and baseline environmental studies that have not yet been done or need to be redone. In areas that have not been mapped in detail, the required work would include lithological mapping, petrogenesis, volcanology, structural geology, hydrogeology, geo-hazard and environmental geology. Among the geophysical surveys used are gravity surveys to determine the density pattern of the geothermal structure and MagnetoTellurics (MT) surveys to show resistivity anomalies. After completion of this phase, the geothermal prospect is evaluated as to its priority for drilling compared with other areas that have been similarly evaluated. During this phase, detailed mapping of geothermal manifestations and detailed study of geological controls on the distribution of the geothermal resources are very important in developing the conceptual model of the geothermal system. Target structures for drilling are identified after consolidation of the interpreted results of the detailed geological, geo-chemical and geophysical investigations.

c. Exploratory Drilling and Delineation Phase

Two or three exploratory wells, 2500 to 3000 metres deep, are prioritised based on the conceptual model of the reservoir. Location of drill pads will depend on environmental considerations in the area. The first well is perhaps the most critical as it is meant to maximise down-hole information. The target structure must have permeability and high temperature in order for a geothermal resource to be present. If the first well does not produce steam, down-hole data is evaluated in conjunction with the initial detailed geological, geochemical and geophysical studies before deciding on the next target drill site. If the first exploration well is a success, a step-out well is drilled. The succeeding step-out (appraisal) wells should not be too distant from the first well and should normally target fractures and other geological structures. Well logging and discharge tests follow after the completion of drilling. Results of the well surveys and tests may confirm the resource and together with the earlier investigation results, a more defined conceptual model can be developed.

d. Resource Analysis and Assessment of Development Potential

After successful discharge of steam from the initial wells, a comprehensive resource assessment is prepared. This is now the feasibility phase of the project. The exploitable size of the resource is established based on the conceptual model of the heat source, geological structure, fluids present and reservoir characteristics. A development strategy has to be formulated together with the conceptual design of the fluid collection and re-injection system (FCRS). The power station's initial design, location and interconnection to the power grid are established at this stage. The feasibility study will yield project cost estimates, development timelines and the economic and financial analyses under probable power demand scenarios. At this stage, in accordance with environmental laws and regulations, a full-blown EIA is prepared which will serve as the basis for the issuance of the project's work permits. Public consultations with local residents, local government units and other stakeholders are also undertaken as part of the endorsement and approval process if a geothermal project is proposed for implementation. The final output of this phase is a complete technical and financial feasibility study that can be used to solicit funding from financiers for the development of the project.

e. Field Development Phase

Upon successful negotiation and closure of financing for the project, the next phase involves production and re-injection drilling, detailed design, procurement and construction of the FCRS. Development of the field, in many geothermal projects, may involve multi-well pad sites. From a single site, up to four cellars can be constructed; from these cellars, up to four directional wells can then be drilled with their bottom targets deviating away from each other. This scheme of development results in a very compact production field and can be particularly useful in rugged and mountainous terrain. The detailed engineering, procurement and construction of the geothermal power station and associated substation and transmission lines are done simultaneously with the production and re-injection well drilling.

f. Steam Production and Resource Management Phase

The satisfactory and efficient operation and maintenance of the geothermal production facility and power plant after the completion and commissioning tests will be the key to the fulfillment of contractual commitments and the realisation of cash flows from the project over the long term. In the process of exploitation, the behavior of each individual well is closely monitored. This leads to a better understanding of the geothermal reservoir and a more comprehensive model is portrayed. Work is done to simulate and predict reservoir behavior under certain exploitation scenarios, to forecast the number of maintenance wells, as well as the drilling targets, over the project's life. Production and re-injection wells must also be managed in order to maximise their capacity and extend their production life.

In some reservoirs, injection wells become available for production as a consequence of extensive boiling and pressure draw-down. Injection management is the third strategy of sustaining generation capacity. Re-injecting the separated brine and power plant condensate should be accomplished with extra care because of their adverse effect on the production sector. Uncontrolled re-injection may cool down sections of the reservoir irreversibly. Monitoring the injection returns employs the use of chemical tracers. The results of chemical tracer tests will play a big factor in implementing the injection dispersion of the brine and condensate among new, idle or active injection wells.